# SAFE DECOMMISSIONING FOR NUCLEAR ACTIVITIES

## Proceedings of an International Conference
## Berlin, 14–18 October 2002

IAEA
International Atomic Energy Agency

# IAEA SAFETY RELATED PUBLICATIONS

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SAFE DECOMMISSIONING
FOR NUCLEAR ACTIVITIES

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".



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# SAFE DECOMMISSIONING FOR NUCLEAR ACTIVITIES

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# FOREWORD

Thousands of operations involving the use of radioactive substances will end during the current century. While there is considerable regulatory experience in the 'front end' of the regulatory system for practices, the experience at the 'back end' is more limited as fewer practices have actually been terminated. When a practice is terminated because the facility has reached the end of its useful life, action has to be taken to ensure the safe shutdown of the facility and allow the removal of regulatory controls. There are many issues involved in the safe termination of practices. These include: setting criteria for the release of material and sites from regulatory control; determining the suitability of the various options for decommissioning nuclear facilities, managing the waste and material released from control (recycling, reuse or disposal), and the eventual remediation of the site. Some countries have put in place regulatory infrastructures and have developed programmes to manage the associated decommissioning and remediation activities. Other countries are at the stage of assessing what is involved in terminating such practices.

The purpose of this international conference was to foster an exchange of information on the safe and orderly termination of practices that involve the use of radioactive substances, including both decommissioning and environmental remediation, and to promote improved coherence internationally in strategies and criteria for the safe termination of practices. The conference explored seven main topics: the overall magnitude of the problem; regulatory approaches and safety strategies; status and development of decommissioning technologies; planning and implementation; funding approaches and strategies; consideration of social issues; and criteria for the removal of regulatory controls. This publication, which constitutes the record of the conference, includes the opening speeches, invited papers, summaries of the panel discussions and sessions, the Conference President's summary and the findings of the conference. A CD-ROM containing the unedited contributed papers in this conference can be found at the back of this book.

The IAEA gratefully acknowledges the support and generous hospitality extended to the conference by the Government of Germany through the Bundesamt für Strahlenschutz (BfS).

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# OPENING SESSION

**Chairperson**

**W. RENNEBERG**
Germany

## *OPENING ADDRESS*

**T. Taniguchi**
Deputy Director General,
Department of Nuclear Safety,
International Atomic Energy Agency,
Vienna

On behalf of the Director General of the IAEA, it is my pleasure and privilege to welcome you to this international conference on Safe Decommissioning for Nuclear Activities. I would like to offer my sincere thanks to the Government of Germany, and particularly the Bundesamt für Strahlenschutz (BfS) (the Federal Office for Radiation Protection) for hosting this conference in the beautiful and historic city of Berlin, now fully restored to its position as the German capital. Let me also thank Dr. Manfred Breitenkamp for joining us in this opening session to present the welcome address on behalf of the City of Berlin. And I would also like to thank you, the 300 or so registered delegates from around the world, for finding the time to participate in this conference. I trust that you will have an interesting and enjoyable week.

The IAEA's overall mission is focused on three 'pillars': the transfer of technology for peaceful applications of atomic energy; verification of States' compliance with their commitments in relation to the non-proliferation of nuclear weapons; and safety. In the 'safety pillar', the IAEA seeks to contribute towards a vision of a strong, sustainable and visible global safety regime by pursuing three main objectives: to establish and maintain a set of safety standards that are universally accepted as global standards; to integrate fully these safety standards and the various mechanisms to provide for their application; and to promote self-sustaining regional and global networks of safety knowledge and experience. The purpose of this conference is to foster the exchange of information, but this is not an end in itself. The aim of this conference is to clarify the key issues within the larger global picture and set out a road map for the future direction and priorities for work on safety standards for decommissioning and for applying those standards. It seems to me that one of these key issues — and I do not have a ready answer to this — is how the kind of integrated, global safety regime I have just mentioned can contribute towards addressing the much more down to earth problem of ensuring that a large number and variety of widely scattered, largely independent, small scale activities, are all terminated safely.

Turning to the business of this week, the title of this conference was carefully chosen and contains an important message. The word 'decommissioning' is often treated as though it was synonymous with dismantling nuclear reactors and returning to a 'green field' site, and we quite deliberately intended to challenge that interpretation. This is not to question the importance of developing the right dismantling techniques, but rather to emphasize that decommissioning is very much broader, in terms of both the range of actions involved and the range of facilities and activities to be decommissioned. By decommissioning, we mean the whole multi-faceted process that is needed to safely terminate an activity involving radioactive material. I should add here, as I am sure you are aware, that discussions are taking place in various other forums on the security of radiation sources and radioactive material, and the IAEA is playing a full part in these discussions. Although some of these security issues undoubtedly intersect with the safety of decommissioning, security is outside the scope of this week's conference.

The subject of this conference, therefore, is one that no country can ignore. All countries — whether or not they have nuclear power programmes or research reactors — make use of at least some applications involving radiation sources or radioactive materials, in medicine, industry, agriculture and research. All of these countries will need to terminate these activities safely. And although a substantial amount of work has already been done, we are really only in the early stages: the need for decommissioning can be expected to increase in the foreseeable future. Some of the major projects under way now result from practices that have already stopped, and a peak in the number of nuclear reactors reaching the decommissioning stage can be expected within two to three decades. However, many other applications involving radioactive materials are still expanding rapidly and will be giving rise to new decommissioning projects many decades from now. These challenges lie ahead, but in the next decade or two we will need to continue to demonstrate that we can decommission facilities and activities safely and successfully in order to ensure that the wide range of beneficial nuclear applications continue to meet people's needs.

Decommissioning is also a subject that has suffered from being addressed in a piecemeal and sometimes ad hoc fashion. The IAEA must take its share of responsibility for this: we have published safety standards on particular aspects of decommissioning, and more general safety standards on the regulatory control of practices, on operational safety, on occupational radiation protection, on the management of different types of radioactive waste and discharges, and we are developing standards on the management of very low activity wastes and of contaminated areas. Yet, we have not succeeded in bringing all these elements together into safety standards to cover the entire process of decommissioning and the termination of practices.

Similarly, the IAEA has recently been involved in the organization of international conferences on the remediation of contaminated areas — in Arlington, USA, and in Moscow — and of an international workshop on the regulatory aspects of decommissioning — in Rome in 1999 — but has not previously attempted to cover in one conference all of the technical and administrative steps that need to be taken to allow regulatory control to be finally removed from a discontinued activity.

Within the IAEA, we have taken one step towards a more holistic approach to the issue by establishing a Technical Group on Decommissioning (TEGDE). This will be a standing group of recognized experts from Member States with a remit to advise the IAEA on its programmes relevant to the various aspects of decommissioning, and to act as an international focal point for the development of harmonized policies and strategies, resolution of common issues and exchange of information. It will be a multidisciplinary group, with experts in the various specialist fields relevant to decommissioning, including technology, safety, management and planning, economics and societal aspects, waste management, remediation and release of regulatory control. We are currently in the process of identifying suitable members of the group, and expect it to begin its work next year.

This conference is another step towards unifying the subject. An important aim of the conference is to bring together the various technical and regulatory strands of the topic, to obtain an overall picture of where we stand, and to consider how we can move forward in a more systematic, holistic manner. From the IAEA's point of view, as I have already stated at the beginning, I hope that the conference will also give us guidance on the key issues and priorities, to assist us in planning our future work in this important area. More specifically, I hope that by the end of this week we will have a set of findings and recommendations that can help guide Member States in addressing this issue, and that we at the IAEA can use as a basis to present to our Board of Governors an action plan of concrete steps to strengthen our safety standards on decommissioning and guide our activities providing for their application in Member States.

Before closing, I would be failing in my duty as a representative of the IAEA if I did not take this opportunity to draw your attention to some other Agency activities that might be of interest to you. Although, as I have emphasized, decommissioning itself encompasses a range a different activities, it also interfaces with other aspects of managing facilities and activities. The 'front end' of decommissioning interfaces with the tail end of operations: in the specific case of nuclear power plants, this means an interface with the question of plant life management, and the IAEA organized a symposium on this issue in Budapest in early November 2002. At the 'back end' of decommissioning is the question of managing the waste. We will only be able to consider decommissioning a success if there are measures in place to manage the waste safely: otherwise, we will simply have shifted the problem. And this provides a link to another IAEA conference, on issues and trends in radioactive waste management, held in Vienna in December 2002. Looking further ahead, I would also like to remind you that the first Review Meeting of Contracting Parties to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management will take place in Vienna in November 2003.

Because the subject of the conference is so wide-ranging, you have a very full programme ahead of you. I wish you well in your deliberations this week, and I look forward to hearing your findings. I would like now to declare the conference open on behalf of the Director General of the IAEA. My very final duty, and pleasure, is to introduce your Conference President for the coming week, Wolfgang Renneberg, who is the Director General in charge of Nuclear Safety, Radiation Protection and Nuclear Fuel Cycle at BMU, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. I give the floor to Mr. Renneberg.

# *OPENING ADDRESS*

**E. Warnecke**
Federal Office for Radiation Protection (BfS),
Berlin, Germany

It is a great pleasure for me to welcome you to the international conference on ‘Safe Decommissioning for Nuclear Activities: Assuring the Safe Termination of Practices Involving Radioactive Materials’, on behalf of the President of the Federal Office for Radiation Protection, Mr. Wolfram König. The BfS is very pleased to host this conference on behalf of the German Government.

We are deeply honoured by the request of the International Atomic Energy Agency to organize this conference and were delighted to accept it. After more than a year of preparatory work we are ready now to start the conference, with its plenary session, the poster presentations and the industrial exhibition.

Decommissioning of nuclear facilities is an important issue in Germany. Following the agreement between the Federal Government and the operators of nuclear power plants to phase out of nuclear power generation within the next 20 years, the successive shutdown of facilities and subsequent dismantling will be a major task for all parties involved. As Germany is in favour of immediate dismantling, all the reactor sites should be brought to green field conditions in about 30 years from now.

Germany has already gained a lot of practical experience in the decommissioning of all types of nuclear facilities. In total, 57 nuclear facilities were shut down and 27 were dismantled. Most of them are research reactors. The shutdown facilities include 17 nuclear power plants. Two of them were completely dismantled to green field conditions. In our definition, ‘nuclear power plants’ mean facilities that were connected to the grid. Of course, many of the facilities are smaller prototype reactors, but larger ones are also included. These are the five WWER reactors of Soviet design in Greifswald, which is claimed to be the biggest decommissioning project in the world, the Würgassen BWR with 640 MW(e) (net) and the Mühlheim-Kärlich PWR with 1220 MW(e) (net). Both facilities, Greifswald and Würgassen, can be visited on Friday in the context of the ‘scientific tours’. Furthermore, an application for the decommissioning of the Stade PWR with 640 MW(e) (net) was submitted to the regulators and is under examination.

It should also be mentioned that nine fuel cycle facilities were shut down in Germany and four of them were completely dismantled. Amongst the fuel cycle facilities is the Karlsruhe prototype reprocessing plant, which has the following specialty: the reprocessing plant is being dismantled and a vitrification plant is being constructed in parallel in order to solidify the roughly 80 $m^3$ of liquid HLW originating from the reprocessing of 208 Mg of spent fuel. Dismantling of the vitrification plant is the last step in this process.

Another outstanding project is the cleanup and rehabilitation of the uranium mining and milling sites of the Wismut company in the German States of Saxony and Thuringia. When the facility was closed at the end of 1990, it had produced about 231 000 t of uranium. At that time, Wismut was the third largest uranium producer in the world. The ongoing work includes the stabilization and remediation of the waste rock piles, dismantling of the mining and milling facilities and underground remediation measures. The total cleanup costs are estimated to be about €6.5 billion. The site is the destination of a scientific tour on Friday. The tour is not yet fully booked. Last minute registrations are possible at the registration desk.

A large amount of research work was carried out in Germany for the development of methods, technologies, etc., for the dismantling of nuclear facilities, which was publicly funded and carried out, for example at universities. A large amount of know how emerged also from the application of equipment in dismantling the actual facilities.

Having this background in mind, it is not surprising that Germany decided on some of the issues that are the subject of this conference, for example release from regulatory control. German experts will provide the respective input for the conference and experience can also be made available to experts from other countries on a bilateral basis. On the other hand, there is great interest to listen to the views and experience from abroad in order to check and, if necessary, to revise the national position.

I am looking forward to a rewarding, top quality conference with interesting results. The overall arrangements of the conference programme give “reasonable assurance” — and this is language from the long term safety assessment of repositories — that this goal will be achieved.

I wish the conference the best of success and hope that the technical arrangements will contribute to reaching this goal. It is also a great pleasure for me to extend an invitation to you to attend the poster reception and the conference dinner. These functions will offer the opportunity to exchange information with the authors of contributed papers and improve personal contacts in a relaxed atmosphere.

# *OPENING ADDRESS*

**M. Breitenkamp**
Department of Environmental Policy,
Ministry for Urban Development,
Berlin, Germany

It is a pleasure for me to welcome you here in Berlin! Just a couple of days ago, on 3 October, the national celebrations of the anniversary of Germany's reunification were held in Berlin for the first time since 1990. This time span of 12 years brought enormous changes, both for the people and the city. I suppose that nowhere in our country is this process of growing together more apparent and the change more visible than here in this formerly divided city. Although — or maybe because — I am not a native, I also dare say that Berlin nowadays is one of the most exciting cities within Europe. And I really do hope that — besides working — there will be enough time for you to get an impression of Berlin. Despite all difficulties, Berlin has become a modern, open and forward looking city filling its role as the German capital with self-confidence and a very special charm.

I really appreciate that this conference is being held here in Berlin. Supporting communication between science and the economy is one of our policy objectives, and we are also determined to develop Berlin's attraction for congresses and conferences.

In the next week you will focus on the 'Safe Decommissioning for Nuclear Activities'. You work in an enormous field! Currently, there are more than 110 nuclear installations in the European Union in varying stages of decommissioning, and an additional 150 installations will be dismantled by the year 2020. This means that decommissioning will no longer be treated in a case by case fashion like, for example, the Greifswald Nuclear Power Plant or the Wismut remediation site, which some of you will visit on Friday. Rather, decommissioning will have to be turned into a full scale industrial process with standardized procedures. Each of these procedures has to be optimized, not only with respect to technical requirements but most importantly in a way that guarantees maximum safety for the workers, for the population and for the environment.

Consequently, the focal points of this conference cover an extremely wide range, including:

— Strategies for the safe termination and the assessment of the adequacy of the current technology,

— Waste management and disposal,
— Release of materials from regulatory control,
— Remediation of sites,
— Social impact of practice termination.

Adequate coverage of all these issues is probably not made easier by the proposed enlargement of the European Union to include a number of Central European and Baltic countries.

At an early stage, it is the scientific community, with its creativity and potential, which conceives novel approaches and designs new processes. But at a certain point the foundation for the successful handling of a complex problem must be enlarged and become more technical. Involving experts from all fields is then crucial for success.

This perception is reflected in the goals of this meeting. It is designed as an extensive information exchange forum between decision makers, regulators, radiation and waste safety specialists, and the nuclear industry. It is this mix which promises high efficiency with respect to solving the problems that you are addressing.

I am sure that the safe termination of practices involving radioactive materials during the decommissioning of nuclear installations is one of the major challenges that industrialized nations will have to face during the next decades.

Therefore, I know that your task is complex — and that you carry great responsibility. In this sense I wish you a successful conference!

*OPENING ADDRESS*

# Safe Nuclear Decommissioning: Need for an International Common Approach

**A. J. González**
Division of Radiation and Waste Safety,
International Atomic Energy Agency,
Vienna

I shall firstly join the previous speakers in welcoming you to this IAEA conference and express my profound thanks to the Government of Germany, and to the Bundesamt für Strahlenschutz in particular, for the wonderful way in which they have organized this important and well attended event.

## 1. THE CONFERENCE'S PURPOSE

Let me apologize for starting with some negative remarks, for I wish to state from the beginning what the IAEA does not expect to be the conference's purpose. The IAEA expects that the conference will not:

— Explore the techniques for dismantling nuclear installations, as the industry knows quite well how to do this;
— Discuss how to terminate the peaceful applications of nuclear energy for good;
— Confine itself to nuclear power plants, as we hope that its findings will be applicable also to other installations involving the use of radioactive materials — for example, the many thousands of medical facilities using radioactive substances and the large number of industrial facilities where radioactive substances are produced or used, such as the hundreds of gamma irradiation facilities for sterilization and food preservation.

The IAEA's expectation for this conference is quite simple: The conference will seek consensus on common international approaches for closing the life cycles of installations involving radioactive substances in an internationally accepted, safe manner.

If this consensus is achieved, new — modern — installations could replace those being closed down. Thus, a basic condition for the sustainability of practices involving radioactive substances would be created. Notwithstanding this, if a country wishes to terminate for all time a particular practice, a necessary pre-condition would anyway be to close the life cycle of the relevant installations in an internationally accepted, safe manner.

Finally the IAEA hopes that it will be possible to translate this conference's findings into an international action plan for ensuring the safe decommissioning of any type of facility used in practices involving radioactive substances; in turn, this could ultimately result in an international code of conduct on safe decommissioning.

## 2. THE LARGE NUMBER OF FACILITIES AWAITING SAFE DECOMMISSIONING

The main issue facing the international community in achieving safe termination of current activities involving radioactive substances can be formulated as follows: a large number of facilities where radioactive substances have been used will have to be decommissioned in due course and their sites converted into what they were when the plants came into operation, namely into what the public call 'green field' condition.

### 2.1. Nuclear electricity generation

In the case of the practice of nuclear electricity generation, and according to preliminary IAEA estimates, the number of nuclear power plants (NPPs) requiring decommissioning will peak around 2025 — for which a huge quantity of financial resources will be required (Fig. 1).

As the President of this conference indicated, the issue of the vast amount of financial resources needed for decommissioning NPPs has rarely been discussed internationally and is probably one of the issues that this conference should address. While the IAEA estimates are very preliminary, they provide a feel for the scale of the problem, i.e. financial resources of hundreds of billions of dollars over the next 50 years.

### 2.2. Other practices

In addition, there are many other installations being used for practices involving non-power applications of nuclear energy which will require safe decommissioning as well. For example, worldwide there are thousands of facilities being used in radiotherapy — many of them in developing countries — which will sooner or later have to be decommissioned safely (Table I). Furthermore, an even larger number of facilities are being used in non-power industrial applications of by-products of the nuclear industry, such as radiation

| | Number of Plants | Cost (million US$) |
|---|---|---|
| 2001 – 2005 | 16 | 5 600 |
| 2006 – 2010 | 31 | 10 850 |
| 2011 – 2015 | 66 | 23 100 |
| 2016 – 2020 | 79 | 27 650 |
| 2021 – 2025 | 123 | 43 050 |
| 2026 – 2030 | 74 | 25 900 |
| 2031 – 2035 | 27 | 9 450 |
| 2036 – 2040 | 22 | 7 700 |
| 2041 – 2045 | 25 | 8 750 |
| 2046 – 2050 | 5 | 1 750 |
| Total US Dollars (millions) | | 163 800 |

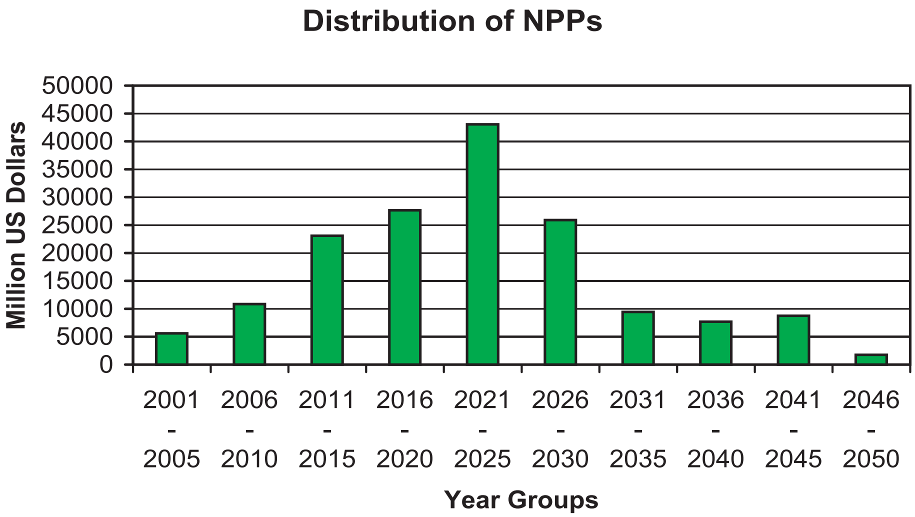


*FIG. 1. Preliminary estimates of the number of nuclear installations that in future years will have to be decommissioned, and of the expected costs, which will peak on the approach of the first quarter of the century.*

TABLE I. NON-POWER APPLICATION FACILITIES, FOR EXAMPLE RADIOTHERAPY

| | Developing countries | Developed countries | Total |
|---|---|---|---|
| Number of countries | 132 (81%) | 30 (19%) | 162 |
| Radiotherapy centres | 2327 (44%) | 2986 (56%) | 5313 |
| Teletherapy | 2195 (35%) | 4097 (65%) | 6292 |
| $^{60}$Co and $^{137}$Cs | 1424 (69%) | 634 (31%) | 205 |
| Accelerators | 771 (18%) | 3463 (82%) | 4234 |
| Brachytherapy | 845 (34%) | 1652 (66%) | 2497 |

and radioactive substances, and they will also have to be decommissioned sooner or later.

## 3. CURRENT INTERNATIONAL SYSTEM FOR SAFE DECOMMISSIONING

At present there is a growing de facto international system (or regime) aimed at the safe termination of practices and the safe decommissioning of their facilities. This regime can be described as follows:

- A system of international binding legal obligation undertaken by parties of relevant international conventions;
- A corpus of international radiation safety standards established by the IAEA, and provisions for the application of these standards.

### 3.1. International conventions

There are in force four legally binding conventions relevant to radiation safety, which impose radiation safety obligations to their State Parties, with some requirements being related to the safe termination of practices and decommissioning of their installations. These are the:

- Convention on Early Notification of a Nuclear Accident,
- Convention on Assistance in the Case of Nuclear Accident or Radiological Emergency,
- Convention on Nuclear Safety,
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the ‘Joint Convention’).

While none of these conventions includes *specific,* legally binding undertakings with regard to termination of practices and decommissioning of their installations, the Joint Convention has certain closely linked obligations. For that reason, it is important to underline the statement of the conference's President, which implied that it is vital for the purposes of this conference that countries accede to the Joint Convention as soon as possible.

### 3.2. International safety standards

The international community can also benefit from a hierarchical corpus of global standards on radiation safety, which are established by the IAEA and have been growing since the middle of the last century. The first standards were issued by the IAEA in 1962. At that time, the standards were prospective in nature, and the notion of "termination of the practice" hardly appeared, even implicitly. Therefore, the concept of "safe decommissioning" was not addressed in that early document, in its first revision in 1967, or in the fundamental revision of 1982, when a new system of dose limitation was introduced. The concept was not even dealt with in the first international fundamental principles for radiation safety issued in 1996, or in the current international requirements governing radiation safety globally, the 'International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources' (BSS)[1]. However, in spite of this apparent lack of basic international standardization for safe decommissioning, the IAEA has produced supporting specific requirements for the predisposal management of radioactive waste, which address decommissioning issues, and particular guides for the safe decommissioning of nuclear power plants and research reactors, for nuclear fuel cycle facilities and even for medical, industrial and research facilities.

The overall system of international radiation safety standards operates in a very transparent and sophisticated manner (Fig. 2):

— The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) provides estimates of the biological effects attributed to radiation exposure, which are periodically reported to the UN General Assembly in large volumes containing the up to date information in this scientific field.

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[1] The BSS are jointly sponsored by the Food and Agricultural Organization of the United Nations, the IAEA, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.


*FIG. 2. The international system of radiation safety standards.*

— The International Commission on Radiological Protection (ICRP) provides basic recommendations on radiation protection, which are available in the public literature;
— On the basis of UNSCEAR estimates and ICRP recommendations, the IAEA establishes the relevant international standards.

The IAEA process for establishing safety standards is very complex because it involves the participation of regulators from all over the world, as well as other relevant sister organizations within the United Nations family, but it is also very transparent. It involves four committees, one on nuclear safety standards, one on radiation safety, one on waste safety and one on transport safety, all of them supported by expert groups and a supervising commission that provides the ultimate approval of the standards before they are endorsed by the IAEA policy making organs.

In summary, the international community has a very elaborate system of international radiation safety standards, which are being established under the aegis of the IAEA, but the system needs to be strengthened in the area of the safe termination of practices and decommissioning of their installations. In fact, this system is not complete in the area of decommissioning, and the reason is that quantified criteria for decommissioning have not yet been developed and established internationally. This is a lapse in the system that hopefully this conference will address. The obvious question is: if the international community has been able to develop over the years a sophisticated and widely applied radiation safety approach, why has such an approach not evolved in the field of the safe termination of practices and decommissioning of their facilities?

## 4. BASIC INTERNATIONAL RADIATION SAFETY APPROACH VIS-À-VIS SAFE DECOMMISIONING

In order to answer the above question, the radiation safety approach formulated in the BSS (on the basis of the ICRP recommendations) need to be analysed. The current international approach to radiation safety divides the possible situations to be regulated by radiation protection standards into two:

— New activities (which are termed ‘practices’), through requirements for design and operational conditions;
— De facto existing situations for which the requirement is for ad hoc protective actions (so-called ‘interventions’).

Conceptually, decommissioning should be planned as part of the practice, and the radiation safety criteria for the termination of a practice should be part of the general radiation safety criteria for practices. However, what happens if decommissioning has not been forecast at the time that the practice was initiated, as is the case for many past practices? Should decommissioning then be treated as an intervention? This dichotomy is at the core of the problem for establishing radiation safety criteria for decommissioning.

The international radiation safety system, be it for practices or for interventions, has to recognize that natural background radiation is exposing everybody in the world. Its levels are very variable: for the majority of people the levels is of the order of 1 mSv/a (the global average is a little higher, 2.4 mSv/a according to UNSCEAR), but with typically high values of around 10 mSv/a that peaks up to around 100 mSv/a and even more in some areas of the world.

### 4.1. The case of ‘practices’

If the introduction of a *practice* is *justified*, taking account of its expected benefits and detriments, it is accepted that the operation of the practice will entail an increase in the background dose — i.e. an additional dose will be caused by the practice, however small such a dose might be, which will be added to the existing background dose as a result of that practice (Fig. 3). This fact is accepted in international standards and in any national regulation, otherwise it would imply a prohibition of practices. The international standards impose a limit of 1 mSv/a to the additional dose from all controlled practices, i.e. they accept a duplication of the minimum background dose as a result of the operation of all practices.

Since the limitation could cover the additional annual doses arising from several practices, each containing several sources, dose constraints per source are also required. At this time a dose constraint of 0.3 mSv/a is being recommended by the ICRP, with a constraint of 0.1 mSv/a for prolonged components. Below the constraint the standards require a process of *optimization of protection,* i.e. reduction of the remaining doses to levels judged 'as low as reasonably achievable' (or ALARA) under the prevailing circumstances, which will indicate the final dose restriction imposed for a particular source. A level of exemption has been agreed internationally: it is in the order of 0.01 mSv/a, which should be underlined because it could be important for termination of practices (see Fig. 4).

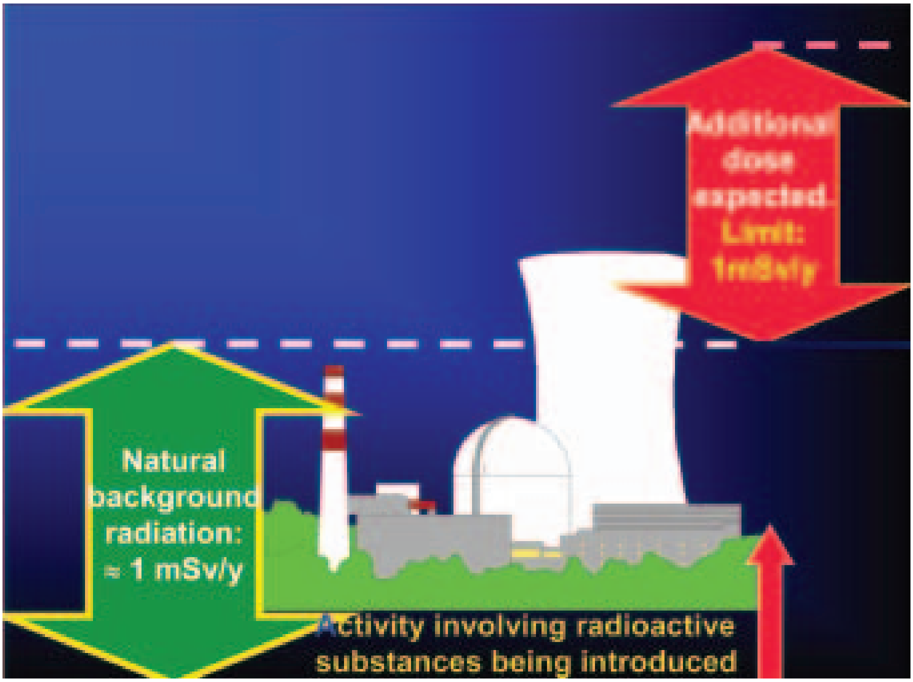


*FIG. 3. How the system works for practices.*

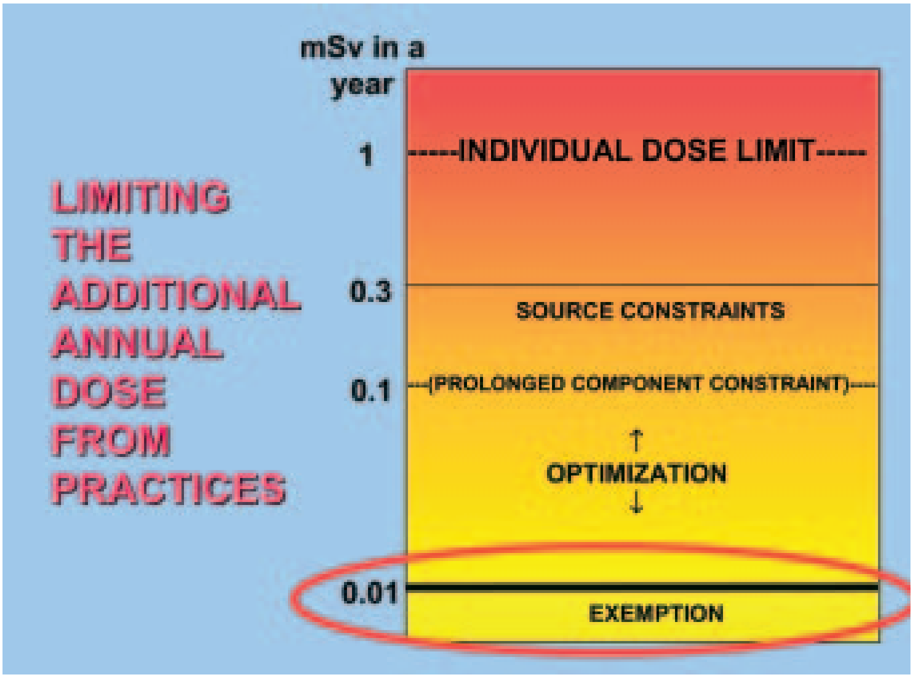


*FIG. 4. Limiting the individual dose from practices.*

### 4.2. The case of 'interventions'

For *interventions,* the situation is of reduction rather than addition of doses. If an extant dose exists in a de facto existing situation, e.g. an area containing radioactive residues, the first radiation safety question is whether such an extant dose should be reduced, i.e. whether it is justified to intervene with protective actions to reduce the dose. If the answer to this first question is positive, then the second question is by how much such a dose should be reduced, i.e. how to optimize the protective actions required by the justified intervention. It is obvious that some residual dose, however small, will remain after the intervention (see Fig. 5).

This means, therefore, that there will be a 'new extant (background) dose' after the reduction of the extant dose by the intervention. It follows that during the process of intervention it is nonsense to apply dose limits: the objective is to reduce doses as much as reasonably achievable, not limit them.

The international criteria for interventions in situations with prolonged extant doses, which are recommended by the ICRP, are based on the level of such extant doses. Basically, they can be formulated as follows (Fig. 6):

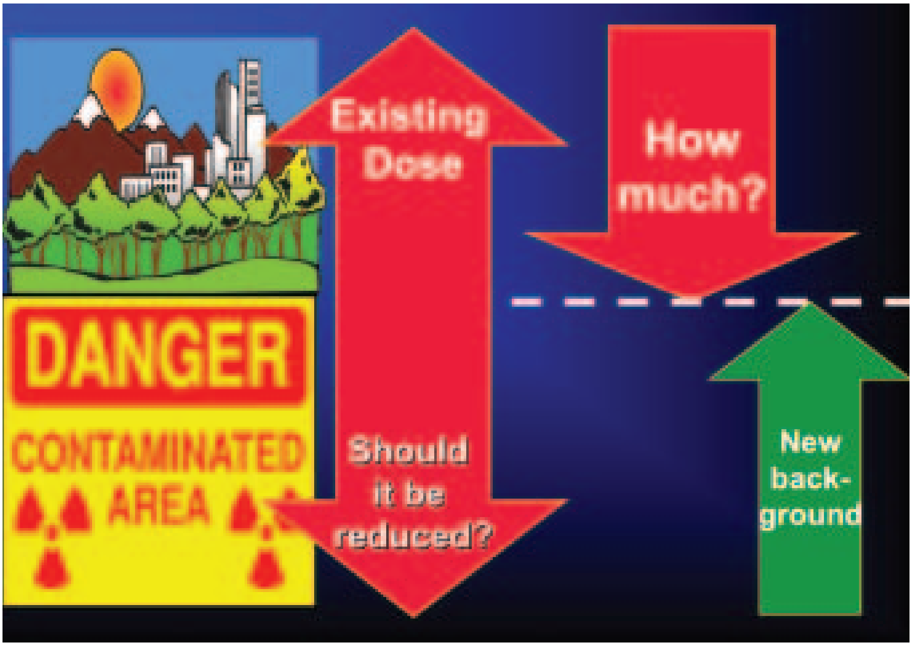


*FIG. 5. How the system works for interventions.*

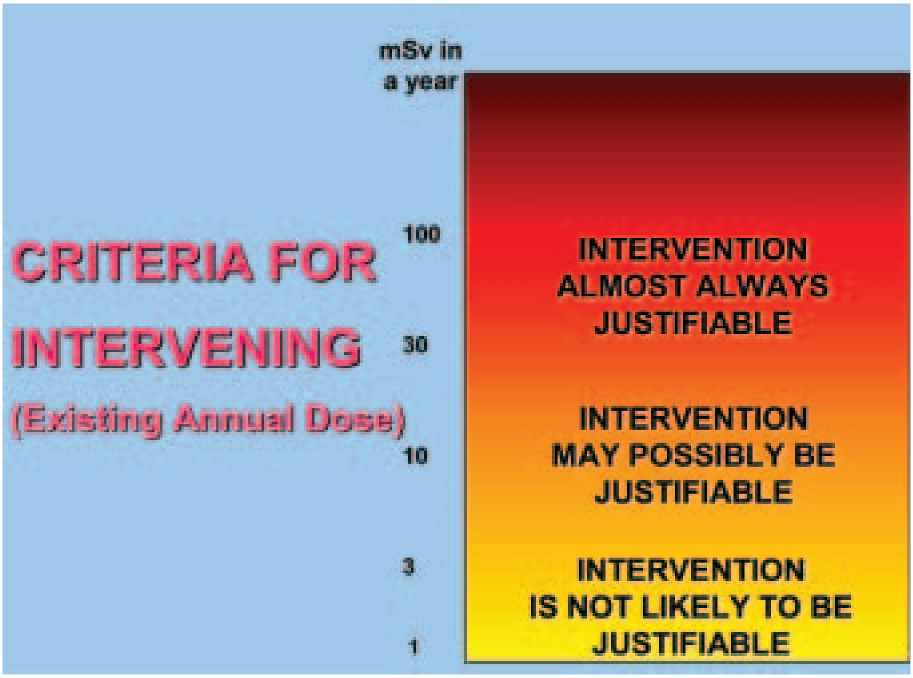


*FIG. 6. Dose criteria for justifying intervention with protective actions.*

— When doses are very high (e.g. approaching 100 mSv/a), intervention is almost always justifiable, i.e. intervention ‘must’ be performed. The qualifier ‘almost’ recognizes the fact that there are a few places in the world where the doses are that high and nothing is being done against them.
— Intervention may probably still be justified when the extant dose approaches values of around 10 mSv/a.
— When the values of the extant dose are very near the average background doses (i.e. in the region of a few mSv per year) intervention is not likely to be justifiable.

These criteria compare well with natural background levels around the world, which were referred to heretofore.

### 4.3. Summary: How the present system works

In summary, the present system of radiation protection works on the assumption that there is an extant background dose with an average of 2.4 mSv/a, which in some areas of the world may rise to a typical high of around 10 mSv/a, or a very high value of around 100 mSv/a and even more. Intervention is rarely justifiable at the low end, may be justifiable in the middle and is always justifiable at the upper end. Above this extant background dose value there are additional doses that may be introduced by justifiable practices, which are restricted with a dose limit of 1 mSv/a, a source constraint of 0.3–0.1 mSv/a and reduced further with a process of optimization of radiation protection; there is an exemption value of 0.01 mSv/a (Fig. 7).

## 5. THE CASE OF SAFE DECOMMISSIONING

The case of decommissioning vis-à-vis these current radiation protection criteria can be analysed by assuming that an installation (e.g. a nuclear power plant (NPP)) is introduced in a given location where there is a given background extant dose. As a result of the introduction the background extant dose will increase, perhaps very little, but will not be zero. If the NPP is regulated following the international radiation protection system, the increase will be kept below the restrictions described above. After its lifetime, the NPP will require to be decommissioned and the site restored. As a result, presumably, the dose will go down. But since it is not feasible to reduce the residual dose to absolute zero, a residual dose, perhaps negligible but not nil, would remain as a lasting addition of dose, a ‘delta dose’, over the original

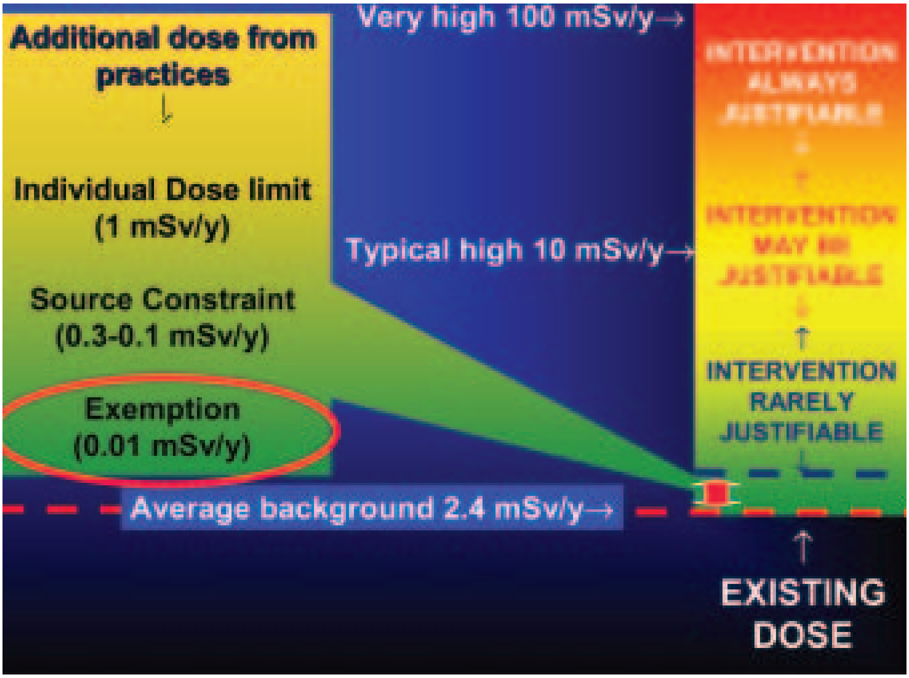


*FIG. 7. Summary: How the present system of radiation protection works.*

background extant dose. The current problem of the international community is that it has been unable to reach a quantifiable consensus on what residual dose, what delta dose, is internationally acceptable when decommissioning a facility that was used during the performance of a practice (Fig. 8).

This, rather than dismantling techniques, is the real problem of decommissioning: if an international agreement on the radiation safety criteria for restoring sites used during practices is not reached soon, the current installations ending their lifetime would perhaps be ‘decommissioned’, i.e. dismantled, but the real technical problem that the public is requesting to unravel would remain unsolved.

### 5.1. The issue of regulating commodities

The best indication that same basic radiation safety criteria are missing for decommissioning is the lack of resolution of the so-called issue of *regulating commodities,* which has engaged the international radiation protection community in a hot debate over past years. The problem is very simple: what is the level of radioactivity in goods, merchandise, products, etc., and, in general in any non-edible ‘commodity’, which requires regulation for radiation protection purposes. In order to illustrate the public importance of this issue, let us imagine the dilemma of a member of the public: he/she has probably learned some essentials about radioactivity, for instance that every product in the world contains some radioactivity. When shopping in a store he/she might ask, “Did the radiation protection regulator authorize this product that I am buying or not?” Surprisingly, the international community does not have a clear, non-convoluted answer to this simple dilemma. From what I heard today from the Conference President, it would be easier for such a curious member of the public if he/she lives in Germany because in this country that answer seems to be unequivocally available. But in most countries, and certainly internationally, there is no clear consensus as to when a radiation protection regulator should intervene regarding a particular commodity. Moreover, the situation is so irrational that while commodities such as nails, wood, bricks, etc., leaving a decommissioned nuclear power plant cannot be reintroduced into the market, a given foodstuff with the same level of radioactivity leaving the same installation can be sold commercially on the market because it would probably

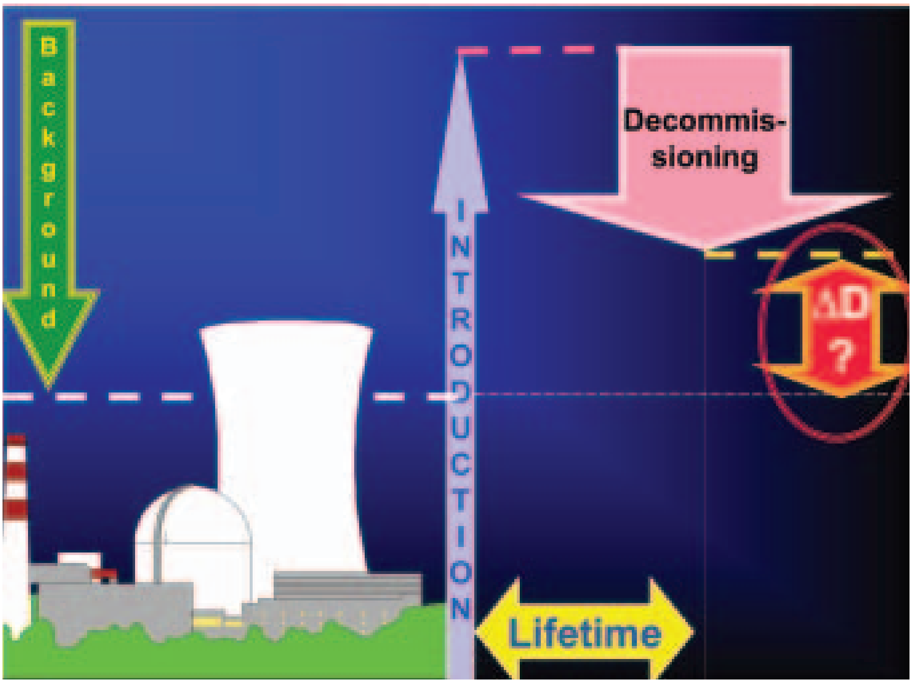


*FIG. 8. The radiation safety issue of decommissioning.*

comply with the international rules established by the Codex Alimentarius Commission that were incorporated into the BSS.

In summary, the current situation is that members of the public would be able to eat products that would normally not be allowed to be sent out from a decommissioned NPP into the market. This is because the Codex Alimentarius levels, which govern the regulations of edible substances, are internationally accepted and in addition are much higher than the levels that national regulators are using for releasing non-edible materials from NPPs. Many experts maintain that this is not necessarily a contradiction because, among other reasons, the models for human ingestion are straightforward, but human habits for the use of non-edible commodities can be extreme and require conservative models, etc. — all this seems to be logical, but for members of the public it is a logic that is difficult to digest.

## 6. OUTLOOK: BETTER COMMUNICATION?

The contradictions described above clearly indicate that in dealing with decommissioning safety criteria there is a serious problem of communication. The Conference President has clearly indicated that this is one of the major issues that hopefully the conference will deal with. The technical community has been unable to inform the public convincingly that they are exposed to cosmic rays, to terrestrial radiation, to radon in their home, to radiation from naturally occurring radioactive material from the extractive industries, to fallout from past events, to normal commodities containing radioactive materials, to residues from accidents that have occurred, to normal releases from current practices — and that decommissioning may conceivably increase the extant dose due to all these causes by just a very small fraction. If the technical community is able to solve this problem of communication, I believe that we will be solving one of the major problems of decommissioning.

In closing, let me express my hope that this conference will provide solid findings, which are planned to be submitted to the Board of Governors of the IAEA and that they can be converted into an international action plan on the termination of activities that could be submitted to the Board at its meeting in September 2004. This international action plan might produce an international code of conduct on decommissioning.

I wish you a very successful conference, with constructive discussions, a fruitful information exchange and solid, far-reaching findings.

Thank you for your attention.

# *OPENING KEYNOTE ADDRESS*

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**Abstract**

Germany is very pleased to host the IAEA international conference on decommissioning because this topic is high on the agenda in Germany in connection with the national phase-out policy. Independent of policy issues, decommissioning is an issue in all countries because nuclear facilities are coming to the end of their useful lifetimes and have to be decommissioned. In this context, it is very important to deal with all facilities and not only to concentrate on big plants. In carrying out the actual dismantling job, it is necessary to have the relevant technology at hand. According to German experience the required technology is available and it is also being improved through R&D activities. Funding is very important. In various instances, funds have not been reserved and decommissioning projects were deferred for several tens of years. It also has to be ensured that funds are available when needed. These are two arguments in Germany that favour immediate dismantling over dismantling after safe enclosure. The release of materials, buildings and sites is important, particularly in decommissioning. Quantitative requirements were included in the German Radiation Protection Ordinance when it was amended in 2001. The existence of a national legal framework is a prerequisite not only for the operation of nuclear facilities, but also for their decommissioning. The Joint Convention on the Safety of Spent Fuel management and on the Safety of Radioactive Waste Management, which also spells out requirements for decommissioning, provides a yardstick for calibrating national approaches and activities against international instruments.

It is an honour for me to act as President of this IAEA conference on Safe Decommissioning for Nuclear Activities: Assuring the Safe Termination of Practices Involving Radioactive Materials. I think the title is a bit bulky, but it fairly describes what will keep us busy in the next few days: a frank discussion of issues in the decommissioning of nuclear facilities. I am very happy that these questions can be discussed in such a big forum of experts.

## 1. THE GERMAN DIMENSION

When the IAEA asked Germany to host this conference, we were readily willing to do so. Many of you may deem this natural, because decommissioning has become a very concrete issue in Germany. But our interest in decommissioning is not only due to the German phase-out policy, which is regulated by the amended Atomic Energy Act. Phase-out began much earlier. For more than 20 years the German utilities have not applied for new licences. As mentioned by Mr. Warnecke earlier, all prototype nuclear power plants and many research reactors are in the decommissioning stage. After German reunification, nuclear power plants of Soviet design also had to be shut down because they did not comply with Western German safety requirements. Altogether, 17 nuclear power plants are presently in different stages of decommissioning. In the wake of this development, Germany has gained considerable experience in the decommissioning of nuclear facilities.

The remaining operating period of the 19 nuclear power plants currently in operation is determined by the residual amount of electricity they produce as laid down in the Atomic Energy Act. We expect the following number of units to be shut down in the forthcoming election periods:

- 2003–2006 → 2 units,
- 2007–2010 → 4 units,
- 2011–2014 → 4 units,
- 2015–2018 → 6 units,
- 2019–2022 → 3 units.

Assuming a period of ten years for dismantling, it can be estimated that complete decommissioning of German nuclear power plants can be accomplished in the 2030s. However, beyond this very concrete interest in decommissioning and the desire to discuss our experience, there were additional and more important reasons to host the IAEA decommissioning conference.

## 2. THE INTERNATIONAL DIMENSION

In recent years the discussion of nuclear safety — here used in a wide sense, including fuel cycle, waste management and proliferation — has been increasingly globalized. One important reason for this is the opening of the former Soviet Union that provided the basis for more co-operation between East and West in nuclear matters as well. One very striking problem today is the Iraqi conflict. If in individual countries — whatever the reason — appropriate precautions are not taken, the consequences touch the international community environmentally, financially and also politically. The importance of international organizations — especially the IAEA — under these conditions is still growing.

The growing importance of the international discussion of nuclear safety may also be seen from the perspective of new mechanisms like the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (Joint Convention). Also, the starting broad discussion on nuclear safety criteria in the European Commission demonstrates the growing importance of international discussions.

There is no doubt that the subject of the present conference, the decommissioning of nuclear facilities, is also the result of this globalization. In addition, decommissioning is not only a topic in countries operating nuclear power plants, whether they continue to generate nuclear power or are phasing it out. It is also a matter of interest in almost all countries in the world as they use radioactive materials, for example, in medicine, industry or research.

Sooner or later all nuclear facilities have to be decommissioned to an acceptable end point. Medical facilities, in particular, pose a considerable hazard to humans and the environment because very powerful radiation sources are being used which have led to several casualties. This hazard potential is sometimes not known sufficiently, as is the need for control over and decommissioning of such facilities. Therefore, increasing awareness of the necessity to decommission all types of facilities involving radioactive materials is an important issue. To push forward this awareness should be an important message of this conference to all parties involved: politicians, regulators, operators and the entire international community.

This conference will not only improve awareness, it will also provide concrete advice for our further activities, for each nation, for the international community. In addition, I hope that the conference will strengthen the process of establishing international guidance on decommissioning. Finally, it should give Member States the opportunity to critically reflect on the provisions they have made for decommissioning.

## 3. JOINT CONVENTION

We are observing a continuous increase in international co-operation in the regulation of nuclear safety and waste management. The Soviet Union disintegrated more than ten years ago. This revealed the nuclear practices in the countries of Central and Eastern Europe. In 1992, the Group of 7 (G-7) nations started to deal with nuclear safety in the countries of the former Soviet Union and allocated funds administered by the European Bank for Reconstruction and Development in London to improve nuclear safety in these countries. In this process it became clear how different were the views on nuclear safety and waste management in the East and the West. A lot of improvements have been achieved in the meantime, but a lot still needs to be done.

The G-7, and later the G-8, also promoted the idea of establishing international conventions on nuclear safety and on nuclear waste management. These conventions are valuable tools to achieve an acceptable level of nuclear safety worldwide.

The Joint Convention is in force. It explicitly deals with decommissioning in Article 26: "Each Contracting Party shall take the appropriate steps to ensure the safety of decommissioning of a nuclear facility." Implicitly, the Joint Convention deals with decommissioning in articles dealing with radioactive waste management, radiation protection, etc. Safe decommissioning requires, in addition to qualified staff, an appropriate legal and regulatory framework.

The first review meeting of the Joint Convention will be in November 2003. The national reports are due by May 2003. As the Joint Convention applies the same review mechanism as used for the Convention on Nuclear Safety, it can contribute considerably to the improvement of spent fuel and radioactive waste management safety in the countries of the contracting parties.

However, up to now only 29 countries are contracting parties. This is a rather low figure, taking into account that almost all countries have to manage radioactive waste and to decommission nuclear facilities. It is also astonishing to see that some of the important nuclear countries have not yet become a party to the Joint Convention. I believe it is important for the international community to work under a common framework of safety goals and safety standards. Therefore, I would like to take the opportunity at this conference to urge those countries that are not yet a party to the Joint Convention to make every effort to accede to it.

## 4. THE NEED FOR INTERNATIONAL SAFETY STANDARDS

The execution of the safety conventions highlights the question of how to measure safety levels. We need reliable and transparent yardsticks to assess whether or not a country is complying with the obligations of the conventions.

These yardsticks are also important in the process of European enlargement. Several countries have applied for accession to the European Union (EU), and the EU wants them to fulfil certain nuclear standards. The European Commission (EC) is even considering establishing binding standards for nuclear safety for all members and to ensure compliance. But, in addition to the question of whether or not the EU has legal competence in nuclear regulation, the problem is which standards can be used. The only internationally agreed nuclear safety standards available are those of the IAEA. They should be further developed so that they can be used as a universally applicable framework for national regulation. The approach to make wider use of international safety standards has also been supported at the top regulator's level at the June 2002 meeting of the Commission on Safety Standards of the IAEA and was reiterated at the meeting of senior regulators during the IAEA General Conference in September. The Commission considers it timely to gradually transform the IAEA safety standards into a set of universally accepted global standards.

Ladies and gentlemen, all this underlines the need for a comprehensive set of internally agreed safety standards. This is the field where the IAEA has played an important role for many years and we would like to support it where we can.

Beyond our national responsibility for the safe use of nuclear energy we feel obliged to contribute to common standards because they are necessary for a globalized environment. In the long term, nuclear residues can pose a serious international threat to human and environmental health if they are not treated adequately. The IAEA has already issued four standards on decommissioning, the predisposal 'Requirements', which include decommissioning, and three decommissioning 'Guides'. These standards are a good basis for national legislative actions as they provide full coverage of aspects that need to be taken into account. Perhaps this conference will help to give some more answers on a more concrete level, perhaps it can contribute to a further development of those guides. In addition, we would like to bring the IAEA to the position of effectively developing strategies to support countries, particularly those with less developed nuclear knowledge and perhaps also fewer precautions in the field of decommissioning.

## 5. TWO IMPORTANT ISSUES OF THE CONFERENCE: FUNDING OF DECOMMISSIONING AND RELEASE FROM CONTROLS

The plan of this conference is to address a limited number of issues dealing with decommissioning and spend half a day of detailed discussion on each issue. I think this plan is very well suited to come to common conclusions on subjects, where up to now very different approaches exist. I am very grateful to Abel Gonzales for promoting this conference plan, because I am convinced that we need a comprehensive international discussion. We have to come to equivalent approaches worldwide. So I hope that at the end of the conference I can report to you substantial progress on the issues addressed.

We will start today with sessions of an informative nature to prepare the ground for the in-depth discussion of the issues during the following days. Each issue will be introduced by invited papers that state the current positions and identify concerns. Then follows a comprehensive discussion by a panel and with you, the participants. Statements from poster contributions can be included.

Let me make some remarks on the issues of funding and release from controls, which are very important to me, although I do not want to anticipate the debates of Sessions 2.C and 2.E.

Without funds it will not be possible to decommission nuclear facilities, manage the respective waste and, if necessary, clean up the site. This means that after termination of a practice an acceptably safe situation will barely be achievable. And there are countries where funds have not been collected and are not available now, or where funds are being collected but is not sure that they will still be available when needed in the future.

Our policy aims for immediate dismantling of shut down nuclear facilities. This avoids shifting the nuclear burdens to future generations and allows one to benefit from the existing experience and skill of the personnel and from the available funds. Internationally, we have to prevent nuclear 'leavings' from becoming a 'common threat', leading to financial and probably environmental burdens placed on the international community. It is not acceptable either for the international community to bear the burden of decommissioning military facilities or equipment because there had been no funding for decommissioning and there is now a lack of money or responsibility, or both. It would be interesting for me to hear whether there is a preferred funding approach or whether a multitude of approaches may be acceptable as long as operational and regulatory powers are clearly allocated and separated.

Another issue of funding is the transfer of plants to a new operator. This is particularly important in cases involving the privatization of facilities. In most cases, funds for decommissioning have not been set aside and are not available for a new operator. What is to be done in such a case? The private operator would easily go bankrupt if decommissioning has to be carried out. Decommissioning then becomes a task for the State or, as we know, for the international community.

A third major funding issue is related to the decommissioning of facilities and the clean-up of contaminated land associated with weapons production and testing. This is a huge effort, as is known from countries working on this task. Other countries have not progressed in cleaning up their respective situations. What is to be done in such situations? I believe the essential needs should be identified and prioritized as a prerequisite for international assistance.

The deferral of decommissioning by many decades or even by one or more centuries leads to another problem of funding. Even if funds are available when a facility is being shut down, it is not at all clear that they will be available when needed for decommissioning in the far distant future. The funds may be lost, for example, due to a crash of the stock market, due to hyperinflation, due to the bankruptcy of an operator and so on. It is indeed very difficult for a regulator to foresee such time-frames and give assurance for the availability of funds after such periods. There is an interesting initiative of the EC to introduce funds administered by a third party, so that the money is not lost as a result of economic events.

Apart from funding, another issue of the conference is the release of materials, buildings and sites from nuclear regulatory controls. Although the subject is difficult, I believe it is necessary to achieve results with regard to this issue in the near future because a do nothing or wait and see approach can be the worst option.

In Germany, a decision was made to put release levels into the national law, i.e. the radiation protection ordinance, which was amended this year, to implement a European Directive. The law specifies quantitative data for individual radionuclides for unconditional and conditional release from nuclear regulatory control. These data actually define the borderline between what is ‘radioactive’ and what is ‘non-radioactive’. What the law perhaps does not address sufficiently is the question of how to practically prevent the so called ‘conditioned’ or ‘unconditioned’ release that leads to a radioactively relevant accumulation in the long term.

Thus, the key questions are the following:

— What are the activity levels that determine whether waste has to be disposed of in a repository for radioactive waste or may be disposed of in another type of repository?
— What are the requirements for a repository for very low level/hazardous/industrial waste?
— What are the activity levels for the safe release of materials from nuclear regulatory controls?
— What are the requirements for ensuring, in practice, compliance with the above mentioned requirements, especially in the long term?

## 6. REACTION OF THE PUBLIC

Before closing my speech I would like to briefly address the question of the reaction of the public. I think public perception is important for all of us, regulators as well as experts and industry. It is the arena within which we act; it gives us the necessary feedback on what we are doing wrong or what we have done well. So, as the most important prerequisite for our work let us be transparent, open and clear in our discussions and in our communication with the public. I wish the conference a good start and real success.

# MAGNITUDE OF THE DECOMMISSIONING TASK

(Session 1.A)

**Chairperson**

**J.T. GREEVES**
United States of America

# MAGNITUDE OF THE NUCLEAR DECOMMISSIONING TASK IN AFRICA AND WEST ASIA

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**Abstract**

The safe decommissioning of nuclear facilities is becoming of ever increasing importance worldwide, and the paper assesses the scope of these activities in the Africa and West Asia regions. With one or two notable exceptions, nuclear technology has not been widely implemented in this region, but there are a number of facilities that are undergoing decommissioning or need to be decommissioned in the future. In the paper, nuclear facilities have been divided into two broad categories: research reactors and their ancillary laboratory and research facilities; and nuclear fuel cycle facilities. The latter includes all aspects of the fuel cycle, from mining and milling operations to the final disposal of radioactive waste materials, including the power reactor itself. Research reactors are present in 14 countries, with 15 of the total of 23 being operational. The rest are shut down, under construction or in the planning stage. With the exception of mining and milling activities, nuclear fuel cycle facilities appear to be largely confined to South Africa. Four decommissioning strategies are identified ranging from care and maintenance, through safe enclosure and entombment to full decommissioning and disposal. The peculiar problems of the region such as lack of infrastructure and adequate financing make entombment an attractive option. Lack of national policies and strategies are another concern that needs to be addressed. Decommissioning liability cost estimates indicate that the Koeberg Nuclear Power Plant in South Africa represents more than half of the region's liabilities, with research reactors comprising about a third. All the other liabilities constitute just over 10% of the total liabilities assessed for the region. The total decommissioning liability for the Africa and West Asia region is estimated to be US $1.25 billion.

## 1. INTRODUCTION

This conference provides an ideal opportunity for extensive information exchange on nuclear decommissioning and environmental restoration, the basic aim of which is the removal of material from regulatory control and the safe termination of practices. This paper explores the current decommissioning programme regarding nuclear facilities on the African continent and in West Asia. Although this region of the world has not implemented nuclear technology on a large scale, several nuclear facilities are either in the process of being decommissioned or need to be decommissioned in the future. These include a nuclear power plant, a number of research reactors, uranium mining, milling and processing facilities, a uranium conversion plant, two uranium enrichment plants and two fuel fabrication plants.

An attempt is made to provide an overview of the current situation in the African and West Asian region regarding decommissioning, inasmuch as information could be obtained about this region. The existing situation is benchmarked against a set of criteria reflecting the applicable international norms and practices. From this assessment, options are explored for resolving the challenges presented by the current situation in the region. The major concerns about the viability of decommissioning implementation are discussed and the support needed to alleviate the constraints is identified. Finally, an overall estimate of the magnitude of the nuclear liabilities pertaining to the region as a whole is provided.

## 2. REGIONAL OVERVIEW

### 2.1. Current situation

A survey was carried out of the existing nuclear facilities in the Africa and West Asia regions, involving research reactors (plus support facilities) and the nuclear fuel cycle (including nuclear power plants). Research reactors and attendant facilities such as isotope production plants are considered together. The nuclear fuel cycle is considered as a whole, that is, consisting of a fuel supply side (front end) and the spent fuel/waste processing side (back end) after the nuclear power reactor. The front end of the nuclear fuel cycle typically comprises the following steps: uranium mining; milling and processing; uranium conversion; uranium enrichment; and fuel fabrication facilities. The back end, for its part, includes spent fuel/waste management activities involving treatment (reprocessing), interim storage, conditioning and disposal.

Individual countries in the region are considered in terms of the above demarcations. That is, the research reactors and support facilities on the African continent are analysed in Table I, and in the West Asia region in Table II. The nuclear fuel cycle in Africa is analysed in Table III, and that in West Asia in Table IV [1].

TABLE I. RESEARCH REACTORS AND SUPPORT FACILITIES IN AFRICA

| Country | Type | Capacity | Application | Status | Age |
|---|---|---|---|---|---|
| Algeria | ES SALAM: Heavy Water | 15 000 kW | Academic training | Operational | 10 years |
| | NUR: Pool | 1000 kW | | Operational | 13 years |
| Democratic Republic of the Congo | TRICO-I | 50 kW | | Shut down | 43 years |
| | TRICO-II | 1000 kW | | Operational | 33 years |
| Egypt | ETRR-1: Tank WWR | 2000 kW | Research | Operational | 40 years |
| | ETRR-2: Pool | 22 000 kW | Research | Operational | 5 years |
| | Radwaste treatment plant | Unknown | | | ±40 years |
| Ghana | GHARR-1: MNSR | 30 kW | Research, academic, isotopes | Operational | 8 years |
| Libyan Arab Jamahiriya | IRT-1 Pool | 10 000 kW | | Operational | 20 years |
| Morocco | MA-R1L TRIGA MARKII | 2000 kW | | Under construction | N/A |
| Nigeria | NIRR-0001: MNSR | 30 kW | | Under construction | N/A |
| Tunisia | TRR | 2000 kW | N/A | Planned | N/A |
| South Africa | Safari 1 MTR Oak Ridge Tank in pool | 20 000 kW | ⇒ Research ⇒ Isotope production | Operational | 37 years |
| | Radioisotope production facilities | Export | Isotope production | Operational | 37 years |
| | Fuel manufacturing | Domestic fuel requirements | Research reactor fuel fabrication | Operational | 15 years |
| | Liquid radwaste treatment plant | Domestic requirements | Treatment | Operational | 40 years |
| | Spent fuel/waste storage | 600 elements | Research reactor spent fuel storage | Operational | 10 years |
| | Disposal sites | Unverified | Disposal of historic research wastes | Shut down | 40 years |

TABLE II. RESEARCH REACTORS AND SUPPORT FACILITIES IN WEST ASIA

| Country | Type | Capacity (kW) | Application | Status | Age |
|---|---|---|---|---|---|
| Islamic Rep. of Iran | ENTC LWSCR | 0 | | Operational | 10 years |
| | ENTC MNSR | 0 | | Operational | 7 years |
| | ENTCLWSCR | 0 | | Operational | 10 years |
| | ENTC MNSR | 30 | | Operational | 8 years |
| | TRR: Pool | 5000 | | Operational | 35 years |
| Iraq | IRT-5000: Pool | 5000 | | Shut down | 35 years |
| | Tammuz-2: Pool | 500 | | Shut down | 35 years |
| Israel | IRR-1: Pool | 5000 | Research, academic | Operational | 42 years |
| | IRR-2: Heavy water | 26 000 | | Unverified | 39 years |
| Jordan | LPNRR | 30 | MNSR | Planned | |
| Syrian, Arab Republic | SRR-1: MNSR | 2000 | | Operational | 6 years |

#### *2.1.1. Research reactors and support facilities*

There are a total of 23 research reactors in the Africa and West Asia regions, ranging from 30 to 26 000 kW in thermal power [2]. They are in 14 countries and 15 are currently operational, with a further unverified reactor believed to be operational. There are three shut down reactors, one in the Democratic Republic of the Congo and the other two in Iraq. The latter two were destroyed by aerial bombardment during the Gulf War in 1991 [3]. Morocco and Nigeria are both currently constructing research reactors, whereas Jordan and Tunisia have one each in the planning stages.

Pool type reactors are the most common, with TRIGA and Miniature Neutron Source Reactors (MNSR) being popular. The reactors are mainly used for academic, research, industrial and agricultural purposes. The nature of the ancillary facilities is uncertain in most instances, but they are likely to include analytical, isotope production and hot cell facilities.

TABLE III. NUCLEAR POWER PLANTS AND THE NUCLEAR FUEL CYCLE IN AFRICA
*(UG: underground; OP: open pit)*

| Country | Facility | Capacity | Application | Status | Age |
|---|---|---|---|---|---|
| Egypt | Mining and milling | None | Extraction of uranium | Semi-pilot plant | |
| Commissioned | | | | | |
| | | | from phosphoric acid | | 1999 |
| Gabon | Mining and milling | | Uranium mining, milling and processing | | N/A |
| | Centre 1: UG | 16 000 t U total | | Shut down 1997 | |
| | Centre 2: OP | 12 000 t U total | | Shut down 1999 | |
| Madagascar | Mining and milling | None | Uranothorianite concentrate production | Shut down 1963 | 10 years |
| Namibia | Mining and milling | | Uranium mining, milling and processing | | |
| | Rossing (OP) | 1999: 4000 t U/a (70 000 t U total) | | | 26 years |
| Niger | Mining and milling | | Uranium mining, milling and processing | | |
| | Centre 1: OP | 1500 t U/a (36 000 t U total) | | Operating | 32 years |
| | Centre 2: UG | 2300 t U/a (43 000 t U total) | | Operating | 24 years |

TABLE III. (cont.)

| Country | Facility | Capacity | Application | Status | Age |
|---|---|---|---|---|---|
| South Africa | Mining and milling: | | Gold mining industry producing uranium as a by-product | | |
| | ⇒ Hartebeest Fontein (UG) | 1959: 17 U plants | | | 46 years |
| | ⇒ Vaal Reefs (UG) | 1999: 3 U plants | | Operational | 25 years |
| | ⇒ Palabora (OP) | 1500 t U/a | | | 23 years |
| | | (153 000 t U total) | | | |
| | Conversion plants (Pelindaba) | Pilot plant | | Decomm. 1985 | N/A |
| | | Commercial plant 1000 t U/a | $UF_6$ production | Decomm. 1999 | |
| | Enrichment plants (Pelindaba) | Pilot plant | HEU production | Decomm. 1990 | N/A |
| | | Commercial plant 300 t SWU/a | LEU production | Decomm. 1995 | |
| | Fuel fabrication plant (Pelindaba) | 100 t·HM/a | PWR fuel fabrication | Decomm. 1997 | N/A |
| | Power plant 2 × PWR reactors (Koeberg) | 2 × 960 MW | Electricity production | Operational | 17 years |
| | Spent fuel storage (Koeberg) | ARS approx. 1500 t HM | Storage in reactor pools | Operational, re-racked 2000 | 17 years |
| | Waste storage/disposal (Vaalputs) | Near surface repository: Variable | LILW(SL) disposal in trenches | Operational since 1986 | 16 years |

TABLE IV. NUCLEAR POWER PLANTS AND THE NUCLEAR FUEL CYCLE IN WEST ASIA

| Country | Facility | Capacity | Application | Status |
|---|---|---|---|---|
| Iraq | Al Skhair uranium mine | Unknown | Uranium production | Entombed |
| | Shargat EMIS Facility | Unknown | Uranium enrichment | Destroyed |
| | Al Quaim Uranium Purification Facility | Unknown | Uranium purification | Destroyed |
| | Jessira Uranium Processing Plant | Unknown | Uranium conversion | Destroyed |

**Note:** Other West Asian countries may have nuclear fuel cycle related facilities, but no public information is available.

South Africa is the only country that is known to fuel its research reactor with locally manufactured fuel elements using indigenous uranium. Other countries import their fuel from the reactor vendor countries, with many having a ‘take back’ agreement with the supplier. Fuel supply countries include the Russian Federation, China and Argentina.

### *2.1.2. Nuclear fuel cycle facilities*

These facilities are largely confined to the mining, milling and processing aspects in the areas under consideration. Gabon, Namibia, Niger and South Africa are the only countries in the region currently producing uranium. Previous producers include the Democratic Republic of the Congo and Madagascar. Production is from both underground and open pit facilities. The production levels of the countries give an indication of the size of the facilities that would need to be decommissioned. On this basis, South Africa would clearly have the greatest liability in that up to 17 uranium plants have been operational since uranium production commenced in 1952. Declines in the uranium market have seen declines in production from all the countries, with South Africa’s current production being derived from only three plants. Most of these facilities involved mining, milling and processing activities, but

Madagascar, for example, had no processing facilities and exported uranothorianite concentrate [4].

The decommissioning activities related to mining operations fall into two categories. One is the safe disposal of the tailings materials and the other is the decontamination of process equipment where radionuclides have concentrated during the extraction processes.

Namibia, Niger and Gabon are all primary uranium producers. The deposits exploited are sandstone hosted in Gabon and Niger, and alaskitic granite hosted in Namibia. Gabon is notable in that some of its uranium production was from the natural reactor site at the Oklo deposits [5]. South Africa produces its uranium as a by-product of gold from quartz pebble conglomerate deposits. Countries such as Iraq and Egypt have investigated the extraction of uranium as a by-product from sedimentary phosphate deposits.

Other fuel cycle facilities such as enrichment plants and conversion plants are limited to South Africa where they have been shut down for some time. Iraq was developing many of these types of facilities as part of its weaponization programme, prior to the Gulf War in 1991, but these have all been either destroyed or shut down and dismantled by the IAEA [3].

The back end of the nuclear fuel cycle is little represented in Africa and West Asia other than by interim storage facilities associated with existing nuclear facilities. South Africa also has the only licensed radioactive waste disposal facility in the region. Facilities of this type will have to be developed to dispose of the waste generated by the decommissioning of existing and future nuclear facilities of all types. They themselves will have to be decommissioned and remediated prior to their final and ultimate closure.

Nuclear fuel cycle facilities may be present in other countries, but their existence has not been publicly acknowledged.

## 2.2. Current and future decommissioning programmes

### *2.2.1. Research reactors and support facilities*

Very little information is available on research reactor decommissioning as such. Countries do not expressly state what their plans are regarding the future decommissioning of their research reactors, except to admit to the eventual need for terminating these practices. As the generic aspects of research reactor decommissioning are fairly well understood, assumptions can be made about a future decommissioning programme [6–9]. This also applies to the various support facilities associated with the reactors, such as research laboratories, isotope production facilities, fuel fabrication plants and storage/disposal facilities insofar as they exist.

### 2.2.2. *Nuclear fuel cycle facilities*

As regards the nuclear fuel cycle, with the exception of South Africa and possibly Israel, most of the activities in the region centre around uranium mining, milling and ore processing. Some information is available on the latter subject as far as Africa is concerned. Even with a dearth of information, fairly accurate assumptions can be made about the typical underground or open pit mining operations, milling plants, filtration plants and solvent extraction facilities associated with these systems. Generic safety requirements for the decommissioning of nuclear facilities have been documented by the IAEA, which has also described appropriate technologies [10–14].

The current producers generally have environmental remediation plans in place and some shut down facilities in places such as Gabon and South Africa have already undergone, or are undergoing, remediation. In countries such as Madagascar, where production ceased decades previously, the need for rehabilitation of uranium mining sites is recognized, but no specific plans are yet in place [4]. A summary of available information is provided in Table V.

## 3. DECOMMISSIONING STRATEGIES

The approach to nuclear facility decommissioning is outlined in Table VI. Strategies are defined in terms of the typical steps in the nuclear liability management process, i.e. pre-treatment (facility dismantling and decontamination), waste treatment (concentrating, packaging and storage of decommissioning waste), waste disposal (permanent isolation of waste, such as entombment [15], near surface or deep geological disposal) and site restoration (remediation and return to green field conditions).

Various decommissioning strategies are possible, i.e. ranging from the minimum care and maintenance requirements following plant shutdown (Strategy 1) to full scale decommissioning, waste management, final disposal and site restoration (Strategy 4) [6, 16]. Table VI also indicates the options and alternatives that would be available to each of the strategies.

The approach adopted here is based on the concept of managing down or ‘discharging’ the nuclear liabilities associated with the decommissioning of disused facilities. The aim of nuclear liability management is the systematic discharge of all the costs that need to be incurred in the future as a result of current and past practices involving nuclear operations. These costs include the treatment steps that need to be gone through until the radioactive waste from decommissioning is finally disposed of and isolated from the biosphere.

TABLE V. NUCLEAR POWER PLANTS AND NUCLEAR FUEL CYCLE DECOMMISSIONING PROGRAMMES

| Country | Facility type | Scope of decommissioning | Scope of environmental restoration | Remarks |
|---|---|---|---|---|
| Egypt | Mining and milling | Semi-pilot plant for the extraction of uranium from phosphoric acid | N/A | N/A |
| Gabon | Mining, milling and processing | | Rehabilitation programme for Centre 1 (Mounana) comprising 7 sites on 60 ha:<br>⇒ Tailings & residues impoundment closure<br>⇒ Tailings cover<br>⇒ Site re-vegetation | ALARA approach<br>Completion date: 2000<br>Long term monitoring |
| Madagascar | Mining and milling | | 50 small deposits of uranothorianite mined in the Fort Dauphin area | In densely populated areas. Reclamation required for future agricultural usage. |
| Namibia | Mining, milling and processing | | Cost estimation completed for:<br>⇒ Monitoring<br>⇒ Waste dump stabilization<br>⇒ Effluent management<br>⇒ Site rehabilitation | Total cost estimate 1999: approx. US $6 million |
| Niger | Mining, milling and processing | | Large amounts of waste material accumulated from mining and milling activities<br>Surface disturbances from 4 open pit mining sites | Current emphasis on market competitiveness |

TABLE V. (cont.)

| Country | Facility type | Scope of decommissioning | Scope of environmental restoration | Remarks |
|---|---|---|---|---|
| | Mining and milling | ⇒ Old gold U/plants decommissioned | ⇒ Clean-up done on demand<br>⇒ Vast areas around gold/ uranium mines contaminated | Environmental issues:<br>⇒ Dust pollution<br>⇒ Surface and groundwater contamination<br>⇒ Residual radioactivity |
| | Conversion plant (Pelindaba) | Stage 3 decommissioning planned for 2006 | Decontaminated facility to be deregulated | Green field restoration not planned |
| | Enrichment plants (Pelindaba) | Stage 2 decommissioning completed in both plants | Decontaminated facility to be deregulated | Green field restoration not planned |
| South Africa | Fuel fabrication plant (Pelindaba) | Stage 2 decommissioning completed | Decontaminated facility to be reused for PBMR fuel plant | |
| | Power plant 2 × PWR reactors (Koeberg) | Plant shutdown planned for 2035. Decommissioning strategy being developed | No reactor site restoration planned | PBMR pilot plant to be located at reactor site |
| | Spent fuel storage (Koeberg) | Pool storage integral part of power reactor facility | | |
| | Waste storage/disposal (Vaalputs) | LILW(SL) disposal facility decommissioning planned for 2030 | Institutional control | Facility to be used for long term storage of LILW(LL) and possibly developed for deep geological disposal |

TABLE VI. DECOMMISSIONING STRATEGIES FOR NUCLEAR FACILITIES

| Strategy | Facility pre-treatment | Waste treatment | Waste disposal | Site restoration | Options |
|---|---|---|---|---|---|
| 1. Care and maintenance | Stage 1 + C&M + regulatory control | | | | *Alternatives:*<br>⇒ C&M in perpetuity<br>⇒ C&M followed by future decommissioning |
| 2. Safe enclosure | Stage 1 + safe enclosure + regulatory control | | | Temporary site restoration | *Alternatives:*<br>If not Strategy 1, then<br>⇒ Safe enclosure subject to regulatory control followed by future decommissioning |
| 3. Entombment | Stage 1 | | Entombment<br>⇒ Termination of regulatory control<br>⇒ Institutional control | Green field site restoration around/over tomb | *Alternatives:*<br>If not Strategies 1 or 2, then<br>⇒ Entombment<br>⇒ Site restoration |
| 4. Full decommissioning | ⇒ Stage 1 + Stage 2 + Stage 3<br>⇒ Release facilities/site from regulatory control | Resulting waste<br>⇒ Treated,<br>⇒ Conditioned and<br>⇒ stored | Waste disposal in<br>⇒ Near-surface and/or<br>⇒ Deep repositories<br>⇒ Termination of regulatory control<br>⇒ Institutional control | Green field site restoration | *Alternatives:*<br>If not Strategies 1, 2 or 3, then<br>⇒ Full scale decommissioning<br>⇒ Disposal and<br>⇒ Site restoration<br>⇒ Termination of regulatory control<br>⇒ Institutional control |

**C&M:** Care and maintenance.
**Stage 1 Decommissioning:** Facility shutdown followed by inventory retrieval.
**Stage 2 Decommissioning:** Process plant dismantling and scrap material decontamination.
**Stage 3 Decommissioning:** Process building demolition/decontamination for green field restoration/reuse.
**Safe enclosure:** Removal of uncontaminated structures, build temporary structure around process plant, cover with earth.
**Entombment:** Seal process plant in thick concrete permanently to isolate radioactivity

### 3.1. End points in current and future decommissioning programmes

The choice of end points for liability discharge is crucial, as these end points will basically determine the magnitude of the liabilities. Examples of end points are: (1) entombment (Strategy 3) that serves as a form of near surface disposal; and (2) near surface/deep geological repository (Strategy 4). It is of course also possible to follow a strategy that obviates the need for an end point altogether, such as in the case of C&M (care and maintenance) (Strategy 1), where a facility is left in its present condition in perpetuity. The question regarding the appropriateness of the choice of end point is the subject of some controversy. Ultimately, however, decisions about end points have to be initiated by the responsible waste management agency in conjunction with the competent authorities in a particular country. These choices are therefore largely country specific and depend on environmental, technological, infrastructural and cost considerations. In many countries today public opinion tends to play a decisive role in the approach to resolving liability management issues.

In general, the main consideration in the selection of end points is to achieve a state of affairs where regulatory control over the nuclear facilities is terminated and institutional control, where necessary, commences. The end points are shown for the different strategies defined in Table VI. There are only two strategies for which regulatory control would not be terminated, i.e. Strategies 1 and 2. In all other cases the strategies will lead to an end point where regulatory control can be terminated.

## 4. NUCLEAR LIABILITY ESTIMATES

A rough estimate is made of the nuclear liabilities of the region with reference to Table VII, based on the assumptions discussed with reference to Table VI.

### 4.1. Research reactors and support facilities

*Strategy 1* (C&M) is considered to be an undesirable option for research reactor decommissioning because of the ongoing nature of the C&M activities at existing nuclear sites. Countries in the region may find indefinite, ongoing C&M to be an unrealistic strategy.

*Strategy 2* (safe enclosure) entails ongoing regulatory control — albeit at a low level — after completion of the enclosure, as the structure needs to be removed at some stage in the future. Because of its temporary nature and

TABLE VII. DECOMMISSIONING LIABILITY ESTIMATES FOR AFRICA AND WEST ASIA

| Facility type | Number of facilities | Proposed decommissioning strategy | Unit decomissioning liability (millions of $) | Estimated liability (millions of $) |
|---|---|---|---|---|
| Research reactors and support facilities (1) | 21 | Strategy 3: Entombment (3) | 17 + 25% | 446 |
| *Nuclear fuel cycle:* | | | | |
| — Milling & processing plant (2) | 22 | Strategy 4: Full decommissioning | 1 | 22 |
| — Front end of fuel cycle facilities (4) | N/A | Strategy 4: Full decommissioning | N/A | 104 |
| — Power reactor (5) | 1 × 2 units | Strategy 4: Full decommissioning | 330 × 2 | 660 |
| — Back end of fuel cycle facilities (6) | Unverified | Strategy 4: Full decommissioning | | Unverified |
| — Waste disposal facilities (7) | 1 | Institutional control | 15 | 15 |
| Total liability for African and West Asian region | | | | 1247 |

**Notes:**

(1) Support facilities are assumed to be 25% of reactor decommissioning liabilities. Spent fuel liabilities are excluded.

(2) Ore milling, processing and extraction plants are included. Mining plant and tailings dams are excluded.

(3) Costs of entombment are assumed to be approximately one third of the cost of full decommissioning, i.e. 1/3 × $50.

(4) Milling, conversion, enrichment and fuel fabrication facilities are included. Individual facilities are not clearly identifiable, estimates are used.

(5) Power reactor decommissioning cost is assumed to be $330 per unit [6–8].

(6) Spent fuel storage/conditioning/reprocessing and disposal facilities (where they exist) as well as liquid effluent management facilities are included. In the case of Koeberg, the spent fuel storage facility is considered part of the reactor complex. Waste disposal (plus repository closure and institutional control) is included in the decommissioning liabilities. Mine tailings dams may be regarded as repositories, if used for dilution and dispersion of radioactive concentrates.

(7) Institutional control of the repositories after closure (Vaalputs).

future requirements, this method may be unattractive to countries in the region.

*Strategy 3* (entombment) should be a relatively attractive approach to countries in the region. In principle, entombment is a fairly straightforward process, whereby closed reactor facilities (sans conventional equipment) are covered in thick concrete. The advantage of this approach is the fact that decommissioning does not generate further radioactive waste. Furthermore, the method offers a permanent and safe end result, including site remediation around the tomb.

Regulatory control of the facility also ceases after entombment, but passive institutional control would still be necessary. The cost of entombment is estimated as approximately one third of the cost of full reactor decommissioning, probably making it attractive to countries in the region.

*Strategy 4* (full decommissioning) is clearly the most thorough method, as it entails the completion of the entire decommissioning process, leaving the reactor site free for full restoration to green field conditions and disposing of the resulting waste in a final repository. This approach is costly and hinges largely on the future use of the reactor site for commercial purposes, as well as the availability of disposal facilities for the resulting waste. Although some countries in the region may elect to pursue this strategy, such as South Africa, it is probably unattractive to the majority of countries in the region.

In this study, research reactor spent fuel management is not taken into account, except insofar as the fuel needs to be transferred from the reactors (Stage 1: decommissioning) into safe storage systems before decommissioning can commence. Countries in the region have different fuel suppliers, with whom some may have take-back arrangements. Those who do not have take-back arrangements or final disposal facilities for their spent fuel clearly need to make provision for these liabilities.

The research reactor support facilities are not handled separately here, but these are (rather arbitrarily) assumed to be 25% of the decommissioning cost of the reactors. Support facilities include fuel manufacturing plants, isotope production facilities and effluent handling plants, spent fuel storage facilities and research laboratories.

### 4.2. Nuclear fuel cycle: Mining, milling and processing

*Strategy 1* (C&M) is not a desirable approach for disused milling and processing plants (including acid and uranium extraction plants), as the levels of radioactivity encountered in these facilities can be very high. Poorly controlled sites would be vulnerable to unauthorized people removing contaminated materials from disused facilities. This strategy would not only burden future generations with the task of protecting disused sites in perpetuity, but would also be very costly to implement in the long run.

*Strategies 2 and 3* (safe enclosure and entombment) are not relevant to these facilities.

*Strategy 4* (full decommissioning) appears to be the only safe and viable method for addressing disused milling and processing plants. By implication, this approach entails full facility decommissioning with attendant waste management, including disposal activities. Old mine tailings dams can be licensed as final disposal facilities depending on the safety standards in force in the various countries of the region. Accordingly, radioactive materials can be released to the tailings dams in diluted form and dispersed.

### 4.3. Nuclear fuel cycle: Power reactors

The Koeberg Nuclear Power Plant in South Africa, consisting of two PWR reactors, is currently the only power plant in the region. The electricity utility Eskom has as yet not put forward a definite plan for the decommissioning of the nuclear power plant. Eskom is making financial provision for decommissioning, as well as spent fuel management including disposal. The liabilities associated with the spent fuel are not taken into account in this analysis.

The assumption is made that the reactor will be fully decommissioned at the end of its useful life around 2025–2030 and that standard decommissioning methodology will apply [17]. The cost of decommissioning of a typical LWR is assumed to be approximately $330 per unit. The decommissioning costs are further assumed to include all downstream liabilities up to and including final disposal. South Africa operates an LILW disposal site at Vaalputs, approximately 500 km north of Koeberg, where decommissioning waste can be disposed of.

### 4.4. Nuclear fuel cycle: Back end facilities

These facilities typically include the various spent fuel management (storage/reprocessing/conditioning/disposal facilities) and operational disposal facilities that need to be decommissioned at the end of their useful life. As the Koeberg Nuclear Power Plant is the only one in the region, it is used as the basis for estimating the costs of decommissioning the back end facilities. There are presently fully re-racked wet storage pools for lifetime storage at the reactor as well as provision for dry storage in four dual purpose casks. The decommissioning of these facilities is considered to be included in the cost of reactor decommissioning.

### 4.5. Nuclear fuel cycle: Waste disposal facilities

The Vaalputs disposal facility in South Africa is the only verified near surface disposal facility in the region. This facility is currently used for disposing of Koeberg operational waste, but will in the future also be used for disposing of short lived waste from Pelindaba. The facility will be closed around 2030–2035 and be subject to long term institutional control.

## 5. MAJOR CONCERNS

*(a) Lack of a national nuclear waste management policy and strategy*. In general, countries in the region lack adequate policies and strategies to guide nuclear waste management programmes. This policy vacuum hampers national waste management agencies in formulating and executing long term plans for decommissioning of disused facilities.

*(b) Lack of financial resources.* A common problem in most countries of the region is the lack of sufficient provision for future plant decommissioning. Strategies therefore need to be developed to put into place solutions that are both safe as well as financially affordable.

*(c) Lack of infrastructure.* There is a lack of infrastructural systems in certain countries of the region to support decommissioning activities. This poses a considerable challenge in terms of implementing full scale facility decommissioning. Solutions therefore need to be found which do not require costly and sophisticated infrastructure. In particular, the lack of licensed final disposal facilities in many countries of the region presents difficulties, as end points are required for fully discharging decommissioning liabilities.

*(d) Public acceptance.* Public awareness of decommissioning programmes is growing worldwide. In general, public opinion seems to favour decommissioning, as these activities result in dismantling or demolition of disused facilities and the release of land for non-nuclear use. The difficulty, however, usually arises when the decommissioning waste needs to be transferred to a final disposal facility at a different site. Experience seems to indicate that decommissioning strategies need to be developed such that waste disposal can be achieved within the parameters of public acceptance.

These concerns need to be addressed if satisfactory decommissioning strategies are to be implemented. The first and the last can only be addressed on an individual national level, but for the second and third, a more global approach may be appropriate. South Africa already carries out expert missions to AFRA countries to assist in conditioning and storing radium sources. This obviates the need for a high degree of specialized local expertise. The funding for these activities is derived from the IAEA. Expert missions may be able to play a similar role in decommissioning research reactors and other nuclear facilities.

## 6. CONCLUSIONS

The decommissioning liability estimates for Africa and West Asia indicate (Table VII) that the Koeberg Nuclear Power Plant constitutes the largest portion (i.e. 53%) of the nuclear decommissioning liabilities in the region. As far as these decommissioning liabilities are concerned sufficient provision is being made by the electricity utility, Eskom, for future decommissioning as well as spent fuel management.

It also appears that research reactors and support facilities make up the second largest decommissioning liability (i.e. 36%) in the region. There are 23 research reactors, of which 19 have been commissioned (both operating and shut down). Two are currently under construction and a further two are in the planning stages. From the available information there appears to be very little planning for the future decommissioning of these reactors and their support facilities. We believe that there should be an initiative, particularly on the part of the IAEA through AFRA, to facilitate forward planning regarding research reactor decommissioning in Africa. On a similar basis, research reactor decommissioning could also be initiated and supported in West Asia.

The decommissioning of front end nuclear fuel cycle facilities, mostly in South Africa, constitutes the third largest liability (i.e. 8%) in the region. South Africa has a draft long term decommissioning plan for disused nuclear fuel facilities at Pelindaba near Pretoria. This plan has as its chief aim the transfer of decommissioning waste, together with the other historical radioactive waste, to a suitable disposal site. The existing Vaalputs site in the Northern Cape Province of the country currently appears to be the most attractive option for disposing of this waste. Furthermore, a site remediation programme is also being implemented at Pelindaba.

The decommissioning of milling and processing plants at mining sites constitutes the fourth largest liability (i.e. 2%) in the region. The decommissioning of old milling and processing plants is a pressing matter because of the significant radioactivity levels typically associated with disused plants. The need for decommissioning of these old mining plants appears to be largely driven by the need for site reuse for industrial non-nuclear purposes.

Finally, the closing and institutional control of near surface repositories in the region, of which there is unfortunately scant information available at present, makes up a small portion (i.e. 1%) of the total liabilities. This figure could be substantially higher if all potential disposal sites are taken into consideration.

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# MAGNITUDE OF THE DECOMMISSIONING TASK IN NORTH AMERICA AND MEXICO, INCLUDING THE US DEPARTMENT OF ENERGY

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**Abstract**

The magnitude of the task of decommissioning nuclear facilities in North America comprises: facilities associated with the commercial nuclear industry and those associated with US nuclear weapons production and research programmes, namely those facilities managed by the US Department of Energy (DOE). Within the commercial nuclear industry, there are currently over 170 nuclear reactors (in the USA, Canada and Mexico). The cost of decommissioning power reactors has recently been estimated at approximately US $325 million per reactor; applied across the area under consideration, this is equivalent to a decommissioning task in excess of $50 billion. Within the DOE's nuclear weapons complex, there are over 114 sites, encompassing over 2 million acres (approximately 810 000 hectares), that need to be cleaned up. In these sites, the scope of decommissioning encompasses over 5000 facilities, with over 100 million $ft^2$ (approximately 9.3 million $m^2$ ) of building footprint. The life cycle estimate for the decontamination and decommissioning of these facilities is estimated at between $11 billion and $19 billion . The DOE has recently adopted a much more aggressive stance to accelerate the decontamination and decommissioning of its facilities, moving from an emphasis on risk management to one of risk reduction and final closure. It has been decided to make the reduction of the nuclear facility footprint a major objective, to be implemented with an appropriate sense of urgency, resulting in commitments to accelerate decontamination and decommissioning by as much as 10–13 years at the various sites.

## 1. INTRODUCTION

Over the past 40 or more years, the commercial nuclear industry in North America (Canada and the USA) and Mexico has grown to the point where there are now over 170 operating nuclear reactors. Of these, 104 power generating nuclear reactors and 36 non-power reactors are located in the USA [1]. In Canada, there are 22 operating power reactors and 7 non-power reactors [2], while there are 2 power reactors in Mexico [1].

The USA has three commercial low level radioactive waste disposal facilities (i.e. Barnwell, South Carolina; Hanford, Washington; and Clive, Utah) that are currently active and four more that are closed (i.e. Beatty, Nevada; Sheffield, Illinois; Maxey Flats, Kentucky; and West Valley, New York). Canada has 18 radiological waste management facilities under license to the Canadian Nuclear Safety Commission (CNSC) [2].

Uranium mines and mills have been operated for decades to produce the raw materials used to fabricate fuel rods for commercial nuclear power plants. In the USA, there were 24 uranium milling sites associated with the production of uranium yellow cake for the Federal weapons programme that have been shut down and decommissioned by the US Department of Energy (DOE). Similarly, there are 5 operating and 11 shut down/decommissioned uranium mills and mines in Canada. Additional commercial nuclear facilities in North America and Mexico include licensed uranium processing and fuel fabrication facilities (operating and in standby mode), spent fuel storage facilities, and miscellaneous radiologically contaminated licensed nuclear facilities.

In addition to the facilities mentioned above, the DOE has an immense inventory of nuclear facilities that were associated with the Manhattan Project and other nuclear weapons programmes over the past 50 or more years. It has been estimated that over $300 billion was spent by the US Government on nuclear research, production and testing that resulted in tens of thousands of nuclear warheads and over 1000 detonations [3]. Today, the DOE owns more than 2 million acres of land (approximately 810 000 hectares) and over 100 million $ft^2$ of buildings (approximately 9.3 million $m^2$). A large percentage of the land, buildings and associated facilities are radiologically and/or chemically contaminated, thus adding to the complexity and expense of the decommissioning task.

The recently completed ‘top to bottom’ review of the environmental management programme [4] looked at the cleanup task being managed by the DOE’s Office of Environmental Management (EM). This office is responsible for the cleanup of 114 sites associated with the research, development, production and testing of nuclear weapons. To date, active cleanup programmes have been completed at 74 of these sites. Since 1998 [5], the estimate for completing this cleanup mission has escalated from $147 billion to $220 billion, with further projections of the total life cycle cost exceeding $300 billion [4].

## 2. OVERVIEW OF THE DECOMMISSIONING STATUS

To date, 100 mines, 90 commercial power reactors, more than 250 research reactors and several fuel cycle facilities have been shut down worldwide [1]. With regard to nuclear reactors, decommissioning is considered to include the cleanup of radioactivity and, ultimately, demolition of the plant. The IAEA lists three decommissioning options [6]:

- **Immediate dismantling (or early site release/decontamination in the USA):** This option allows for the facility to be removed from regulatory control relatively soon after shutdown or termination of regulated activities. Usually, the final dismantling or decontamination activities begin within a few months or years, depending on the facility. Following removal of regulatory control, the site is then available for reuse. Examples of the successful use of this option include San Onofre 1, Shippingport and Fort St. Vrain.
- **Safe enclosure (or Safstor(e)):** This option postpones the final removal of controls for a longer period, usually of the order of 40–60 years. The facility is placed into a safe storage configuration until the eventual dismantling and decontamination activities occur. This approach has been used at Rancho Seco and Three Mile Island 2.
- **Entombment:** This option entails placing the facility into a condition that will allow the remaining on-site radioactive material to remain on-site without the requirement of ever removing it totally. This option usually involves reducing the size of the area where radioactive material is located and then encasing the facility in a long lived structure, such as concrete, that will last for a period of time to ensure that the remaining radioactivity is no longer a concern.

### 2.1. Commercial sector

Since over 80% of the commercial nuclear reactors under consideration for this paper are in the USA, the following discussion focuses on the expense and schedule of the decommissioning task only in the USA.

As of late 2001, 14 power reactors in the USA had undergone decommissioning using Safestor, and 6 have utilized Decon. A total of 27 US commercial reactors have been shut down and are in some stage of decommissioning.

The cost of decommissioning commercial power reactors in the USA has recently been estimated to be approximately $325 million per reactor [6]. This translates to a decommissioning task in Canada, Mexico and the USA of more than $50 billion. This number is a rough approximation, given the wide range of decommissioning options (i.e. Decon, Safstor, Entomb and multiple combinations), schedule and complexity (e.g. size and type of reactor, degree of contamination, volume and type of waste requiring disposal, and time period for decommissioning). A major factor in costs is the end state to be achieved for the site. For example, cleanup of a reactor site to an unrestricted usage or 'green field' condition is more expensive than a site planned for restricted usage (i.e. 'brown field').

Following reactor shutdown, the spent nuclear fuel is removed from the reactor core and stored in the spent fuel pool. Next, the fuel rods are moved to interim storage such as dry cask storage on or near the site. The third phase entails a waiting period for reduction of residual radioactivity through naturally occurring decay of the isotopes. For example, in the three years between closure and the onset of dismantling, the reactor core for the Shippingport PWR had decreased from an initial radioactivity level of 30 000 Ci to 16 000 Ci [7].[1] Built in 1957, Shippingport was the first large scale nuclear power reactor in the world. Another 'first' was that the DOE completed decontamination and decommissioning of the reactor in 1990, the first such cleanup of a power producing nuclear reactor in the USA. Finally, dismantlement or entombment takes place.

The 104 commercial power generating reactors in the USA have operating licences that expire between 2009 and 2036 [1]. Some of them may be able to have their operating licences extended following rigorous safety and operational inspections. However, as of this writing, 50 reactors are scheduled to shut down prior to 2020, an additional 47 before 2030 and the remaining 7 by 2036. This represents a virtual 'bow wave' of decommissioning activity and costs in the USA starting in the next seven years. Commercial power reactors in the USA operate under Federal regulations and statutes that require a percentage of the money charged for electricity to be accumulated in a fund for decommissioning. However, a 1997 study [8] indicated that as many as 40 nuclear power plants are likely to close by 2005 for economic reasons. Not only will this have a negative impact on the domestic power supply, but early closure

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[1] 1 curie (Ci) = $3.70 \times 10^{10}$ Bq.

will also result in insufficient funds being accumulated for decommissioning. This liability must be addressed early on.

In addition to the power reactors, there are 36 non-power reactors (i.e. research and medical isotope reactors) operating in the US commercial sector. There are 15 more that are under decommissioning orders or are otherwise not permitted to operate. Although these types of reactors are generally smaller than power generating reactors, their decommissioning costs will certainly total in the hundreds of millions of dollars.

## 2.2. USDOE

The DOE was responsible for decommissioning 24 uranium milling operations located in 10 States. These facilities were operated by private companies to process uranium ore for the US Atomic Energy Commission (later DOE). Once the plants were shut down, the remaining tailings piles represented the potential for long term health issues caused by low level radioactivity and various hazardous substances associated with ore processing. The radioactive and hazardous components were spread through the wind and water, resulting in contamination of soil, groundwater and surface water. Several instances of contaminated drinking water wells were also found. It has been estimated that 96% of the contaminated waste (by volume) for which the DOE is responsible is the result of uranium mill tailings.

Additionally, more than 5000 "vicinity properties" required decontamination and/or decommissioning. Vicinity properties are areas outside the original mill site that were contaminated through the wind and water as well as by human activities. For example, in the area surrounding Grand Junction, Colorado, the mill tailings were considered to be an excellent source of aggregate material used in construction projects. As such, a large number of foundations and backfill areas in, around and beneath public and private buildings were found to be contaminated with low levels of uranium. Direct gamma radiation from the decay of uranium can result in significant health issues. Additionally, one of the most significant health issues resulting from uranium contamination is that one of the natural decay products, radon gas, can accumulate within buildings. The US Environmental Protection Agency (EPA) has noted a strong correlation between high levels of radon gas in buildings and various health problems, including increased occurrences of lung cancer.

All of the 24 ore processing sites have been decommissioned, with the tailings excavated and removed to engineered disposal facilities or capped in place. Decontamination and remediation of the vicinity properties has also been completed. The total cost for this work was nearly $1.5 billion [9]. The disposal sites are now under long term stewardship, including institutional controls and monitoring as required under US Nuclear Regulatory Commission (NRC) licences. Estimates of all decommissioning and cleanup costs of uranium producing projects in the USA total nearly $2.5 billion [9]. Additionally, groundwater restoration projects will continue for a number of years at many of these sites.

As indicated at the beginning of this paper, the latest estimate for life cycle costs of the DOE's Office of Environmental Management is at least $220 billion and potentially greater than $300 billion [4]. This does not include the costs associated with DOE operating facilities not currently within the EM programme. At the end of Fiscal Year (FY) 2001, the DOE estimated its environmental liability for active facilities [10]. By definition, this estimate did not include those facilities covered in the EM life cycle cost estimate, nor did it account for facilities considered elsewhere by the programmes or sites responsible for managing them. The estimate for "the future costs of stabilizing, deactivating, and decommissioning contaminated active facilities" is approximately $19 billion [10]. As can be seen by these estimates, the costs for the DOE facilities managed by the EM programme represent the lion's share of decommissioning costs.

One of the major decisions facing the DOE, its regulators and its stakeholders is 'How clean is clean'? That is, do all sites have to be cleaned up to the same standards (i.e. green field or unrestricted use), or can some sites planned for restricted use such as reindustrialization be cleaned up to lesser (i.e. brown field) standards? These decisions must be made very early on in the planning process associated with decommissioning and cleaning up a site.

The amount of waste generated from various decommissioning strategies [3] will be vastly different. For example, a site that will be under long term institutional controls restricting site access could be expected to generate about 1 million $m^3$ of waste during decommissioning. The same site, if slated for brown field 'mixed land use' (e.g. industry) may generate about 35 million $m^3$ of waste during cleanup. If the green field unrestricted land use approach is adopted (i.e. residential/agricultural), the waste volume would be expected to nearly triple to about 100 million $m^3$ [3]. The amount of time, work and expense associated with cleanup to various land use standards also rises in a similar pattern.

There must be a balance between the costs involved with cleaning up a site and the amount and quality of land use needed/wanted. Transportation and disposal costs for the wastes rise every year. Additionally, the 'low hanging fruit' (i.e. smaller and less technically complex) cleanup projects have already been completed by the DOE. Much improved technology and cleanup procedures are going to be needed in order to keep decommissioning costs from rising exponentially in the future. Equally important is adoption of a graded approach to cleanup whereby ‘how clean is clean’ is determined on a site by site basis. These same decisions face the commercial sector as it tackles the bow wave of decommissioning that lies ahead.

### 2.3. The DOE’s approach to decommissioning

The DOE has adopted the approach of determining a balance between the likely future use of a contaminated site, the current and future risks associated with that site and the cost of cleanup. If all of the DOE’s facilities and underlying land were to be cleaned up to pristine ‘pre-1940s’ conditions, the costs in time and money would likely be a trillion dollars or more. The risk reduction to the public and the environment associated with such cleanup to ‘unrestricted use’ conditions would often be negligible when compared with cleanup to a brown field condition meant for reindustrialization. When the cost to cleanup workers in deaths, injuries, and exposure to radioactivity, chemicals, and other hazardous materials is also considered, the minimal additional risk reduction is far overshadowed.

As such, the DOE has worked with local communities, State Governments, tribal nations, regulators and other stakeholders early on in the planning process to come to an agreement on future land use. For example, DOE’s Mound Facility in Miamisburg, Ohio, was listed by the EPA as a Superfund Site. The standard Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial investigation/feasibility study (RI/FS) process would have resulted in years if not decades of study before the first cleanup actions began. The DOE, EPA and Ohio EPA (OEPA) agreed to use a “modified Removal Site Evaluation (RSE) process, informally known as MOUND 2000 to accelerate the cleanup and to involve stakeholders earlier in the process” [11].

The original six operable units under Superfund were considered in the light of preliminary characterization data and historical information. This resulted in consideration of more than 400 potential release sites (PRSs). Each was then evaluated individually rather than in one of the six operable units, thus eliminating the need to treat large expanses of land as if they were all contaminated equally (and at the highest level noted in the unit). The focus of the evaluation was to determine an appropriate action, rather than conducting exhaustive, often unnecessary, study. When cleanup of a particular PRS was necessary, it was conducted through a CERCLA removal action instead of the much longer RI/FS process. For those instances where not enough information existed to determine if a given PRS posed an elevated risk, the costs of more study were weighed against the cost of performing a removal action at the site. In other words, if it were more cost effective to go ahead and complete a removal action (whether or not specific contamination was known to exist), that approach was adopted [11]. This enlightened approach to cleanup and release for restricted use resulted in an expedited transition from safe shutdown to effective reuse as a high technology industrial park. This ultimately saved the taxpayers millions of dollars and assisted the Miamisburg community in building a better employment base.

One of the major hurdles to expedited decommissioning of DOE facilities was the lack of reliable, long term disposal sites that could accept radioactive waste. In 1999, the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, became the USA's first operating permanent storage facility for transuranic (TRU) waste associated with the production of nuclear weapons. Until that point, such waste had to be placed in temporary storage, usually on or near the original DOE site. This was very expensive, posed risks to site workers and potentially the local public and environment, and caused serious shortages of storage space. At some locations (e.g. Rocky Flats), the lack of on-site storage space for TRU waste was seen as a major impediment to completion of the cleanup mission.

Since WIPP began accepting TRU waste, 1279 waste shipments have been received from five different DOE facilities. These sites, with the number of shipments in parentheses, are: Rocky Flats Environmental Technology Site (693); Idaho National Engineering and Environmental Laboratory (525); Los Alamos National Laboratory (26); Savannah River Site (23); and the Hanford Site (12). Additional sites from which WIPP is expected to receive TRU waste shipments include: Argonne National Laboratory; Lawrence Livermore National Laboratory; Mound Plant; Nevada Test Site; Oak Ridge National Laboratory; and 13 "Small Quantity Sites" across the country.

Similarly, the DOE is working diligently to open the Yucca Mountain Site in Nevada to accept non-defence radioactive wastes, including spent nuclear fuel rods from commercial power reactors throughout the USA. As discussed above, the very first step in decommissioning nuclear power plants is removal of the fuel assembly. Additionally, spent fuel from 30–40 years of operation is currently stored at reactor sites in the USA. Numerous studies have shown that long term storage of fuel rods above ground has the potential for increased risk to site workers, the public and the environment. Only when the Yucca Mountain Site begins accepting this radioactive waste for permanent disposal will the reactor sites be able to undergo complete decommissioning.

A more extensive decommissioning project is under way at the Rocky Flats Environmental Technology Site (RFETS) near Denver, Colorado. For decades, the RFETS was involved with highly complex activities associated with producing plutonium triggers or 'pits' for nuclear weapons. Following shutdown of operations at the site, the DOE began studying various options for decommissioning the site, including making decisions on the ultimate end use of the underlying land. The goal is to decommission and clean up the site to the point where, in 2006, all spent nuclear material (SNM) and waste have been removed from RFETS, the buildings have been demolished and environmental cleanup allows future open space and light industrial use of the land. It is anticipated that less than 100 acres (40 hectares) of the site will be capped and require access controls. Approximately 300 acres (121 hectares) will be made available for light industries and 6100 acres (2500 hectares) will revert to open space.

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# MAGNITUDE OF THE DECOMMISSIONING TASK IN SOUTH AND EAST ASIA AND OCEANIA

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**Abstract**

In South and East Asia and Oceania, there are approximately 140 reactor facilities in operation, including nuclear power plants and research reactors, as well as many non-reactor facilities. Nuclear power plants are operated in several countries, and most of them are of a relatively young generation. One experience of nuclear power plant decommissioning to achieve green field condition was in Japan, and several research reactor decommissioning projects are ongoing or in the planning stage. The establishment of regulatory and waste management systems for decommissioning is one of the most pressing issues in this area for the safe and economical decommissioning of nuclear facilities.

## 1. INTRODUCTION

There are approximately 90 nuclear power plants and 50 research reactors operating in South and East Asia and Oceania as of 2002. China, India, Japan, Republic of Korea, Taiwan (China) and Pakistan have operated nuclear power plants, and most of them are of a relatively young generation. Tarapur 1 in India has been operated for 33 years, since 1969. A few nuclear power plants have been operated for more than 30 years, and these are getting to be old enough for consideration of decommissioning. The Japan Power Demonstration Reactor (JPDR) was the first nuclear power plant to be dismantled to achieve a green field condition. The Tokai Power Station (TPS), which is a commercial nuclear power plant, is now in the decommissioning phase in Japan. Some countries are considering the decommissioning of research reactors that were constructed at an early stage in their nuclear development and have become surplus after achieving their objectives. There are also surplus non-reactor facilities to be decommissioned. These countries need certain measures and suitable waste management systems for decommissioning to protect the environment and public. Regulatory systems for decommissioning and waste management are therefore important and need to be established. It can be very useful for these countries to learn from the experience and the regulatory systems for decommissioning of other countries, and from international organizations, in order to implement decommissioning projects in a safe and economical manner.

This paper deals with the present status of nuclear facility decommissioning in South and East Asia and Oceania based on the information that was reported in international meetings and from other sources.

## 2. OUTLINE OF NUCLEAR ACTIVITIES IN SOUTH AND EAST ASIA AND OCEANIA

Table I [1–3] lists the number of nuclear facilities in South and East Asia and Oceania. In the table, the non-reactor facilities include reprocessing facilities, fuel fabrication facilities and conversion facilities. The major countries having nuclear activities are Australia, Bangladesh, China, India, Indonesia, Japan, Republic of Korea, Malaysia, Pakistan, Philippines, Taiwan (China), Thailand and Vietnam in South and East Asia and Oceania. Among this group, China, India, Japan, Republic of Korea, Pakistan and Taiwan (China) are operating nuclear power plants, while 12 countries are operating research reactors. Fifty-one research reactors are being operated in these countries and more than 10 research reactors have been permanently shut down and are awaiting suitable measures for decommissioning. As shown in Table I, a few countries have decommissioning experience, with only Japan having a range of decommissioning experience. The Japan Power Demonstration Reactor (JPDR) was a nuclear power plant that was completely dismantled to a green field condition. A few decommissioning programmes for research reactors are ongoing: KRR-1 and 2 (Republic of Korea), TRR (Taiwan (China)) and TPS (Japan) are the ongoing decommissioning projects. In addition, some countries have decommissioning or refurbishment programmes for non-reactor facilities. Table II lists the present status of nuclear facility decommissioning in South and East Asia and Oceania.

TABLE I. PRESENT STATUS OF NUCLEAR FACILITIES IN SOUTH AND EAST ASIA AND OCEANIA

| | Nuclear power plants [1] | Research reactors [2] | | Non-reactor facilities [3] |
|---|---|---|---|---|
| | | Operation | Shutdown | |
| Australia | — | 1 | 2 | — |
| Bangladesh | — | 1 | — | — |
| China | 3 | 14 | 2 | 3 |
| India | 14 | 5 | (4) | 7 |
| Indonesia | — | 3 | — | — |
| Japan | 53 (2) | 18 | 3 (3) | 10 (4) |
| Korea, Rep. of | 16 | 2 | 2 | 3 |
| Malaysia | — | 1 | — | — |
| Pakistan | 2 | 2 | — | 2 |
| Philippines | — | — | 1 | — |
| Taiwan (China) | 6 | 2 | 2 (2) | — |
| Thailand | — | 1 | — | — |
| Vietnam | — | 1 | — | — |
| Total | 94 (2) | 51 | 12 (9) | 25 (4) |

( ): Decommissioned.

TABLE II. MAJOR DECOMMISSIONING ACTIVITIES IN SOUTH AND EAST ASIA AND OCEANIA

| Items | Major facilities |
|---|---|
| Decommissioned facility | JPDR (Japan ) |
| Ongoing decommissioning projects | Tokai Power Station, JRR-2 (Japan)<br>KRR-1 and 2 (Republic of Korea)<br>TRR (Taiwan (China)) |
| Planning of decommissioning of research reactors | TRR-1(Thailand),<br>PT PKP Gresik (Indonesia), PRR (Philippines) |
| Refurbishment of nuclear facilities | CIRUS (India), Hot Cell (India),<br>TRF(Bangladesh), PARR-1(Pakistan) |

## 3. DECOMMISSIONING ACTIVITIES IN INDIVIDUAL COUNTRIES

### 3.1. China

There are 3 nuclear power plants and 14 research reactors in operation in China. Most of the research reactors have been operated for more than 20 years. However, China has no experience in decommissioning nuclear facilities. Since it was recognized by the Government that decommissioning of nuclear facilities would be an important issue, some activities related to decommissioning were started in the 1980s in such areas as the preparation of decommissioning standards, decommissioning plans, and a regulatory system. Technologies have been also developed in the areas of decontamination, dismantling, waste treatment and databases. A regulatory system on decommissioning has also been prepared; it requires decommissioning document preparation, review by government sectors, decommissioning activities supervision, etc. In the licensing process, safety analysis, environmental impact assessment, decommissioning plans and cost estimation are also required.

### 3.2. India

There are 14 nuclear power plants and 5 research reactors in operation in India. There has been no major decommissioning experience in recent years except refurbishment of a research reactor and a hot cell of a high level radioactive waste vitrification plant. CIRUS is a tank type research reactor (40 MW(th); heavy water moderated and light water cooling type), which had been operated since 1964 and is now undergoing refurbishment. The major activities are removal of the primary coolant outlet cross-header, primary pipes and heat exchanger supports. The experience and data obtained in the refurbishment activities will give guidance for the future decommissioning of CIRUS in a safe and economical manner.

### 3.3. Indonesia

There are several nuclear facilities in operation such as research reactors and small non-reactor facilities. Among these, the PT PKP Gresik, i.e. a phosphate purification process plant, is waiting for decommissioning. It was decided to cease operation in 1989, since the facility was getting old. At this moment, only the physical security system remains to prevent unauthorized access to the plant. When a guideline for decommissioning nuclear facilities is prepared, it might be possible to decommission the PT PKP Gresik. The

Nuclear Energy Control Board was established to prepare guidelines in terms of regulations and procedures, which will be followed by the licensing process.

### 3.4. Japan

There are 53 nuclear power plants in operation, providing approximately 35% of the electricity supply in Japan. The TPS, the oldest Japanese nuclear power plant operated by the Japan Atomic Power Company, was permanently shut down in 1998, and the decommissioning project is in progress. To ensure a stable energy supply in the future, decommissioning of retired nuclear power plants is indispensable for gaining public acceptance of nuclear energy and for securing the site for the next nuclear power plant as well. Dismantling is required as part of the basic policy on decommissioning nuclear power plants. Consequently, research and development programmes have been conducted in both government organizations and the private sector. The establishment by the regulatory authority of regulatory systems for decommissioning, including waste management systems, has made great progress, taking into account this trend.

### 3.5. Republic of Korea

Although there are 16 nuclear power plants in operation, no decommissioning project is expected for these plants in the Republic of Korea. At present, one decommissioning project for research reactors is in progress. The KRR-1 and 2 decommissioning project started in January 1997. Preparatory activities, such as radiation measurement and analysis, environmental monitoring and assessment and decommissioning design, were carried out to implement the decommissioning project efficiently. The decommissioning plan was submitted to the competent authority in 1998 for approval of the start of decommissioning activities. The license was then obtained in 2000. Practical decommissioning activities are being conducted according to the method statement and work procedures approved by the authority. In parallel with the preparatory activities, research and development programmes have been launched in preparation for decommissioning commercial nuclear power plants.

### 3.6. Malaysia

There is no nuclear power plant, but only one research reactor (1 MW(th)) in Malaysia. Regulatory systems have been developed to deal with technically enhanced naturally occurred materials (TENORM) such as a mineral processing plant and other related activities. The national radioactive waste management centre is responsible for the management and treatment of low and intermediate level radioactive wastes generated from nuclear applications for the medical and industrial sectors, as well as research institutes and universities. The centre has the necessary facilities, consisting of a low level treatment precipitation plant, storage room and tanks, temporary storage facility, segregation cabinets, decontamination facility and compactor and so on.

### 3.7. Philippines

There is no nuclear power plant, but there is one research reactor in the Philippines. A research reactor, PRR-1, was constructed. However it is not operated at the present time. Since teletherapy $^{60}$Co machines were found to have unacceptable performance from the regulatory standard point of view, six teletherapy facilities were decommissioned by the licensees under contract with service providers. The spent sealed sources were transferred to the Radwaste Management Facility in the Philippine Nuclear Research Institute (PNRI). It was required to ensure that the facility was cleaned up for unrestricted use. For effective radioactive waste management, the PNRI established a centralized, low level, radioactive waste treatment facility and it maintains an interim storage facility for conditioned radioactive wastes. It is necessary to train technical staff for the preparation of decommissioning activities for PRR-1 in the future. In addition, infrastructures will be necessary to establish a safe waste management system to address regulatory, administrative and technical issues specific to the management of the decommissioning wastes.

### 3.8. Thailand

The first Thai Research Reactor (TRR-1), which is of a swimming pool type, has operated from 1962 to serve national needs in research and development in nuclear science and technology for over 38 years. It was decided in 1989 by the Thai Cabinet to relocate the reactor to a more appropriate and safe location. The original decommissioning plan was expected to be completed 12 years after the competent authority approved the conceptual decommissioning plan. The TRR-1 decommissioning schedule was set out as follows: preparation of the conceptual decommissioning plan (1994–1996); review and approval of the conceptual decommissioning plan (2000); preparation of a detailed decommissioning plan (2001); and review and approval of the detailed decommissioning plan (2001). The reactor will be shut down in 2003. The fuels will be removed and decommissioning activities will start with decontamination and dismantling of the facilities (2004–2005). After completing the measures for fuels such as storage and/or disposal, a final survey will be conducted. The Office of Atomic Energy for Peace (OAEP) is responsible for the management of radioactive wastes arising in the country.

## 4. MAJOR DECOMMISSIONING ACTIVITIES

### 4.1. Japan Power Demonstration Reactor (completed project [4, 5])

The JPDR is a BWR type reactor with a power initially of 45 MW(th) (JPDR-I). It started generating electricity in 1963 and operation was continued until 1970. The power was then increased to 90 MW(th) (JPDR-II) for enhancement of the neutron irradiation capability. The JPDR was restarted in 1974 after renovation of the system. However, several problems were found during the operation and it was finally shut down in 1976.

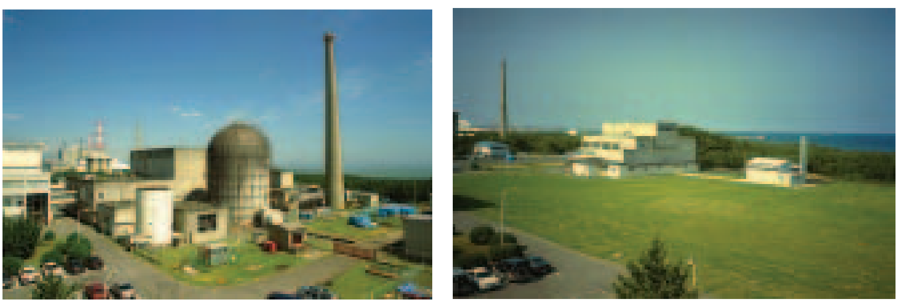
The JPDR decommissioning programme started in 1981; in the first phase (1981–1986) various technologies were developed for dismantling JPDR. In particular, efforts were made to develop remote dismantling techniques. In the second phase (1986–1996), the actual dismantling was conducted by applying the technology developed in the first phase. The reactor internals were removed by the underwater plasma arc cutting system. The plasma torch was handled in most cases by a mast type manipulator having four degrees of freedom. First each reactor internal was removed from the reactor pressure vessel (RPV) and transferred underwater to the spent fuel storage pool to be segmented into small pieces for packaging in shielded containers. The RPV was dismantled using the underwater arc saw cutting system after removing the pipes connected to it. Three techniques were applied for demolition of the biological shield. The diamond sawing/coring system and the abrasive water jet cutting system were applied to demolishing the projected part of the biological shield with relatively high radioactivity. The waste was put into containers for storage. A controlled blasting technique was applied to the rest, and the waste was disposed inthe Japan Atomic Energy Research Institute (JAERI) site as a demonstration test for near surface disposal. After all components were removed, the inner surface of the buildings was decontaminated, followed by a radioactivity survey. Table III summarizes the JPDR decommissioning project. Figure 1 shows the JPDR site before and after the dismantling project.

### 4.2. TPS

The TPS (gas cooled reactor, 166 MW(e)) was operated from 1966 to 1998 as the first commercial nuclear power plant in Japan. The TPS decommissioning

TABLE III. OUTLINE OF THE JPDR DECOMMISSIONING PROGRAMME

| | |
|---|---|
| **Overview** | |
| Period | : Dec. 1986–Mar. 1996 |
| Cost | : 23 billion yen (including R&D) |
| Waste arising | : 3770 tonnes (radioactive) |
| Worker dose | : 306 man·mSv |
| **Characteristics** | |
| Demonstration | : application of developed techniques |
| Dismantling activities | : data collection on project management |
| Radioactive waste management | : storage of high radioactivity waste and disposal of low radioactivity waste |



Before After

*FIG. 1. The JPDR site before and after dismantling.*

project is in line with the government's policy. The site will be recovered to a green field condition for the next nuclear power plant. Removal of the spent fuels started after the final shutdown and it was completed in March 2001. The decommissioning plan was submitted to the competent authority for approval of implementation; the plan is divided into three phases, and the authority approved the whole plan and the detailed procedures for the first phase. The dismantling activities then started in December 2001. In the first phase, decommissioning activities concentrated on preparatory work and removal of conventional facilities such as cleaning of the spent fuel pond surface, reformation of utility systems and auxiliary cooling systems and removal of turbine systems and the fuel exchange machine. In the second phase, steam raising units will be dismantled over five years. In the third phase, the reactor area and buildings will be dismantled. The detailed procedures on removal of core parts will be planned after confirming availability of the final waste disposal facility. According to the current plan, the decommissioning will be completed by 2017.

### 4.3. KRR-1 and 2

The first research reactor in the Republic of Korea (KRR-1, TRIGA Mark-II) has been operated since 1962, and KRR-2, the second one (TRIGA Mark-III) since 1972. Both reactors shut down in 1995 since they reached the end of their operating lifetime, and the new research reactor (HANARO) in Taejeon started operation. According to the Atomic Energy Act, the Korea Atomic Energy Research Institute (KAERI), the owner of KRR-1 and 2, is responsible for decommissioning the research reactors. The KRR-1 and 2 decommissioning plan was reported to the Nuclear Development and Utilization Committee in 1996. The decommissioning project started in January 1997.

The decommissioning plan, including the environmental impact assessment, was submitted to the Ministry of Science and Technology (MOST) in 1998. The Korea Institute of Nuclear Safety (KINS) reviewed the document and submitted the review report to MOST in 1999, which approved it in 2000. Meanwhile, preparatory activities for decommissioning have been carried out since 1998, such as installation of radiation measuring and analysis equipment and construction of radioactive liquid waste treatment facilities. Decommissioning activities started in 2001 according to the method statement, radiation protection procedures and work procedures. Contaminated laboratories were first cleaned up before dismantling activities started. Radioactivity was measured all around the laboratories in 1 m x 1 m sections. The ten lead hot cells were decontaminated and dismantled by the end of May 2002. The main dismantling activity will start in 2003 in KRR-2. The decommissioning will be completed by 2008.

### 4.4. TRR

The Taiwan Research Reactor at Lung-Tan, Tao-Yuan, is a heavy water moderated and light water cooled reactor (40 MW(th)) that operated between 1973 and 1988. It has been decided that the TRR would be partially dismantled to build a multi-purpose research reactor (TRR-II) at the same site. The facility will be partially dismantled in two phases. In the fist phase, the reactor vessel, the shields in the reactor cavity and redundant systems are to be dismantled. The waste arising from the dismantling activities will be managed in the second phase. The fuels and the heavy water were removed from the core in 1990. All systems and components within 5 m of the reactor block had been dismantled before 1994.

The reactor block will be transferred to a specially built building, where the reactor will be segmented using the underwater plasma arc cutting system. The cutting platforms and manipulators have been developed for the segmentation activities. The cutting performance was evaluated using such technologies as underwater plasma cutting, abrasive water jet and electric discharge cutting. As the storage space for radioactive waste is limited in Taiwan (China), an interim storage silo has been constructed for receiving the wastes arising from TRR dismantling. It will have 93 stainless steel lined vaults. After the removal of the reactor vessel and redundant systems, the TRR building will be cleaned up to release limits (4 Bq/100 $cm^2$) to allow the construction of the new TRR-II.

## 5. TECHNOLOGY DEVELOPMENT

The research and development programmes on decommissioning technologies will be useful in conducting decommissioning of nuclear facilities safely and economically in the future. Such programmes are ongoing in China, Japan, the Republic of Korea and Taiwan (China). Technologies developed in the programmes are decontamination, remote cutting and handling, radiation measurement and project management methodology, including cost estimation. The mock-up tests were found to be useful for efficient dismantling, one of the lessons learned in the JPDR decommissioning programme. In the case of the TPS, robotic technology is being tested using the mock-up system to verify its applicability to the actual dismantling. Also, a mock-up system was used to verify the cutting performance for segmenting the reactor vessel of the TRR in Taiwan (China).

## 6. CONCLUDING REMARKS

The use of nuclear energy has spread widely in South and East Asia and Oceania. China, India, Japan, the Republic of Korea, Pakistan and Taiwan (China) operate nuclear power plants, while many of the other countries have no nuclear power plants but have a research reactor and a radioisotope facility which are of small scale. Therefore, decommissioning experience is limited to small facilities. Japan has a variety of decommissioning activities: the JPDR was decommissioned to achieve a green field condition, and the TPS decommissioning project is in progress, the first such instance for commercial nuclear power plants. The regulatory system for decommissioning waste management is almost ready. Decommissioning projects are also in progress in the Republic of Korea and Taiwan (China). The experience gained and information on TPS, KRR-1 & 2, TRR and JPDR, as well as from international organizations, will be useful for South and East Asia and Oceania for safe and economical decommissioning in the future.

## ACKNOWLEDGEMENTS

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# MAGNITUDE OF THE DECOMMISSIONING TASK IN EUROPE

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**Abstract**

The paper deals with the current and future decommissioning of nuclear facilities in Europe, excluding the Commonwealth of Independent States. The following topics are addressed in detail: current decommissioning projects; decommissioning strategies; future decommissioning projects; and conclusions.

## 1. CURRENT DECOMMISSIONING PROJECTS

Table I shows the current decommissioning projects in the area under review, that is Europe but excluding the Commonwealth of Independent States (CIS). They are broken down by country (in alphabetical order) and type of nuclear facilities, namely:

— nuclear power plants,
— research reactors,
— other nuclear facilities.

The last item includes facilities, such as hot cells, laboratories, fuel production plants, reprocessing plants and plants for uranium ore production and processing. However, it cannot be guaranteed that every small plant currently undergoing decommissioning is listed here. Furthermore, there are several purely military facilities that are not within the scope of this paper. The table shows that 50 nuclear power plants, 50 research reactors and approximately 50 other

TABLE I. DECOMMISSIONING PROJECTS IN EUROPE (EXCLUDING CIS)

| Country | Nuclear power plants (incl. pilot and prototype plants) | Research reactors | Other nuclear facilities[a] |
|---|---|---|---|
| Austria | | 1 | |
| Belgium | 1 | 1 | 2 |
| Bulgaria | | 1 | |
| Denmark | | 1 | 1 |
| France | 11 | 11 | 11 |
| Germany | 15 | 12 | 8 |
| Greece | | 1 | |
| Hungary | | 1 | |
| Italy | 4 | 4 | 4 |
| Netherlands | 1 | 1 | |
| Norway | | | 1 |
| Poland | | 2 | |
| Romania | | 1 | |
| Slovakia | 1 | | |
| Spain | 1 | 4 | |
| Sweden | 2 | 1 | |
| Switzerland | 1 | 2 | |
| United Kingdom | 12 | 10 | 17 |
| Yugoslavia, Fed. Rep. of | | 1 | |
| *Total* | 49 | 55 | 44 |

[a] Excluding uranium mining and milling facilities.

facilities are currently being decommissioned. Figure 1 shows how these projects are distributed among individual countries. As expected, the larger countries operating nuclear facilities, namely France, Germany and the United Kingdom, have the majority of projects.

However, focusing just on the numbers does not reveal anything about the magnitude of the decommissioning task. In order to assess the importance of the groups of facilities it is necessary to compare some typical and characteristic data for the types of facilities mentioned above. The data have been compiled for a nuclear power plant, a research reactor, a uranium mine, a fuel production plant and a reprocessing plant using the following criteria:

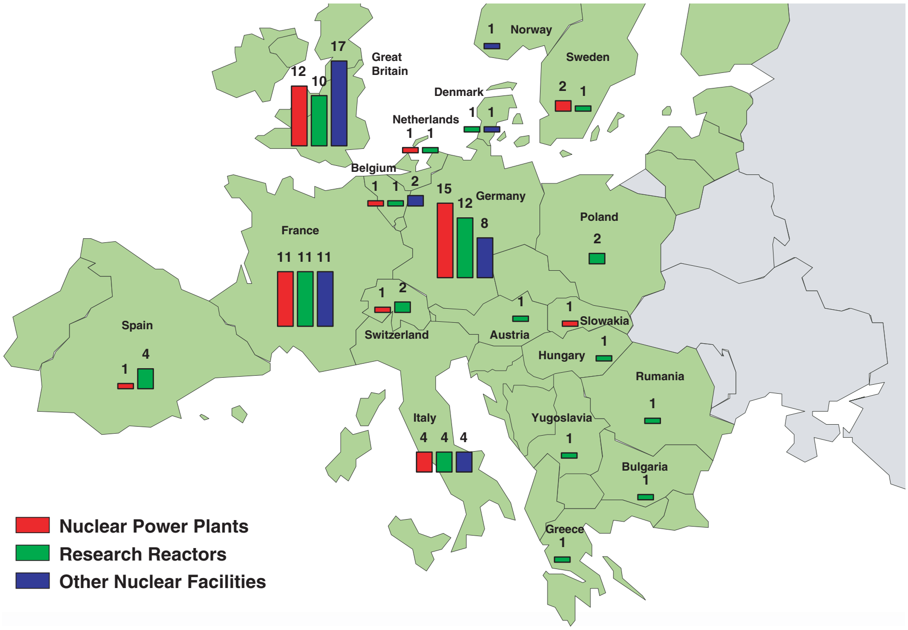


*FIG. 1. Distribution of current decommissioning projects in Europe.*

— mass or the volume of buildings and facilities to be decommissioned,
— activity inventory,
— indicator nuclides,
— quantity of radioactive waste expected.

The comparison is presented in Table II. The right hand side of the table shows the data for fuel facilities, of which there are only a few in Europe. Each needs special attention and plant specific solutions. They constitute only a small fraction of the total future decommissioning task. The left hand side of the table shows commercial power reactors and research reactors. Research reactors are usually of a special type and also need special technical attention. Due to their low mass, they constitute only a minor fraction, with commercial power plants representing the major part of the current decommissioning task.

Considering that nuclear power plants already dominate the decommissioning scene and will do so even more in the future, it is appropriate to concentrate on the decommissioning of nuclear power plants in the following in order to assess the magnitude of the decommissioning task. Figure 2 shows all 49 nuclear power plant decommissioning projects, their electrical capacity (vertical axis) and their periods of operation (horizontal axis). The type of the plant, namely gas cooled reactor (GCR), boiling water reactor (BWR), pressurized

TABLE II. COMPARISON OF NUCLEAR FACILITIES

| | Nuclear power plant | Research reactor | Uranium mine | Fuel production plant | Reprocessing plant |
|---|---|---|---|---|---|
| Mass/volume | 200 000 Mg | 25 Mg | 500 million $m^3$[a] | 65 000 Mg | 120 000 Mg |
| Radioactive inventory | $1 \times 10^{17}$ Bq | $7 \times 10^{10}$ Bq | $2 \times 10^{15}$ Bq | $5 \times 10^{11}$ Bq | $1 \times 10^{18}$ Bq[b] |
| Nuclide(s) | $^{60}Co$; $^{137}Cs$ | $^{60}Co$; $^{133}Ba$ | $^{226}Ra$ | $^{234}U$; $^{235}U$; $^{236}U$; $^{238}U$ | $^{137}Cs$; $^{241}Am$ |
| Quantity of radioactive waste | 5000 Mg | 5 Mg | — | 1000 Mg | 5000 Mg |
| Number of projects | Many | Many | Few | Few | Few |

[a] Overburden + tailings.
[b] Including the leftovers of HAWC.

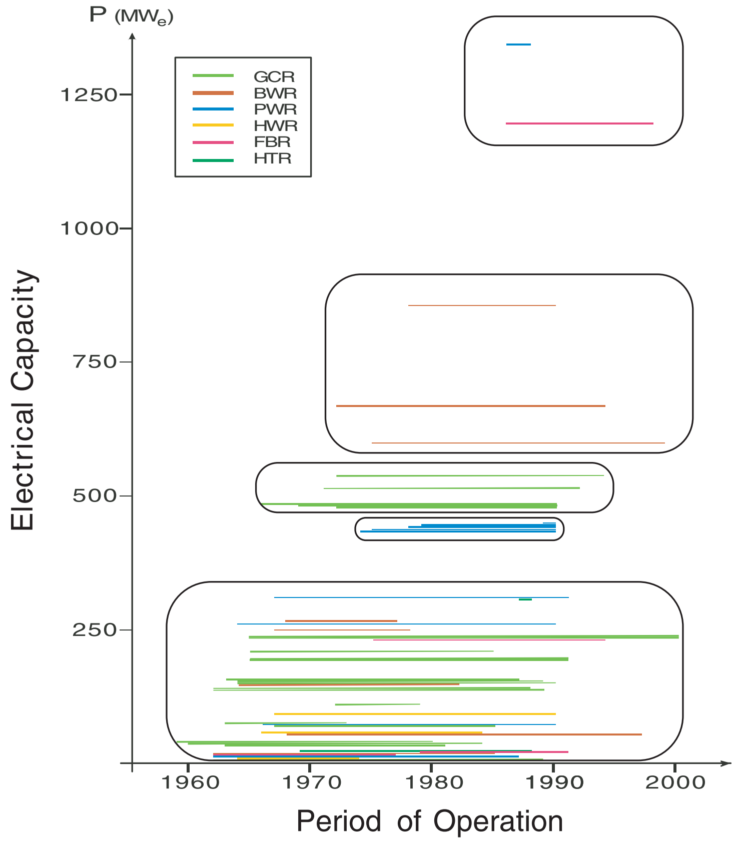


*FIG. 2. All 49 nuclear power plant decommissioning projects in Europe.*

water reactor (PWR), heavy water reactor (HWR), fast breeder reactor (FBR) and high temperature reactor (HTR), is also given. While at first glance the picture may appear quite complicated, it gives a good overview of the general situation, the range of affected nuclear power plants in Europe and the current situation with respect to decommissioning. Five groups of decommissioning projects can be distinguished.

### 1.1. Group 1

Starting with the range up to 300 MW(e), in addition to prototypes and pilot plants of various designs, there is a large group of GCRs. These are basically British first generation MAGNOX plants commissioned in the early 1960s (for instance, Berkeley and Hinkley Point).

### 1.2. Group 2

The next group consists of five PWRs of 440 MW(e). These are plants of Russian design, the so-called WWER-440, located at Greifswald, in Germany, and decommissioned in the wake of German reunification in 1990. Incidentally, a large number of other plants were also decommissioned around 1990.

### 1.3. Group 3

In the 500 MW(e) range are GCRs commissioned around 1970. These include four French first generation plants (Bugey-1, Chinon-A3 and St. Laurent A1 and A2), as well as Vandellós 1 in Spain.

### 1.4. Group 4

This group consists of three BWRs of more than 600 MW(e), which were commissioned after 1970: Barsebäck 1 (Sweden), Würgassen (Germany) and Caorso (Italy). Two of them, namely Barsebäck and Caorso, were shut down as a result of the moratoriums in Sweden and Italy. Würgassen was closed for economic reasons.

### 1.5. Group 5

Finally, there are the special cases with a capacity of more than 1000 MW, namely the Superphénix (France) and the Mülheim-Kärlich nuclear power plant, which was finally shut down because of an agreement with the German Government.

## 2. DECOMMISSIONING STRATEGIES FOR NUCLEAR POWER PLANTS

Turning to the decommissioning strategies pursued in the individual projects, it is necessary to distinguish between immediate removal, which means that the plant is dismantled completely immediately after shutdown, and deferred removal, which means that the plant or a part of it is safely enclosed before it is dismantled completely after a period of time. These basic strategies give the operator or owner a range of different ways to finally clean up the site. Many aspects have an impact on the decision in favour of one or the other option (Fig. 3):

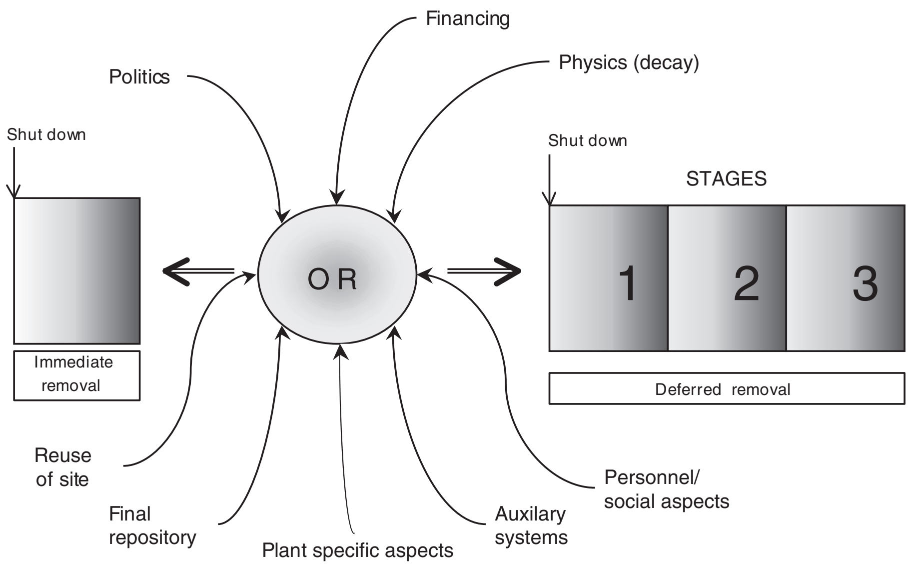


*FIG. 3. The two basic decommissioning strategies and the aspects that have an impact on the choice of strategy.*

— availability of a final repository;
— future plans for the site;
— political influence;
— financing (availability of funds required);
— using radioactive decay;
— continued staff employment and other social aspects;
— operational efficiency of the auxiliary systems required for dismantling;
— plant specific aspects (multiple units, etc.).

The availability of a final repository is of particular significance for quick, economic and final clearance of the site, and thus influences the overall decommissioning strategy. It is also evident that the provision of a final repository will save a considerable amount of money. Table III shows countries with nuclear power plant decommissioning projects which can provide a final repository for low level (LLW) and medium level radioactive waste (MLW); this includes waste from decommissioning. In particular, two of the countries with the majority of projects, France and the United Kingdom, own final repositories, while Germany does not.

Figure 4 gives an overview of all plants to be decommissioned, broken down by type of reactor, country and decommissioning option. On the far left

TABLE III. FINAL REPOSITORIES FOR LLW AND MLW IN OPERATION

| Country | Site | Capacity ($m^3$) |
|---|---|---|
| France | Centre de l'Aube | 1 000 000 |
| Slovakia | Mochovce | 41 000 |
| Spain | El Cabril | 58 000 |
| Sweden | Forsmark | 60 000 |
| United Kingdom | Drigg | 800 000 |

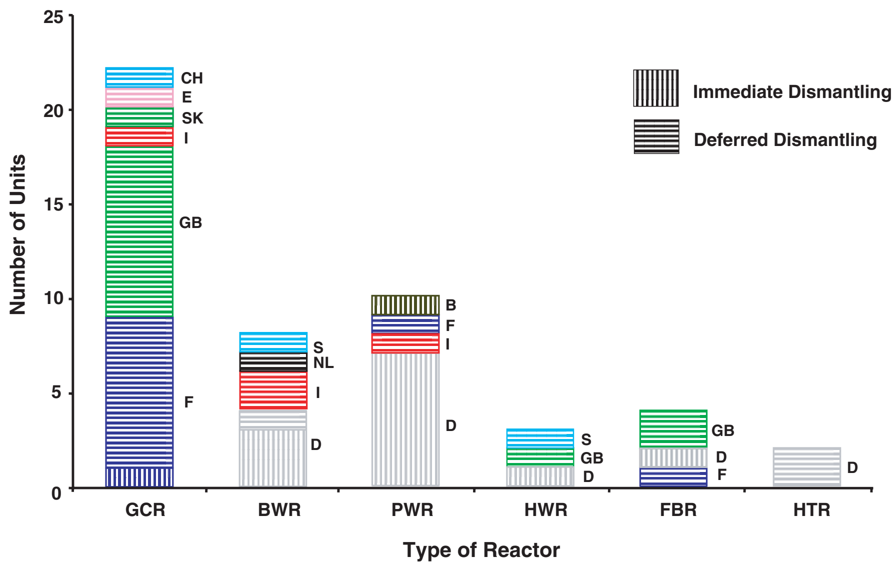


*FIG. 4. Overview of the nuclear power plants to be decommissioned, broken down by type of reactor, location and decommissioning option.*

are the first generation GCRs of France and the United Kingdom, which have already been identified as groups in one of the previous figures. A deferred decommissioning approach was chosen for the overwhelming majority of these plants. However, France has now chosen a more offensive strategy according to which first generation reactors are to be removed completely by 2025. The intention is to demonstrate that dismantling on an industrial scale is possible, and to prepare for the dismantling of PWRs currently in operation but scheduled to be shut down after 2020.

The second large group of plants consists of German LWRs. Although no final repository is available, most of them will be removed immediately. In most cases, staff issues are decisive, i.e. the intention is to further employ the existing operating staff and to use their knowledge of the plant for the dismantling process. Obviously, a great deal of the experience gained in dismantling nuclear facilities stems from these projects. The vast majority of the remaining plants in the different countries will be dismantled later.

The experience gathered from these projects is sufficient to provide a full set of different technologies for more or less any decommissioning project. For all types of nuclear facilities, including uranium mining and milling facilities, conversion, enrichment, fuel production and reprocessing facilities, there are examples where safe decommissioning has been demonstrated worldwide. Many of these ongoing or completed projects will certainly be addressed at this conference. However, there is and must further be a very intense exchange of information between these facilities worldwide in order to optimize this process.

In most cases involving decommissioning and dismantling of a nuclear facility the end point of this process is a clean and reusable site. In achieving this goal, there are two key processes:

— decontamination and clearance of material for further reuse or disposal;
— conditioning and packaging of the residual nuclear waste for storage in a final repository.

These two processes play a key role in ensuring quick, safe and of course economic decommissioning. Thus, it is extremely important to have clear and practical rules and regulations for both processes.

## 3. OUTLOOK FOR FUTURE DECOMMISSIONING PROJECTS

At the moment there are about 170 commercial nuclear power plants in operation with a total electrical capacity of about 140 GW. Figure 5 gives an overview. The units shown here consist of 120 PWRs, 20 BWRs, about 30 GCRs in the UK and 2 RBMK reactors in Lithuania. They constitute, as mentioned before, the major part of the future decommissioning task. A model calculation gives an idea of when these tasks need to be performed and what consequences can be expected.

The following assumptions are made for all currently operating plants:

— a nuclear operational time of approximately 40 years,

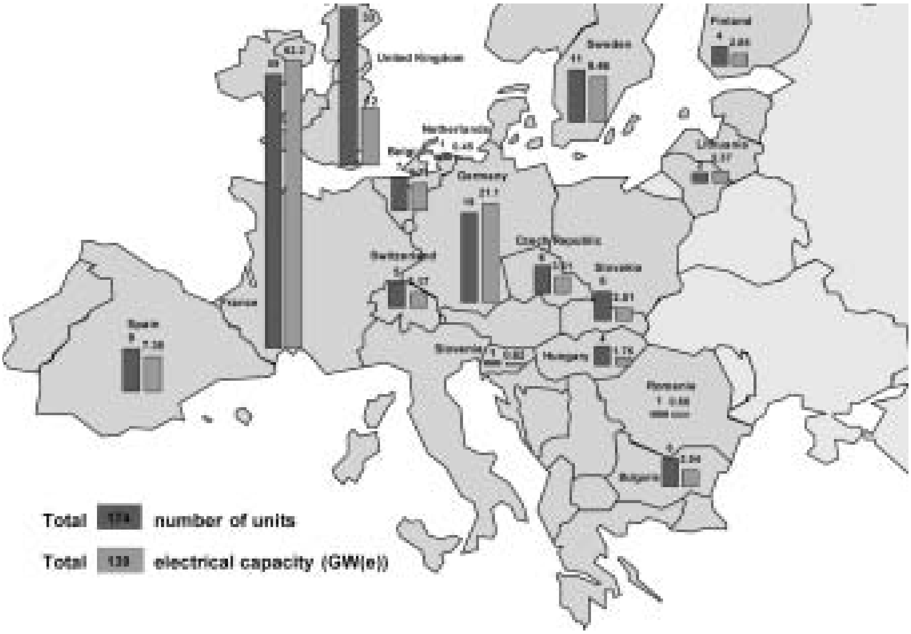


*FIG. 5. Number and location of commercial nuclear power plants in Europe at the present time.*

— radioactive waste to be disposed of in a final repository of approximately 5000 t/plant,
— costs for the dismantling of approximately €300 million/plant.

In this context it should be noted that the 40 year operational lifetime seems rather arbitrary. On the one hand, we know that the operational life of a nuclear power plant can be extended by many more years. On the other hand, the operational lifetime may be limited by State law rather than by safety or economic considerations, as in Germany. Nevertheless, we assume an average lifetime of approximately 40 years for all plants.

Figure 6 shows the number of calculated shutdowns of commercial nuclear power plants over the next 50 years. The figure shows that within the time period 2020–2030, according to the model, there will be approximately ten shutdowns per year. This corresponds to an average nuclear capacity of the order of 10 GW per year. The figure also shows the corresponding installed nuclear capacity for the next 50 years under the assumption that no new nuclear plants will be built. The decrease in nuclear capacity is dramatic around 2020. It will be very interesting to see how this loss of capacity will be compensated for without increasing $CO_2$ emissions.

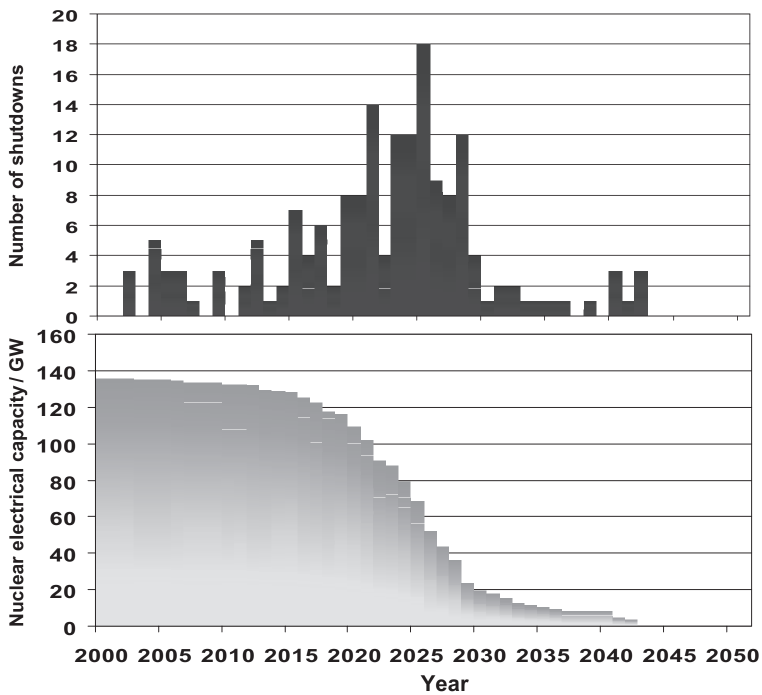


*FIG. 6. Number of shutdowns of commercial nuclear power plants expected over the next 50 years.*

In order to assess the magnitude of the future decommissioning task, we introduce different decommissioning strategies which can be incorporated into the model (see also Fig. 7):

**Strategy A:** Direct dismantling begins about three years after operation ends and lasts about ten years.

**Strategy B:** After two years in the post-operational state and one year for preparation of safe enclosure, the plant will stay in a safe enclosure or care and maintenance state for 25 years. After 28 years, dismantling will begin and will last ten years.

**Strategy C:** Identical to strategy B, except that safe enclosure lasts 50 years.

The results of the model calculation give us an idea of the magnitude of the decommissioning task over the next 100 years. For this purpose, we distinguish between two scenarios:

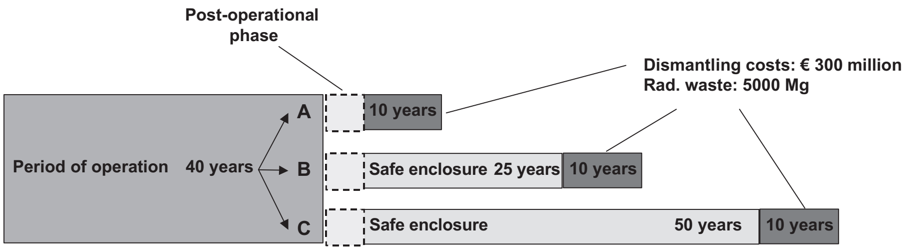


*FIG. 7. Three different strategies used in the model for the magnitude of the future decommissioning task.*

- — Scenario 1 assumes direct dismantling (A) for all of the European nuclear power plants;
- — Scenario 2 tries to be a bit more realistic, assuming a fifty–fifty mixture of direct dismantling (A) and deferred dismantling after 25 years (B) for all PWRs and BWRs. For GCRs and RBMKs, strategy C is assumed here.

Figure 8 shows the number of active dismantling projects. There will be something of the order of 50 decommissioning projects in parallel with a maximum of about 100 in the first scenario. This is a challenge not only for the operators but also for the nuclear industry. In particular, it will be interesting to see how we preserve know-how for such a long period of time (especially for the second scenario) without developing and operating nuclear plants.

In this model we do not indicate preparatory work, post-operational period, the time for preparation of safe enclosure or the operation of a safely enclosed plant. We also do not consider the effect of sites with several units, where the care and maintenance option may also lead to a delay in dismantling until other units on-site are shut down. This will further smooth the distribution of active dismantling projects.

Another interesting aspect is the question of radioactive waste. Assuming about 5000 t of radioactive waste per plant, the total amount of waste produced from nuclear power plant decommissioning will be less than a million tonnes. It should be noted that final repositories for medium and low active waste of more than one million tonnes capacity do exist.

A simple calculation can be done for the total dismantling cost. Assuming an average cost of about €300 million per plant means that the total spending will be about €50 billion within the next few decades. This leads to yearly costs of the order of €1–3 billion per year. In view of these costs, further optimization of the decommissioning process is clearly needed.

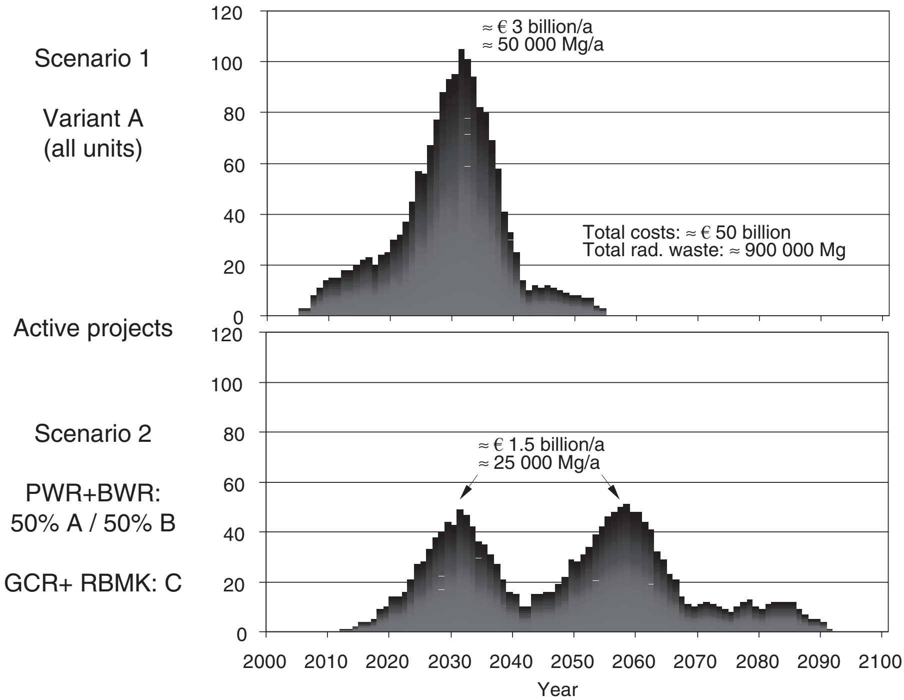


*FIG. 8. Number of active dismantling projects.*

## 4. CONCLUSIONS

In this paper we have shown that there is already a lot of experience from completed and ongoing decommissioning projects. The decommissioning scene in Europe is dominated by the dismantling of commercial nuclear power plants. The experience shows that the technology is present and that different strategies can be pursued that fulfil all conditions of safety.

The future magnitude of the task is also dominated by commercial nuclear power plants. They face several challenges over the next 100 years. The key problems are:

— Replacement of nuclear capacity, especially between 2015 and 2030;
— Preservation of know-how for long periods of time;
— Setting up of common rules and regulations for clearance and waste management.
— Provision of final repositories;

— Management of many large scale decommissioning projects in parallel;
— Search for the most economical method of decommissioning.

It will be interesting to hear more about these perspectives in detail during this conference.

# DECOMMISSIONING OF NUCLEAR INSTALLATIONS IN THE RESEARCH FRAMEWORK PROGRAMMES OF THE EUROPEAN COMMISSION*

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## 1. BACKGROUND OF EUROPEAN COMMISSION (EC) ACTIVITIES IN DECOMMISSIONING

Decommissioning is the final phase in the life cycle of a nuclear installation and is to be considered part of a general strategy of environmental restoration after the final suspension of industrial activities. At present, over 110 nuclear facilities (nuclear power plants, fuel cycle facilities, particle accelerators and nuclear research installations) within the European Union (EU) are at various stages of the decommissioning process and it is forecast that at least a further 160 facilities will need to be decommissioned over the next 20 years (within the present 15 EU member States). Enlargement of the EU would contribute to a rapid increase in the number of nuclear facilities to be decommissioned (at least 50 facilities).

Since 1979, the EC's Directorate-General for Research has conducted four successive five-year research and development programmes on the decommissioning of nuclear installations performed under cost sharing contracts with organizations within the EU. The main objective of these programmes was, and still is, to establish a scientific and technological basis for the safe, socially acceptable and economically affordable decommissioning of obsolete nuclear installations.

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* The views expressed here are those of the authors and may not necessarily reflect those of the European Commission.

These programmes were carried out by public organizations, research institutes and private companies in the member States under shared cost contracts and through concerted actions. The main objectives of these activities were to strengthen the scientific and technical knowledge in this field, with a particular view to enhancing safety and environmental protection aspects, and minimizing occupational exposures and dismantling costs as well as radioactive waste arisings.

Since 1979, more than €60 million have been spent on:

— Development of decontamination and dismantling techniques for different kinds of nuclear installations;
— Technologies for waste minimization, such as melting of steel components;
— Development of decommissioning strategies and management tools;
— Development of remote handling systems for high activity components (TELEMAN programme);
— Development of planning and management tools for decommissioning projects

In the beginning of the 1990s, four pilot decommissioning projects were chosen to compare the differences in the approach of a:

— fuel processing plant (AT1 in La Hague),
— gas cooled reactor (WAGR in Windscale),
— boiling water reactor (KRB-A Gundremmingen in Germany),
— pressurized water reactor (BR3 in Belgium).

Five years ago, a WWER type reactor (Greifswald in Germany) was added to this list of pilot decommissioning sites.

The WAGR dismantling, for instance, served as a bridgehead for the future dismantling of graphite gas cooled reactors. It was an extremely important textbook case, which rightly used the most modern techniques, thus enabling the choice of the scenario that is best suited to lower the doses received by the operators, the costs and the volumes of the wastes.

Operations to remove the reactor internals were undertaken with the use of innovative dismantling techniques involving amongst others:

— Computer controlled remote dismantling machine using stereoscopic television cameras to assist in the dismantling process;
— Acoustic cleaning of electrostatic pre-filters;

— Ultraviolet laser to decontaminate vital parts of the machine before maintenance;
— Video gamma camera to identify and sort radioactive materials and hot spots.

The dismantling of the BR3 in Belgium concentrated successfully on developing dry and underwater cutting techniques for the high activity core internals. The Greifswald decommissioning project, one of the largest in the world, started the stage 3 dismantling of five commercial WWER-440 reactors in Greifswald and one WWER-70 reactor in Rheinsberg. The remote controlled dismantling of the first reactor pressure vessel and reactor internals, using a newly developed robotic system, will start in 2001.

In KRB-A (Germany), a 250 MW(e) boiling water reactor, the dismantling of the core internals, the heat exchanger, the activated concrete bio-shield and the reactor pressure vessel was finished.

The AT1 reprocessing plant in France has successfully completed its decommissioning period and the site is currently being cleaned up for further use.

Within the EC programme, two databases on decommissioning have been created:

— EC DB TOOL for collecting technical performance data;
— EC DB COST for collecting data on waste arisings, doses, etc.

Both are now being merged into one database, EC DB NET, which is available on the Internet (so far only for members of the project group).

The interest shown by the IAEA, the OECD/NEA and the EC in the development of a common understanding of the decommissioning process led to the creation of a list of ‘Standardized Decommissioning Cost Item Definitions’ (INCOSIT), another project under FP-4, to ease worldwide comparability and transferability of data on decommissioning. With this set of standardized decommissioning cost items it should be possible to create a common tool for the calculation of whole decommissioning projects, regardless of the type of reactor or the chosen method of dismantling. Under FP-5, a benchmark exercise on the decommissioning costs of WWER reactors will be executed. Similar activities, using the same list, are currently being conducted in the IAEA and OECD/NEA.

With the support of the EC, conferences, workshops and seminars were held on:

— Melting of dismantling steel,
— Decommissioning strategies,

— The use of databases,
— Dismantling techniques.

Under the 4th Research Framework Programme of the EC (1994–1998), a 20 year period of EC funded research activities in the decommissioning field was concluded, which has been qualified as essential in that sector. It can be stated that most of the dismantling techniques and technologies involved in the decommissioning process have reached industrial stage. A large number of final reports and publications on various aspects of decommissioning are available at our EC service or from the relevant authors.

The activities in decommissioning which are supported in FP-5 are clearly shifting from research on technology to:

— dissemination of results from former research activities,
— exchange of experience and provision of training,
— collection of relevant data from decommissioning projects,
— development of decision-supporting and management tools,
— integration of the needs of the candidate countries.

The current work programme in nuclear fission research supports the creation of *networks* to:

> "exchange information between national and Community sponsored research; promote exchange and feedback between the research and user communities; achieve consensus or a common understanding on key technical/scientific issues; identify research needs and develop strategies for how they can be addressed, promote training activities within a specific area, etc."[1]

And in the 'Communication of the Commission on the European Research Area (Oct.2000)', which will be created within the period of FP-6 (2002–2006), the EC proposes 'European Networks of Excellence' around special areas of interest.

For this purpose the EC decided to support the creation of a 'Thematic Network on Decommissioning' (*www.ec-tnd.net*) as an effective instrument for facilitating these objectives. This network is in line with the EC's current and future intentions of interconnecting individual, national and European initiatives in a certain field and has the ability to serve as a forum for

[1] Nuclear Energy Work Programme, 1998 to 2002, Official Journal L26 (1999).

extended exchange of experience and the integration of future members from Eastern Europe. It will involve research facilities, the decommissioning industry, ongoing and future decommissioning projects as well as authorities and regulators.

It is foreseen to provide free access to the EC DB NET database for the members of the network, with the objective on one side to disseminate collected experience from different decommissioning projects, but also to receive more data to improve the usability of the database. An extended set of data and a large number of clients are indispensable conditions for a long lived database.

Besides the Thematic Network and the database, some other projects which deal with innovative remote dismantling techniques or cost estimation for the decommissioning of WWER nuclear power plants receive substantial financial support from the EC. There is also support given to the organization of training courses and to the creation of a compendium on the state of the art in decommissioning, taking into account experience gained in this field during the last two decades.

Recently, other services of the EC, such as the Directorate-General for Energy and Transport, in continuation of the Directorate-General for Environment, have also contributed with studies and projects on decommissioning but with an emphasis on safety and regulations, environmental impact assessments and the economic implications as major topics. As an example, the recent "Study on the Methodologies for the Calculations and Financial Planning of Decommissioning Operations", carried out by an international consortium, shed light on the impact of the main driving factors involved in the strategic decision making on decommissioning.

## 2. THE ENLARGED EU

The process of enlargement of the EU has also brought in new demands to the EC in the nuclear area. As part of the negotiations for accession, the Council, with the help of experts from the member States and the relevant services of the EC, started a safety review process of nuclear installations, including those whose closure was already planned upon the request of the EU.

These nuclear power plants receive specific treatment by the EC, which has allocated funds, directly or through international financial institutions, to support measures oriented to immediate pre-decommissioning activities, and also to compensate for the effects of early closure on the energy systems and the economies of the affected countries.

## 3. INTERNATIONAL CO-OPERATION

European Commission services participate in a number of initiatives on decommissioning started by other international organizations such as the IAEA or OECD/NEA, with the aim of having a complementary approach to solving common questions. The EC supports the idea of close co-operation with the different international bodies in this field.

An example is the co-operation in the field of cost estimation methodologies, where the OECD/NEA (Liaison Committee on Decommissioning), the IAEA (cost studies on WWERs) and the EC/Directorate General for Energy and Transport have recently initiated complementary investigations focusing on different cost aspects of decommissioning.

## 4. PRESENT PRIORITIES FOR THE COMMISSION

In addition to the above mentioned projects under the Framework programmes, the following are the main issues on which the EC has focused further activities.

### 4.1. Financial aspects of decommissioning

The cost of decommissioning should reflect all activities of the decommissioning process, starting with the planning of the project, the licensing procedures, post-operation or after shutdown unloading and cleansing, continuation of the decontamination and dismantling activities, completion of final disposal of spent fuel, and radioactive waste management, thus completing the radiological release of the site. If the decommissioning is deferred for an extended period of time, surveillance and security of the facility should also be taken into account. According to the legal framework, a mechanism has to be established before operation in order to secure the funds needed for the decommissioning of each facility. However, for plants that were constructed earlier, i.e. in the 1950s and 1960s, or under different legal frameworks as in the Eastern European countries, funds are often limited, which may have an impact on the decommissioning strategy that is chosen.

Decommissioning projects have demonstrated that costs can be managed. Comparisons of individual cost estimates for specific facilities have shown relatively high variation, however, which result mainly from the use of different cost estimation methodologies and different data requirements. There is a need for continued discussion, standardization and harmonization, guidance and support for cost estimates for nuclear decommissioning.

Methodologies should remain simple, understandable and transparent, however. They should contain boundary conditions and allow the identification of cost drivers. It is also important to share the experience on cost calculations versus decommissioning costs that have been incurred in practical decommissioning projects.

The subject of the funding of *future* decommissioning costs is also a matter of growing interest, given the implications of radiological protection and nuclear safety, and also as regards the impact on the balance sheets of the companies operating the installations. The different approaches in managing the necessary reserves and/or the external dedicated decommissioning funds may have an effect on the competition rules of the nuclear and electricity market. The EC is at present taking the initiative on legal instruments to set the minimum criteria for the constitution and management of the decommissioning provisions. The goal is twofold. Firstly, ensuring the availability of the necessary resources for the decommissioning work, when the time comes, and secondly, providing a clear framework within which such funds have to be used in order to avoid undue risks or impacts in the market.

## 4.2. Radiological protection during decommissioning

In 1996 the EC issued a 'Directive on Basic Safety Standards' (Directive 96/29/EURATOM). This introduced a series of new measures to improve the protection of the health of workers and the general public. For this purpose, the Directive reduced the dose limits and contains explicit provisions for intervention situations. It also structures the concept of clearance and exemption for radioactive materials.

To advise member States on the implementation of the Directive, the Directorate-General for the Environment has issued several publications:

— Definition of clearance levels,
— The as low as reasonably achievable (ALARA) concept in decommissioning,
— Radiological protection criteria for the clearance of buildings,
— Calculation of individual and collective doses from the recycling of metals from the dismantling of nuclear installations,
— Practical use of the concepts of clearance and exemption.

There is a need for clarification and coherence of the current system regarding such aspects as optimization, dose limits, triviality, and public and environmental protection. The use and necessity of the concept of 'triviality' in the context of radiation protection regulation should continue to be discussed.

There is also growing awareness of NORM (naturally occurring radioactive material), and its concentration in various non-nuclear industrial processes, and that there is no reason to treat it according to different risk evaluation standards from radioactive material from nuclear industries. It should be noted that two of the largest sources of TENORM (technologically enhanced naturally occurring radioactive material) are the coal and the oil and gas industries.

A number of final reports from EC funded research projects deal with radiological aspects in decommissioning. With respect to operator safety during interventions in hazardous environments, such as areas with alpha contamination, the development of safe and comfortable and, at the same time, cost effective protective clothing equipment is needed. This also includes the efficiency of protective clothing as well as the biological and physical monitoring of the operator.

### 4.3. Environmental impact of decommissioning

In January 2001, a workshop was organized by the EC on the 'Current Regulatory Status of the EU Member States and Applicant Countries' concerning 'Environmental Impact Assessment [EIA] for Decommissioning of Nuclear Installations'.

The study, which was initiated and financed by the Directorate-General for Environment, aimed at reviewing the requirements of the relevant EIA Directive of the EC (97/11/EC), and to provide guidelines for their application to the specific issue of decommissioning. Special consideration has been given to public involvement in this process.

As there is presently limited experience in applying EIAs to the decommissioning of nuclear power plants, either in the EU or in the applicant countries, it is believed that there is a need for discussion and exchange of experience on this aspect. Topics of interest are:

— Review of legal and regulatory requirement for the application of EIAs to nuclear decommissioning projects in EU member States.
— Application of the EIA process to the development of the decommissioning strategy.
— Integration of the EIA into the overall decision process.
— EIA requirements for other facilities such as nuclear laboratories and research centres.
— Development of practical guidelines for the:

- screening and scoping process with specification of criteria,
- methodologies for assessing impacts,

- impact minimization and mitigation,
- post-decision monitoring,
- cost and resource implications.

In this context the extended work on environmental questions of decommissioning, which has been done by the Directorate-General for Environment during recent years, should be stressed.

## 4.4. Material management, recycling, reuse and release of dismantling waste

The management of large volumes of materials arising from the decommissioning of nuclear facilities represents one of the major tasks to be undertaken and one of the most substantial cost items. According to current experience, less than 1% of the materials produced will be managed as low and intermediate level radioactive wastes.

Various international organizations, such as the IAEA and the EU, have issued a number of release recommendations relating to exemption and clearance criteria, i.e. the present EC recommendation on unconditional clearance of scrap metal (EC Radiation Protection 89, Recommended Radiological Protection Criteria for the Recycling of Metals from the Dismantling of Nuclear Installations, 1998). In addition, each member State has its own strategies and policies about waste management, including the material release criteria.

Harmonization of waste management practices and clearance levels among the member States or worldwide would be beneficial not only in terms of equivalent levels of safety in waste management and disposal, but also in the minimization of wastes through release and recycling. Within the EU member States, there is a quite strong tendency towards settlement on common criteria to manage decommissioning waste streams. The lack of common characterization procedures and techniques between the various countries is a sensitive issue that makes the circulation, recycling and reuse of materials and possible use of regional repositories much more difficult. The ‘Thematic Network on Decommissioning’, funded under the 5th Research Framework Programme, could promote the creation of a broadly accepted and coherent system of characterization methods and release criteria, as well as associated regulations for the recycling and reuse of materials from decommissioning, taking into consideration all aspects of global optimization.

## 4.5. Socioeconomic, political and public perception issues

The major non-technical problems influencing decommissioning projects are socioeconomic, political and public perception issues. They should be addressed as early as possible in the conceptual phase of a decommissioning project. In the case of early shutdown of a plant, these issues will gain even more importance.

As some of the Eastern European operators will have to face the challenges of early shutdown, it is beneficial to have the possibility to gain from outside experience in building a strategy on employment of redundant staff, educational and training programmes and site development and reuse. Particularly noteworthy in this respect is the successful strategy on reuse of the Greifswald decommissioning site, where currently €700 million in foreign investments are under negotiation (which, by the way, supports the strategy of immediate dismantling and site clearance).

Public perception is one of the main issues related to nearly all activities in the nuclear field, and there is room for great improvement. Therefore, the current co-operation projects under the 5th Research Framework Programme should provide a forum for the exchange of experience and the start of new initiatives. In this respect, the EC supported decommissioning web site (*http://www.eu-decom.be*) should be mentioned, which provides an opportunity for all interested parties working in the nuclear decommissioning area to provide data and information and make it an interactive forum to communicate with the public.

## 5. CONCLUSION

The EC recognized very early on the need for research, development and demonstration of the effective and safe decommissioning of nuclear installations after completing operation. With more than 140 nuclear power plants and almost the same number of research reactors within the member States, there was a clear need for a programme on decommissioning and dismantling of those installations.

Relating to the results of a 20 year research and development programme comprising all aspects of a decommissioning project, including the management and treatment of dismantling waste, this programme contributed significantly to the fact that the European nuclear industry currently is probably one of the few industries that has demonstrated that it is able to manage successfully the end-of-life of its installations. It can be stated that decommissioning and dismantling of nuclear installations has reached an industrial stage and is a mature technology.

In order to disseminate the accumulated know-how and improve the exchange of information within the participating organizations, databases have been set up, a thematic network open to all interested parties has been created, and a compendium of information on state of the art knowledge in decommissioning and dismantling is being prepared. This wide dissemination of knowledge and best practices in decommissioning through international co-operation, networking, training activities, conferences and workshops integrating future member States of the European Union should provide the basis to keep and enhance the existing high European level of expertise in this field.

However, there is still room for discussion and improvement, especially in strategy and funding, reduction of waste arisings, harmonization in recycling and reuse of materials, free release levels as well as on assessment of environmental impacts and public perception issues.

Despite the view that the EC should further decrease the funding of *research* activities in nuclear decommissioning, there is also a view toward continuing support for dissemination of best practices and accumulation of knowledge within networks of excellence, and through co-operation with international organizations that are active in this field. Such networks are universities and research centres bringing together private and public resources by networking national research programmes in a co-ordinated fashion, and by supporting special actions focusing on research infrastructures of European interest. Finally, conclusions are drawn on the main achievements of the framework programme on research and on new stakeholders in European research in a changing world.

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# DECOMMISSIONING OF ITALIAN NUCLEAR INSTALLATIONS: EXPERIENCE AND FUTURE PLANS

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**Abstract**

An overview of decommissioning activities in Italy is presented covering both the Società Gestione Impianti Nucleari (SOGIN) and ENEA/FN plants. The recent change in decommissioning strategy decided by the Italian Government is presented. Design activities developed to verify the practicability of the new strategy are discussed. The main results of the effort to redefine the national strategy are commented on, and critical items still to be solved are discussed.

## 1. INTRODUCTION

The main aim of this paper is to present a general overview of the decommissioning activities of nuclear installations in Italy. In the last three years, starting from December 1999, the national decommissioning strategy has been completely redefined by the Italian Government, shifting from safe storage to immediate dismantling. In addition, important steps have been taken to fix new targets for nuclear operators and create the conditions necessary to support this new policy. However, in order to make these targets completely achievable, some crucial problems, such as the siting and construction of a national repository for low and intermediate level waste (LILW), must be solved.

In the following, a general picture of the Italian situation is presented (covering both nuclear power plants (NPPs) and research installations), together with a discussion of the critical aspects still under consideration. Also, the conditions that need to be fulfilled to make the proposed targets realistically achievable are examined.

## 2. NUCLEAR INSTALLATIONS IN ITALY: HISTORY AND CURRENT STATUS

Nuclear installations in Italy include NPPs, research reactors, nuclear fuel fabrication installations and research laboratories, waste management centres, and smaller facilities such as medical installations, support facilities for industrial applications. Nuclear installations are spread over quite a large area in Italy. Figure 1 provides a general overview of the location of the most important installations in the country (medical centres and local industrial applications are not included). However, in the following only the largest


*FIG . 1. Nuclear installations in Italy.*

installations, i.e. Società Gestione Impianti Nucleari (SOGIN) NPPs and research/industrial installations owned by ENEA-FN, are considered in some detail. With the decision to phase out nuclear energy in Italy, the number of nuclear installations that are still active is continuously decreasing, though a number of such facilities (mainly for medical, industrial and research applications but also a few research reactors) will survive in the future.

Figure 2 gives details on the location of the existing NPPs, which were formerly owned by ENEL — the Italian national utility — and are currently owned by SOGIN. These power reactors are currently being decommissioned. The research facilities to be decommissioned, currently owned by ENEA and FN, are presented in Fig. 3. Other facilities currently owned by different operators (universities, industries, etc.) should also be decommissioned in the near term. However, no further details on these facilities are given in the following due to their lower relevance.

## 3. THE NUCLEAR LEGACY IN ITALY

The nuclear industry was well developed in Italy from the 1960s, both in the field of power production and in the research domain. Research in the nuclear field began in the 1950s, and at the beginning of the 1960s different Italian utilities, at that time independent companies before the nationalization

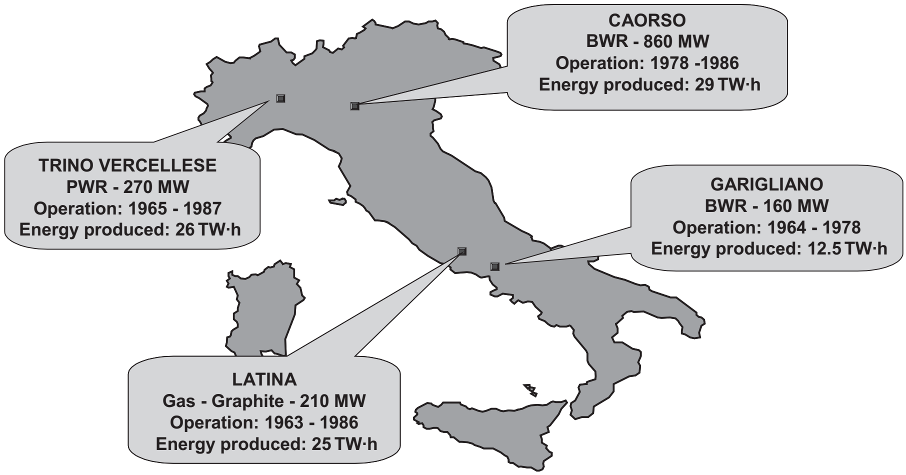


*FIG . 2. SOGIN NPPs.*

of the electric power industry, pioneered the development of nuclear power, building different kinds of reactors (Table I).

After nationalization, ENEL continued developing nuclear power, building the Caorso plant, participating in the design, construction and operation of Superphénix (NERSA Consortium) in Creys-Malville, and building the Alto Lazio (two unit BWR) and Trino 2 (two unit PWR) plants. Construction of both Alto Lazio and Trino 2 was disrupted by the Chernobyl accident and by the subsequent strong emotional reaction in Italy.

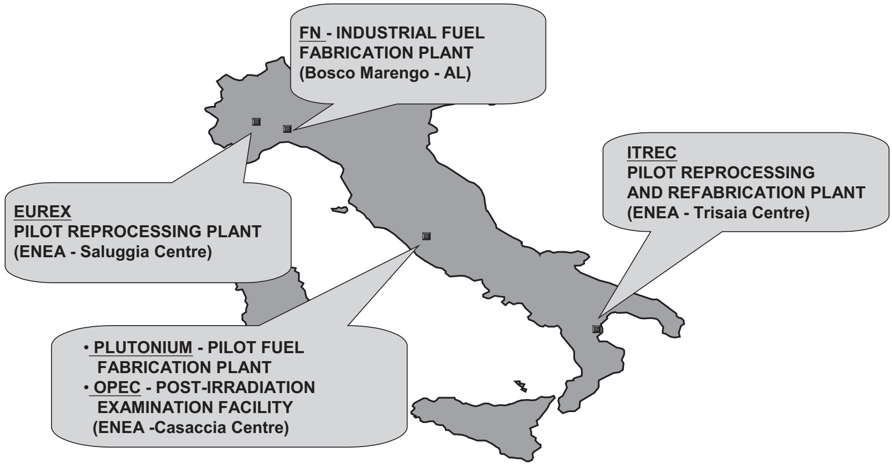


*FIG. 3. SICN plants.*

TABLE I. NUCLEAR POWER PLANTS IN ITALY

| Utility (at construction time) | NPP | Reactor type | MW(e) | In commercial operation since | Shutdown |
|---|---|---|---|---|---|
| SIMEA | Latina | Magnox | 210 | 1963 | 1986 |
| SENN | Garigliano | BWR | 160 | 1964 | 1978[a] |
| SELNI | Trino | PWR | 270 | 1965 | 1987 |
| ENEL | Caorso | BWR | 860 | 1978 | 1986 |

[a] Due to technical reasons.

### 3.1. Phasing out nuclear energy

A referendum held in 1987 on issues linked to the use of nuclear energy was interpreted as a desire to abandon the use of nuclear energy for electricity production. After a five year moratorium the decision to definitely abandon nuclear energy was taken. In the meantime, all of the NPPs were permanently shut down.

ENEL began to study a possible approach to decommissioning. In fact, the problem was at that time already under discussion due to the fact that the Garigliano plant was shut down by a decision of the Board of ENEL in 1982, adopting the safe storage strategy to decommission the plant. Activity to bring the Garigliano plant into safe storage was started in 1985.

The reasons for the choice of this strategy were several:

— No repository was available for the final disposal of LILW in Italy;
— No clearance levels were available to release material deriving from decommissioning activities;
— Funds were accumulated by ENEL during plant operation to support the safe storage strategy.

In the following years, when the decision to shut down all of the other NPPs was confirmed, the adoption of this strategy was renewed, since the reasons for adopting it, summarized above, are still valid.

### 3.2. Decommissioning experience

Activities to bring plants to a safe storage condition have been carried out for the Garigliano plant in 1985, for Latina in 1988 and for Caorso and Trino in 1990. A quite significant amount of experience has been accumulated, mainly in conditioning LILW, but also in activities to recover waste (e.g. from underground reservoirs), for cleaning contaminated structures, dismantling systems and components, etc. A few examples related to the Garigliano and Latina plants are presented in Figs 4–6.

### 3.3. From ENEL to SOGIN

In March 1999, in the framework of the liberalization of the electricity market, SOGIN was constituted as a company of the ENEL Group in charge of the management of Italian NPPs. In November 2000, all of SOGIN’s shares were transferred to the Italian Ministry of Finance. The SOGIN mission is summarized by three main tasks:

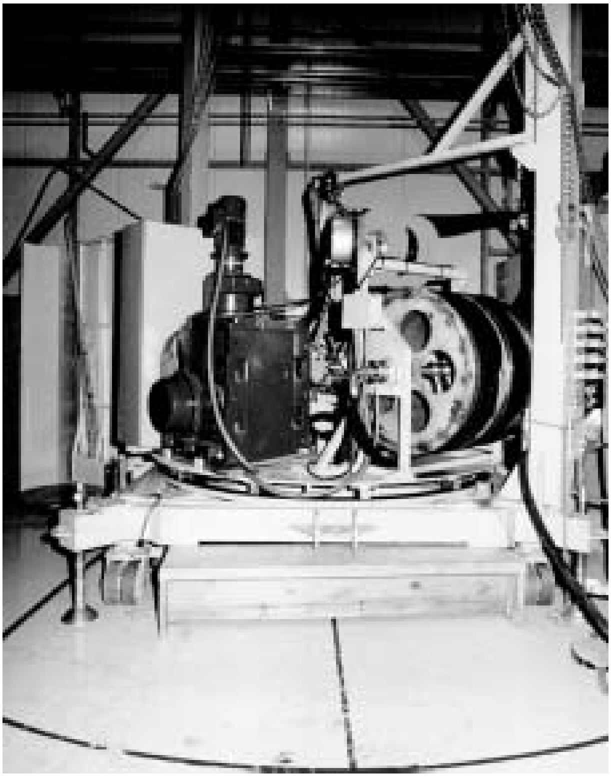

FIG. 4. Waste retrieval at the Garigliano NPP.

FIG. 5. HLW retrieval at the Garigliano NPP.

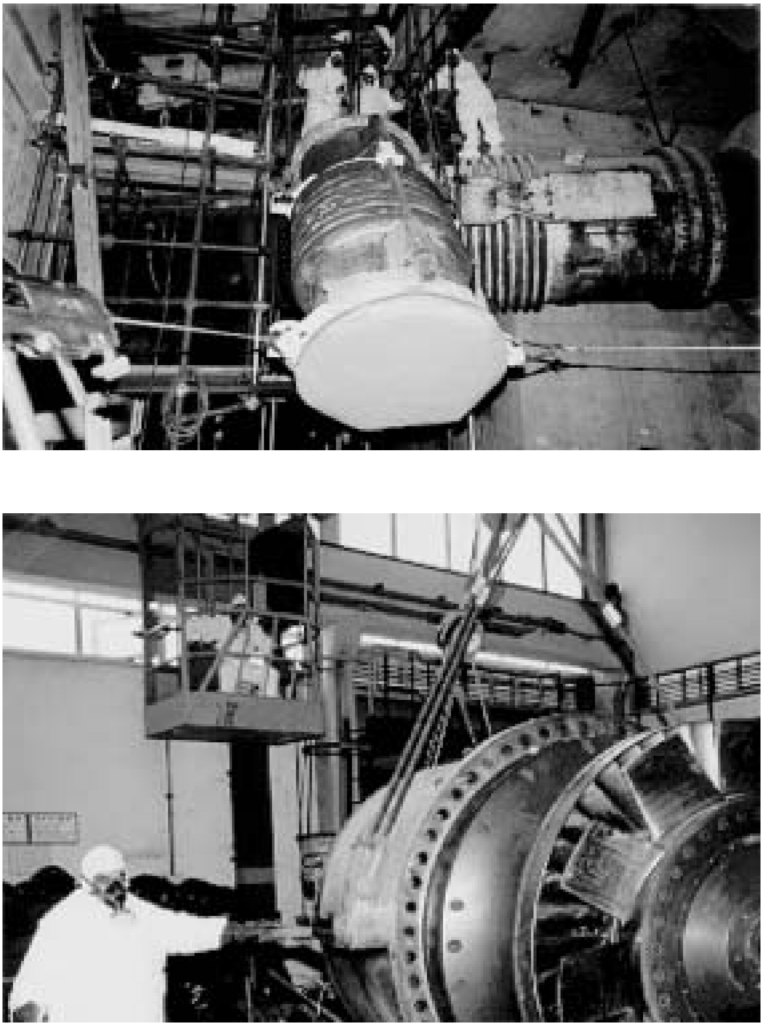

FIG. 6. Latina NPP primary circuit dismantling.

— Post-operation activities for the four Italian NPPs;
— Decommissioning, spent fuel management and site restoration and/or reuse;
— Business development.

All the assets and liabilities of ENEL in the nuclear field were transferred to SOGIN.

### 3.4. A new approach to decommissioning in Italy

Quite recently (December 1999–January 2000), three major new tasks were given to SOGIN by the Italian Government:

— Review the applied decommissioning strategy, moving from safe storage to immediate dismantling, with the target of releasing all of the Italian nuclear sites — from radiological constraints— by 2020;
— Plan for a national LLW repository — together with an interim storage for spent fuel and HLW — to be available in Italy in the medium term;
— Classify the additional costs resulting from this acceleration of the decom-missioning plans as ‘stranded’ costs, i.e. costs recognized by the law as general costs of the electricity system, to be covered by a levy on the kilowatt-hour price established and controlled by the Italian Authority for the Energy Sector.

## 4. DECOMMISSIONING OF NUCLEAR INSTALLATIONS — THE MAIN ACTORS: SOGIN AND SICN

In this new scenario, SOGIN is in charge of the following:

— Implementation of the governmental guidelines on decommissioning, reaching by 2020 the complete release of the SOGIN sites;
— Taking care of the closure of the fuel cycle (spent fuel dry storage plus completion of the existing reprocessing contract in place with British Nuclear Fuels Limited);
— Co-ordinating with ENEA (the Italian research body engaged in the past in the field of nuclear energy) for the decommissioning of the nuclear research facilities in Italy.

Migration to the new strategy will take place by adapting the speed of this process to the milestones established by the governmental plan, and specifically with the established time schedule for siting and construction of the national repository to dispose of LILW. The redefinition of decommissioning plans that SOGIN has prepared assumes these dates as the cornerstones for the new strategy.

In 2001, a consortium (SICN) was created involving ENEA-FN and SOGIN, with the task of managing the activities related to decommissioning plants and facilities of the nuclear fuel cycle owned by ENEA and FN and, at the same time, to prepare the transfer to SOGIN of the facilities themselves. The consortium is expected to complete its activity by December 2003. The relationships between the different partners of the consortium and SOGIN itself are highlighted in Fig. 7.

## 5. COST EVALUATION; FUNDING; CONTROL BY THE AUTHORITY FOR THE ENERGY SECTOR

The new strategy obviously required a complete re-evaluation of the cost of the whole decommissioning programme. This re-evaluation was performed by SOGIN and by the SICN consortium and a lack of funding was immediately in evidence. In fact, funds to cover decommissioning costs had been accumulated by ENEL during the years of plant operation (1964–1987) and re-invested (at a 5% rate of return) until 1999 (i.e. the founding of SOGIN). These funds were collected to cover a safe storage strategy. However, the acceleration in the decommissioning strategy and the additional costs accruing from the fact that SOGIN has been set up as an independent company have resulted in the accumulated funds no longer being sufficient to support the entire decommissioning plan. To cover theses additional costs — which have been considered as stranded costs — a levy on kilowatt-hours has been decided by the Italian Government.

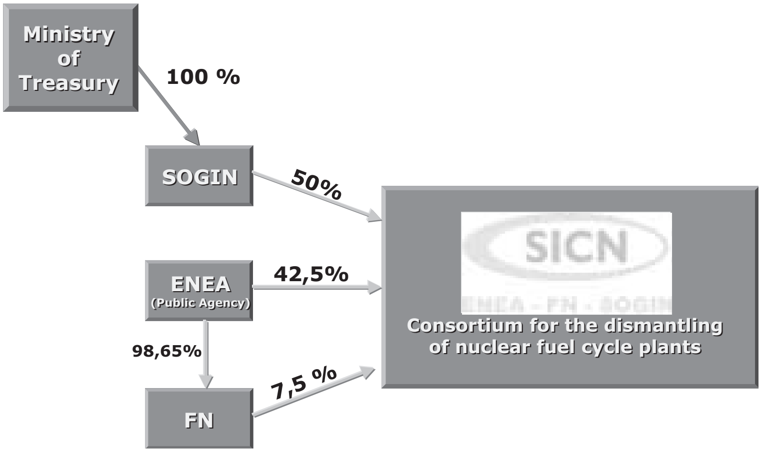


*FIG . 7. The SICN consortium.*

A provisional value of the levy has been fixed by the Authority for Energy to cover the costs of SOGIN and SICN for 2000 and 2001. In April 2002, the Authority, having examined the overall decommissioning plan presented by SOGIN, defined the funding for 2002–2004, in agreement with the SOGIN proposal. The overall SOGIN funding mechanism is presented in Fig. 8.

## 6. PLANNING THE DECOMMISSIONING ACTIVITIES

On the basis of the new inputs received by the Italian Government, the decommissioning activities were completely replanned. This exercise was completed by considering the entire programme logically, subdivided into three parts to allow safe management and in line with the possible evolution of the waste repository programme. The programme logic is presented in Fig. 9, and the programme that was decided upon is presented in Fig. 10.

A similar effort has been developed by SICN for the ENEA-FN installations. The main ENEA effort in the short to medium term will be devoted to waste conditioning that, due to the nature of ENEA installations (i.e. research laboratories fuel treatment facilities, etc.), is much more complex than that for the NPPs. Dismantling will be performed when the national repository is available.

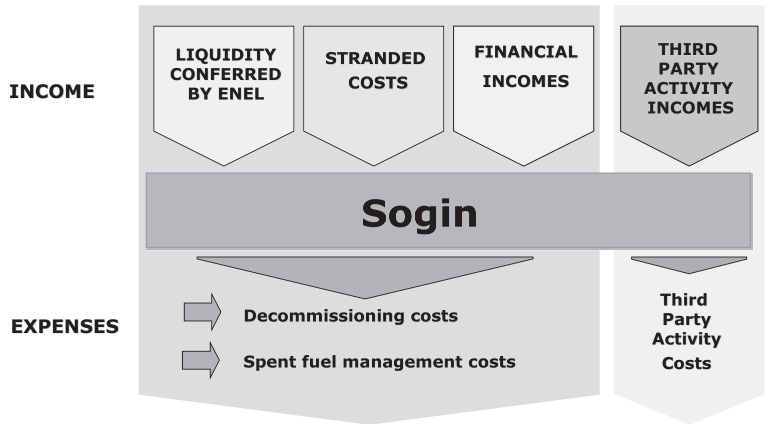


*FIG . 8. The SOGIN funding mechanism.*

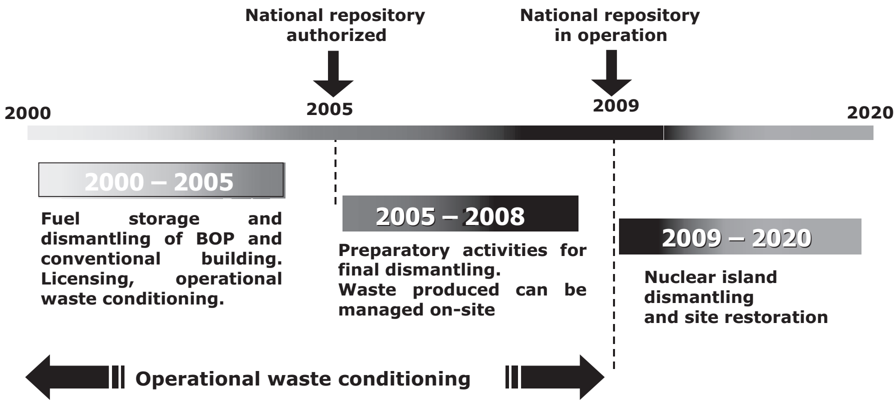


*FIG. 9. The three main stages of the SOGIN strategy.*

## 7. ACTIVITIES ALREADY COMPLETED

During 2000, having completed preliminary rescheduling of the activities, SOGIN started developing in more detail the conceptual design of the decommissioning activities with the goal of:

— confirming the preliminary evaluation of the time schedule and costs;
— supporting the licensing process to be launched;
— acquiring more precise information on the production of waste, personnel exposure, possible accident scenarios and related safety analyses.

From 2000 until now, a quite detailed design of the decommissioning activities has been developed. For each NPP, several tasks have been fully engineered up to a level of a feasibility study and the practicability of the proposed technical solution has been assessed.

A solid basis for the entire licensing process has been built. In fact, general applications for the SOGIN plants have been filed with the Ministry of Industry and ANPA (the Italian Safety Authority) between August 2001 and February 2002. Special tools have been developed to perform this design activity. In particular, it is worth mentioning the 3-D model and the associated database developed in co-operation with Ansaldo Nucleare for each plant to simulate the dismantling activities and to be used for waste management and tracking. An example related to Trino is presented in Fig. 11.

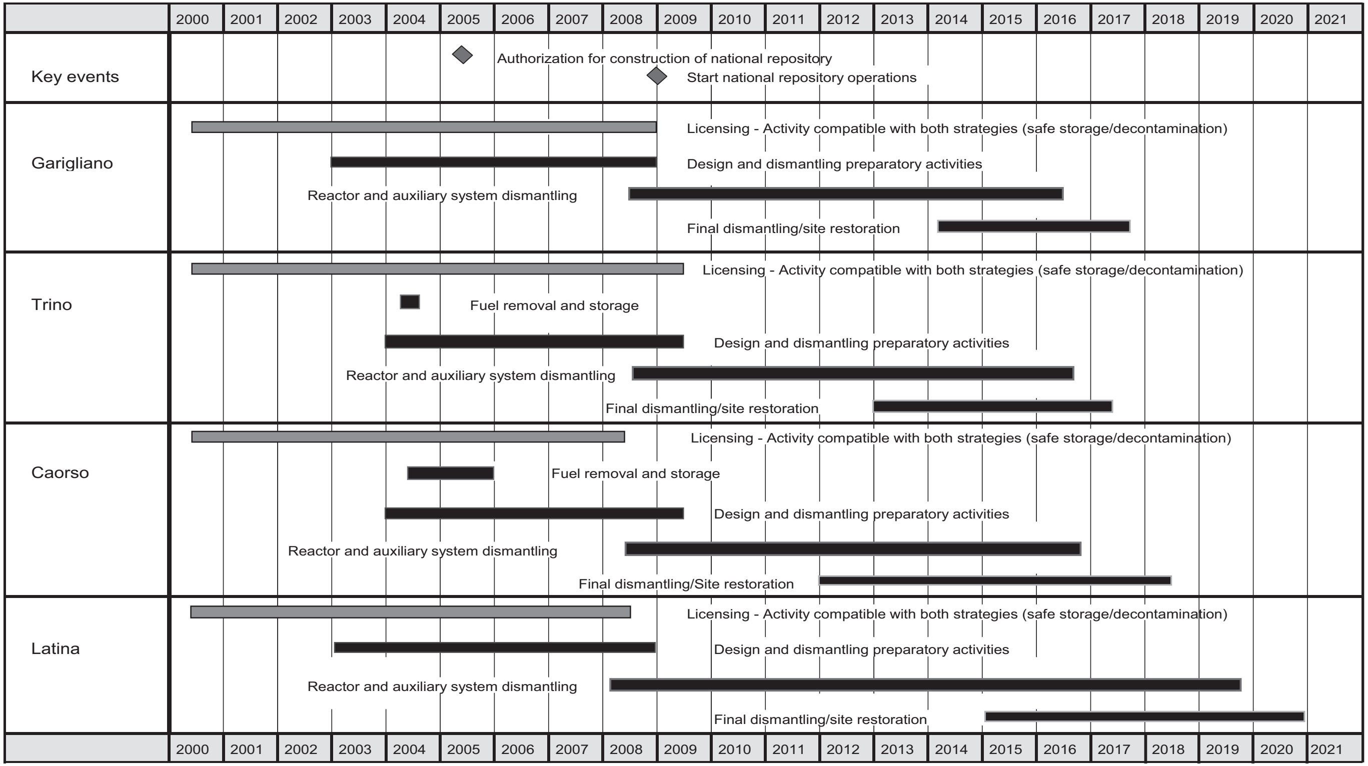


*FIG. 10. The SOGIN decommissioning plan.*

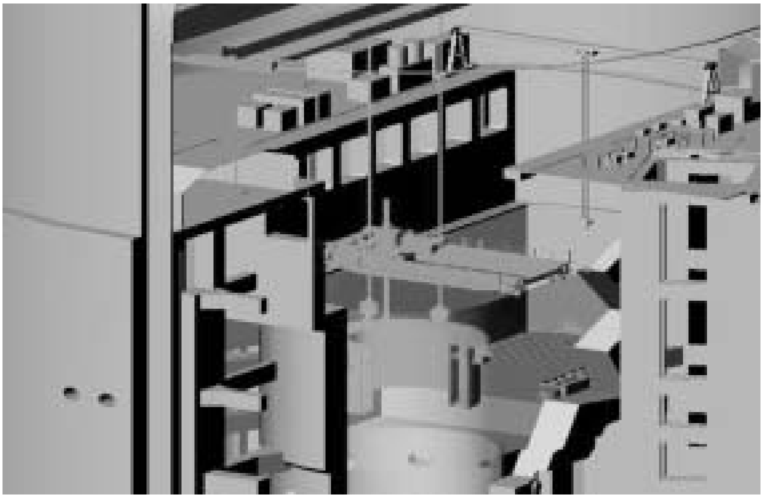

*FIG. 11. The Trino NPP — neutron shield tank removal.*

## 8. DECOMMISSIONING TIME AND COSTS AND OTHER CRITICAL PARAMETERS

The main results of the activities described in the previous section are summarized in Table II for the SICN consortium and in Table III for SOGIN NPPs. The cost profile for the SOGIN plants in the years up to 2020 is shown in Fig. 12, together with the cumulative costs. These costs include waste disposal (a value of 9400/m$^3$ has been provisionally assumed). The total estimated number of staff to perform the decommissioning activities has been estimated at 14 million person-hours for the four SOGIN NPPs.

Other parameters of interest were also evaluated. Among others, it may be of interest to present the main results achieved in terms of waste production (see Table IV) and expected dose to personnel (see Table V). The distribution of dose during the decommissioning activity period versus the person-hours spent in on-field activities is presented in Fig. 13.

## 9. CONCLUSION: KEY ISSUES

On the basis of the experience of this first period of activity, after the setting up of SOGIN and after having shifted to a new decommissioning strategy, there are some key issues that are worthwhile pointing out. In the following some of these key points are presented and discussed.

TABLE II. SICN DECOMMISSIONING COSTS (IN MILLION € 2002)

| Facility | Total cost (includes contingencies) |
|---|---|
| ITREC (Trisaia) | 250 |
| EUREX (Saluggia) | 330 |
| Casaccia plants (Rome) | 400 |
| FN (Bosco Marengo) | 50 |
| *Total* | €1030 million |

TABLE III. DECOMMISSIONING COSTS FOR SOGIN NPPs (IN MILLION € 2002)

| Item | Total cost (includes contingencies) |
|---|---|
| Caorso | 550 |
| Garigliano | 300 |
| Latina | 750 |
| Trino | 300 |
| Fuel cycle | 700 |
| *Total* | €2600 million |

### 9.1. Rules and standards

Italian regulations, including nuclear law (decree 230/95), have until now only marginally considered decommissioning processes. An effort to set up a body of rules and procedures concerning decommissioning is now in progress. For example:

— Release limits are not defined by the law at the national level. Until now limits have been fixed on a case by case basis for specific activities (e.g. Garigliano in the 1980s, Caorso in August 2000 for specific activities).

— Waste conditioning is currently regulated by Technical Guide No. 26 (issued in 1985 by the Italian Safety Authority), which essentially considers waste from plant operations. Important aspects are missing for waste deriving

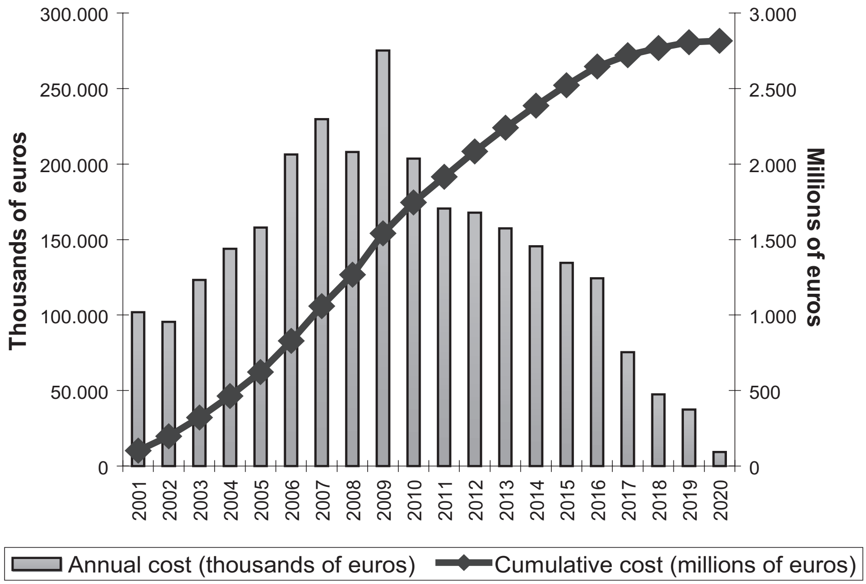


*FIG. 12. Decommissioning costs of the SOGIN plants (€ 2002).*

TABLE IV. WASTE PRODUCTION

| Plant | LLW ($m^3$) | ILW($m^3$) |
|---|---|---|
| Caorso | 4200 | 150 |
| Garigliano | 4500 | 20 |
| Latina | 13 500 | 3700 |
| Trino | 3800 | 120 |
| *Total* | 26 000 $m^3$ | 4000 $m^3$ |

TABLE V. PERSONNEL DOSE

| Plant | Dose (man·Sv) |
|---|---|
| Caorso | 6.0 |
| Garigliano | 4.8 |
| Latina | 4.1 |
| Trino | 3.8 |
| *Total* | 18.7 man·Sv |

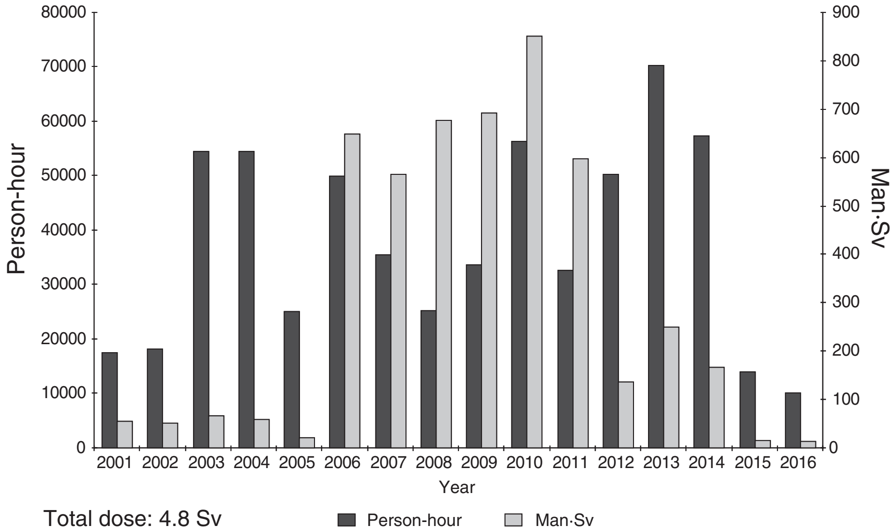


*FIG. 13. Person-hours versus dose for Garigliano NPP decommissioning.*

from plant decommissioning (e.g. non-homogeneous waste, HLW, etc). Repository waste acceptance criteria are not yet defined due to the lack of a body in charge of construction and management of the repository.

### 9.2. Licensing and EIA procedure

There has been a large effort to set up a licensing process for decommissioning. Different aspects remain to be defined, among which there is the procedure for the Environmental Impact Assessment (EIA) and its interaction with the licensing procedure. EC Directive 97/11, dated 3 March 1997, is now in force in Italy, but specific guidance must be set up for its application and possible interaction/interference with other national procedures.

### 9.3. National repository for the disposal of LILW

The availability of a national repository for the disposal of LILW is obviously a key issue that may strongly impact the decommissioning plans. A specific decree — for definition of the national repository siting procedure and the setting up of decommissioning regulations — has been recently issued by the Government. Progress in this area may greatly help to better define the boundary conditions for the entire decommissioning process.

### 9.4. Setting up an industrial framework in anticipation of the opening of the decommissioning market: Searching for international co-operation

SOGIN is trying to build up a network of co-operation with different potential partners (industries, utilities, universities, research bodies), both in Italy and abroad, to create possible synergies among the different areas involved in decommissioning activities. There is also the goal of building partnerships within the framework of an enlargement of the decommissioning market. Exchange of experience and information, and possible co-operation agreements, have been discussed with France, Germany, Spain, Sweden, UK and USA.

# REGULATORY APPROACHES AND SAFETY STRATEGIES
(Session 1.B)

**Chairperson**

**A.-C. LACOSTE**
France

# THE IAEA'S DECOMMISSIONING CONCEPT

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**Abstract**

The IAEA has been developing guidance and technical information relating to the decommissioning of nuclear facilities for over 20 years. During this time, the international concept of decommissioning, and its importance, has changed. The basic approach adopted by the IAEA is discussed in the paper. It also identifies issues that still require resolution at the international level.

## 1. INTRODUCTION

The decommissioning of nuclear facilities is nothing new. Decommissioning was performed in the early 1960s in the USA and has continued till today. The bulk of decommissioning activities still needs to be accomplished since a majority of the current operating facilities will permanently shut down in the next 40–50 years. The IAEA is currently performing a study to determine the liability that will be incurred throughout the next 50 years. This study will identify when resources will be needed to support this large effort.

## 2. DECOMMISSIONING PLANNING

The primary basis for the decommissioning process is the definition of decommissioning. The IAEA defines decommissioning as the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a nuclear facility. The key is that decommissioning results in the removal from control.

The typical life cycle of a facility is that it is designed, built, operated and eventually demolished. For facilities that use radioactive material, there is another element added, and that is the control of this material during all stages of the facility's life. There are many factors that can be incorporated into the design of a facility that can assist in the eventual implementation of the decommissioning strategy. These factors range from modular construction of massive shielding structures to the selection of the paint for walls. They can have a large impact on the overall complexity and cost of the decommissioning programme.

During the design phase of the building, the initial decommissioning plan should be prepared. The purpose of this plan is to capture these design considerations and to develop an initial cost estimate for the eventual dismantling or decontamination. The cost estimate is just one part of the decommissioning plan, but it is important for future considerations. There are many reasons for this initial cost estimate, but the primary reason is to know how much money must be collected during the facility's operation to ensure that the implementation of the decommissioning strategy can be carried out when desired and in a safe manner. Of course, many of the final conditions of the facility will not be known during the design stage, such as the final radiological status of the components, but educated assumptions can be made and documented in the cost estimate. As the facility operates, the decommissioning plan, along with the cost estimate, is updated to take into account changes in government policy, new technology, and changes in the facility condition. It is recommended that this update occur every five years. As information is collected, the assumptions in the cost estimate become facts. Approximately five years before the facility is scheduled to permanently cease operations, the final decommissioning plan is prepared and submitted to the regulatory authority for approval. Once it is approved, the implementation of the decommissioning strategy can begin.

There are many situations where the planning for decommissioning does not start until the plant shuts down. In this case, the planning should begin as soon as possible, while maintaining the facility in a safe condition.

## 3. DECOMMISSIONING STRATEGIES

Back in the 1980s and early 1990s, the IAEA identified three stages of decommissioning. The definition of these stages (identified as Stages 1, 2 and 3) was not completely clear. The end point of each stage was even less clear. There was some confusion as to what each stage meant and some did not result in a final solution.

In the mid-1990s, the IAEA adopted three decommissioning strategies: immediate dismantling, safe enclosure and entombment. These strategies have been well defined and are currently used in all IAEA safety standards.

### 3.1. Immediate dismantling

The implementation of the immediate dismantling strategy normally begins very soon after shutdown of the plant, usually within five years. All radioactive material above a specified level is removed and the end point of the project is that the site or facility can be cleared or used without any regulatory restrictions. This strategy allows the current work force to be used to perform the decontamination and dismantling activities. This work force, although reduced from the operating phase, remains fairly constant during the period. This option does not allow for any significant decay of radionuclides. It also implies that waste and spent fuel management, as applicable, must be available. This does not mean that a disposal site must be in place, but some type of waste management system (i.e. interim storage) must be available. Of course, the funding must also be available to allow the resources to be committed. This is the option preferred by the IAEA.

### 3.2. Safe enclosure

There might be cases where the final disposition of the facility may be delayed for a period of time. This decommissioning strategy is called safe enclosure (or sometimes safe storage or deferred dismantling). The facility is placed into a long term storage condition for up to 50 years, followed by the final decontamination and dismantling of the facility to allow removal of all regulatory control. To allow this storage period to occur, all of the liquids are drained from the systems, any operational waste that has been collected during the operational period is removed and areas not normally in need of access during the storage period are secured. This option does allow for the decay of radionuclides, but this is not normally the primary reason this strategy is chosen.

There are many advantages to this option. Some minor decontamination may occur and allow the boundary or 'footprint' of the controlled area to be significantly reduced, which will save money and other resources over the 50 year period. Portions of the facility or site may be used for other purposes. Large exclusion or buffer zones are no longer needed. This option also allows for the collection of funds over the safe enclosure period.

There are also some disadvantages to this strategy. The work force will be drastically reduced during the storage period. This means that the operational workers will have to find other employment. When the final phase approaches, workers will have to be rehired, but after 50 years, most of the experienced personnel will not be available. Also, as the operational workers leave the plant, the facility and operation knowledge leaves with them. There must be some system in place to capture and retain this knowledge.

Spent fuel may also be an issue. It is preferred that all spent fuel is removed from the site before the long-term storage period begins. This reduces the safeguards and security concerns and allows for a large reduction in the overall risk of the facility. It also reduces the number of systems that must be maintained to ensure safety during the 50 year period.

The safe enclosure option is normally selected if a national waste management strategy is not in place. This allows time for a final solution for the waste issue to be resolved. This option is also selected if sufficient funds are not available to support the dismantling activities. It may be the preferred option if there are multiple facilities on the site which will require decommissioning. This allows better allocation of resources when they are needed, because workers can go from one facility to the next performing decommissioning activities and the work force remains more stable.

### 3.3. Entombment

The last decommissioning strategy is entombment. In this situation, the overall controlled area is reduced and the remaining radioactive material is encased on-site, normally in concrete. The remaining structure must be monitored and maintained for a period of time. This site essentially becomes a near surface waste repository. All the requirements for such a waste repository will have to be met, to include the siting and design requirements. It has been found that most sites for nuclear facilities will not meet these requirements. However, this may be an acceptable option for countries with very small nuclear programmes that include just a research reactor.

## 4. ISSUES

The IAEA has identified a number of issues that relate to decommissioning activities. It is felt that these issues are serious enough that they should be addressed in some detail.

### 4.1. Status of nuclear facilities

The first issue is the status of shut down facilities. The IAEA publishes a Reference Data Series publication on nuclear research reactors in the world [1]. As of September 2000, when the last version of this publication was issued, there were 283 operational research reactors, with 106 having been decommissioned and 254 shut down. Our concern is the real status of these shut down reactors.

There is no consistency or clear definition of what constitutes a ‘shut down’ reactor. This can range from being shut down for refuelling or maintenance to being permanently shut down and in a state of safe enclosure.

If the decision has not been made to permanently shut down the facility, it should be considered as still being operational. Once the decision has been made that the facility will not be operated in the future, then the classification can change to decommissioning. However, this does not mean that the facility is abandoned and that no further control is required. According to IAEA definitions, the implementation of a decommissioning strategy should begin at this point. If the facility is already shut down, the decommissioning planning process should begin immediately. During this process the facility must be maintained in a safe condition and still meet any licensing conditions.

The general consensus is that at least half of the identified ‘shut down’ research reactors are no longer operational, but decommissioning planning and implementation has not been started. This is a serious concern, as funding is normally reduced, thereby leading to a reduction in the monitoring of safety conditions, and further leading to potential safety concerns.

### 4.2. Availability of resources

The second issue is the lack or insufficiency of the appropriate resources when needed. A number of nuclear facilities changed ownership when the former Soviet Union broke up. The newly independent countries inherited facilities, but without the proper resources for their eventual decommissioning. With many of these facilities, decommissioning planning was not started when they were transferred to the new countries. This is also the case for many developing countries. As a result, the planning starts late in the facility’s life, or even possibly after the facility stops operation. This does not allow the collection of funds that are needed to implement the decommissioning strategy. Also, as described previously, when a facility stops operation, there is no longer any income and the owner must rely on other sources for funds to maintain the facility.

Another resource problem is the retention of qualified personnel. When a facility stops operation, the future of employment becomes in doubt. Many people will try to find employment at other facilities and leave the area. Normally, the best qualified people are offered new positions first. This means that incentive programmes must be in place, which will help ensure that the well qualified people stay until the end of the decommissioning project. This can be accomplished in the form of an incentive pay and possibly a completion bonus that is paid if the individual stays until the project is completed. Without a proper programme in place to ensure that resources are available when needed, the facility will deteriorate to a point where it becomes a safety concern.

### 4.3. Availability of the waste management route

Many countries do not have waste disposal sites available for the waste that currently exists or has been generated during the operation of the facility. Their solution is to store this waste for an indefinite period. This also applies to spent fuel from nuclear power plants and research reactors. It is normally kept in the storage pool until a decision is made. The problem is that, in many cases, the decision on the final disposition of waste and spent fuel is always postponed.

Even if a country does have a waste disposal site, there is no guarantee that it will be able to accommodate the waste from decommissioning activities. Normally, decommissioning will generate more waste than was generated during the operational period. Many disposal sites were not designed to handle this large amount of additional waste. Another point is that different waste streams with different chemical, physical and radiological characteristics may be generated during the decommissioning process that were not generated during operation. The capabilities of the existing waste disposal sites must be carefully reviewed to ensure that they will be able to safely allow disposal of these new waste streams.

If a disposal site is not available, the waste must be placed into a temporary waste storage facility. Again, these storage facilities are not normally designed to accommodate the large amount of waste generated during decommissioning activities. This means that new facilities may have to be constructed. Of course, these facilities will also have to be decommissioned some time in the future, thereby requiring more resources to be available.

So what is the solution? Many countries adopt a 'sit and wait' strategy. This is not acceptable. An aggressive programme must be developed to ensure that funds and properly trained personnel will be available when the implementation of the decommissioning strategy is started. It also means that an integrated waste management programme must be developed as soon as possible.

### 4.4. Removal of material from control

Probably the most important issue concerning decommissioning is when work is finished and it must be determined what can be thrown away as everyday waste and what has to be controlled from a radiation protection standpoint. This issue has been around for over 20 years. Many organizations have tried to solve this problem, with limited success.

As stated earlier, many of the waste disposal sites do not have sufficient capacity to accommodate the large amounts of material that will be generated as a result of decommissioning. The logical solution is to minimize this waste and dispose of as much as possible in commercial landfills. No matter what approach is used to try and accomplish this, i.e. decontamination, volume reduction, administrative controls, etc., the final outcome is: what is the definition of clean material? It must also be recognized that much of the material coming from a decommissioning project could be recycled if appropriate conditions are met.

The IAEA is developing a new safety standard that will address this issue, along with a related issue concerning the international trade of commodities. Much of the material released as a result of the decommissioning of a nuclear facility, i.e. metal, can be traded or sold on the commercial market. This new standard will provide guidelines as to when, and under what conditions, material can be removed from regulatory control. These guidelines will also define when material does not enter regulatory control in the first place.

### 4.5. Types of facilities

Most activities associated with the safety of nuclear facilities focus on nuclear power plants and research reactors. This has also been the case concerning decommissioning, which is logical since a nuclear power plant represents the greatest risk during operation, and during decommissioning there is a large commitment of resources. Some attention is now being focused on other large facilities such as fuel reprocessing plants and enrichment plants; however, the smaller facilities are largely ignored.

These smaller facilities may range from single room laboratories to large research and manufacturing plants. The types of research facilities include those of pharmaceutical companies, accelerators, university laboratories and medical facilities. There are many industries that use radioactive material in the manufacture of commercial products. Some of these products include smoke detectors, optical equipment, paints, watches, light bulbs, camping supplies, instrument dials and aircraft parts. All of these facilities need to be controlled and eventually undergo some type of decommissioning activity. The USA alone has over 15 000 licensees, and at least 10% of them will require decommissioning to some extent. Many other developed countries have similar facilities in comparable numbers. The cost of decommissioning these facilities ranges from a few thousand dollars to a few million dollars each.

The IAEA is currently performing a study to determine the decommissioning liability for the next 50 years. This study includes nuclear power plants, research reactors, research facilities, weapons plants, fuel cycle facilities and commercial facilities. Initial findings show that the cost to decommission these facilities could be close to a half trillion dollars over the next 50 years.

### 4.6. Safety standards

As mentioned earlier, the IAEA has recognized that decommissioning is an important safety issue and has integrated this topic into its set of safety standards. A Safety Requirements [2] volume was published in 2000 and three Safety Guides [3–5] were issued in 1999 and 2001. Over 20 Safety Reports and Technical Reports dealing with specific aspects of decommissioning have also been issued.

## 5. SUMMARY

Decommissioning is an important part of the overall life of a nuclear facility, one that is often neglected. The IAEA sees decommissioning as starting during the planning and design phase for a facility and not when it is permanently shut down. The primary objective of decommissioning is the protection of human health and the environment when the services of the facility are no longer needed.

It must not be thought that since planning for decommissioning did not start at the facility conception that it cannot be started later. The decommissioning process can be entered at any time, though the sooner the better. The proper passage of control from the operating to the decommissioning organization is an important process. This is a time when worker morale is low, funding is reduced and the greatest number of uncertainties exist.

There are still a number of issues that need resolution. It is the responsibility of the entire nuclear community to work together to assure the public that the life cycle of a nuclear facility can be safely closed.

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# CO-OPERATION AND CONSENSUS IN THE DEVELOPMENT OF DECOMMISSIONING APPROACHES

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**Abstract**

Decommissioning is an issue facing most of the developed countries with ageing nuclear power plants. However, the concept of transforming a regulated nuclear activity or facility to one that is no longer active or operational is a goal not limited to nuclear power plants alone. In some cases, the restoration of legacy sites and sites contaminated by natural radioactivity from non-nuclear resource development also falls under this broader transformation goal. The international technical community recognizes this need to decommission nuclear facilities to result in better protection of workers, the public and the environment, and to do so in a more cost efficient manner. Whether the aim is termed 'decommissioning' or whether decommissioning is part of this broader goal of safety and environmental protection, the focus is the same: maintaining consistent levels of radiation safety and protecting the environment. The global community recognizes the need to address decommissioning within a waste management programme by including it under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (Waste Convention). The recommendations by international organizations (the IAEA, OECD Nuclear Energy Agency, International Commission on Radiological Protection, European Commission) include decommissioning and, in most cases, restoration of contaminated sites as part of a regulatory infrastructure for radiological protection and radioactive waste management. From these recommendations, individual countries can establish national regulations to protect individuals and the environment within the context of each nation's range of options, whether they are limitations on waste disposal strategies or resource (e.g. financial) limitations. Although an international goal may be uniformity and harmony in setting decommissioning requirements — and the international community is making great progress on that front — the higher objective is timely decommissioning. Flexibility within the national regulatory frameworks will help each nation reach that higher objective, leaving the environment cleaner for future generations than would otherwise be the case.

## 1. INTRODUCTION

Let me begin by mentioning what a pleasure it is for me to be here today and to have the opportunity to share my thoughts on this very important topic. I also want to extend my appreciation to the IAEA and our German hosts for formalizing and sponsoring this effort, as well as to welcome all of you that are participating in the week' s events.

I can see by the diversity in the number of countries in attendance that the international community has a sincere collective interest in the establishment and implementation of a sound infrastructure to safely manage our legacy and future decommissioning wastes. We are all here because we do recognize that it is an international responsibility to safely manage these wastes in a way that reasonably assures adequate protection to the worker, the general public and the environment, for both our present and future generations. We are also here to address the fundamentals that are needed for establishing, implementing and integrating decommissioning programmes so that site remediation can take place effectively and efficiently.

Over the years, the progress that has been achieved in the area of decommissioning and environmental restoration is due, in large part, to the consensus and co-operation forged by the collection of efforts among international and national organizations to rehabilitate facilities and sites located throughout the global community. The collective representation and efforts of international bodies such as the IAEA, the International Commission on Radiological Protection (ICRP), the OECD Nuclear Energy Agency (OECD/NEA) and the European Commission (EC) recognize that in order to facilitate better protection of workers, the general public and the environment, the decommissioning of ageing and/or non-operational nuclear installations needs to be conducted.

In the USA, as is the case in many other countries, the situation is complicated. There is a diverse range of entities with vested interests and active roles in areas involving decommissioning and environmental restoration, which I will discuss later. I believe this collective assembly of international experts shares a common vision with respect to decommissioning and restoration, and has set into motion a vertical structure for radioactive waste management under which decommissioning and restoration are included. The top of this structure is led by international treaties such as the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management (Waste Convention), and is complemented by related regulatory fundamentals, standards and guidance. In this fashion, the international regulatory community has constructed a top to bottom template for establishing a regulatory system for managing radioactive waste in general, and decommissioning in a more focused sense. Following along these lines, many Member States have put into place a similar set of laws, regulations and guidance.

This conference forum will serve as an opportunity for all of us to discuss decommissioning in general, as well as specific component issues such as timeliness, finality and institutional considerations, to name a few.

## 2. INTERNATIONAL ENVIRONMENT

Whether the aim is termed 'decommissioning' or whether decommissioning is part of the broader goal of safety and environmental protection, the focus remains the same. Specifically, that is to maintain reasonable and consistent levels of radiation safety and protection of the environment. Recognizing that there may be differences in the terminology chosen or the process utilized by which each nation arrives at safe and stable termination practices or in the remediation strategy associated with interventions, I remind you that such differences should only be viewed as preferential nomenclature as long as the fundamental objective is to return a site or facility to a safe and, if possible, beneficial state. Whether decommissioning is part of the radioactive waste management programme or a separate element of the cradle to grave spectrum of a practice, we should not let terminology or regulatory distinctions hamper the focus in mind.

I have already mentioned several of the international organizations with efforts fostering this focus. Because whatever efforts they have under way will be subjects of discussion throughout this conference, I will mention them occasionally during the remainder of my comments. I will briefly discuss the complex system in the USA and then get into some of the policy and technical issues we face.

## 3. THE STRUCTURE IN THE USA

In the USA, we have a number of organizations which have an investment and a role in the decommissioning and remediation of both legacy and non-legacy sites. For example, the National Council on Radiation Protection and Measurements (NCRP) has a similar role at the domestic level in the USA to that of the ICRP at the international level, and works closely with the ICRP in addressing radiation protection strategies and approaches. Specifically, the NCRP provides recommendations to assist in the formulation of the technical basis for radiation protection efforts in the USA.[1] Governmental organizations,

[1] The NCRP's web page is: *http://www.ncrp.com*.

industry and other non-governmental groups solicit the NCRP for guidance and information with respect to their specific radiation protection programmes and activities.

In the same vein, the US Federal and State regulatory community also has access to independent expert bodies such as the National Academy of Sciences to provide independent advice, insights and support in waste related and decommissioning areas. Additionally, the Health Physics Society, the Conference of Radiation Control Program Directors (CRCPD) and the Organization of Agreement States (OAS) are examples of other organizations that cut through institutional boundaries to provide a balanced approach in addressing issues important to the use of nuclear materials in US society at the national and regional levels.

These organizations of excellence provide two important services to the US regulatory and stakeholder communities with respect to decommissioning and environmental restoration. They provide:

— A national level of expertise for guiding regulatory authorities and developers in the safe conduct of nuclear activities, including facility decommissioning;
— An objective venue to deliberate the pros and cons of decommissioning strategies and approaches.

The US regulatory infrastructure for decommissioning is, however, of a hybrid nature in that there is no one agency that is completely responsible for the entire decommissioning spectrum. From the US perspective, this makes international consensus achievement quite impressive. Although there is regulatory diversity in the USA, our regulatory fabric is held together by laws and past experience, which help us manage the challenges in controlling the use and application of radioactive materials, both within our confines and abroad. As we move in a direction where nuclear power installations and other regulated facilities may need to be decommissioned, we must ensure that:

— Decommissioning will be performed in a safe and environmentally sound fashion,
— Safe decontamination and subsequent beneficial reuse is realistically considered,
— There are sufficient disposal options available for the resultant radioactive wastes.

Within the USA, the division of roles and responsibilities addressing the control of practices and the conduct of interventions generally sits as follows. The US

Nuclear Regulatory Commission (NRC) has the primary regulatory role in regulating practices relative to commercial nuclear facilities and operations, which primarily includes power reactor, as well as conversion, enrichment, fuel fabrication and medical and other industrial facilities. With respect to decommissioning, the NRC has a more expanded role, which also includes regulatory involvement with its sister agency, the US Department of Energy (DOE). Our involvement with the DOE includes activities such as the Yucca Mountain High-Level Waste Repository, the West Valley Demonstration Project and the MOX Fuel Fabrication and Reactor Operations. Additionally, the US Environmental Protection Agency (EPA) has primary responsibility for addressing and establishing generally applicable public health and environmental standards, so at times the EPA has issued regulatory standards for practices which the NRC has been required to adopt and implement on its licensed community.

However, the DOE does maintain the lion's share of responsibility for the remediation of legacy sites resulting from nuclear defence related programmes. Frequently, other Federal agencies such as the US Army Corps of Engineers, the US Geological Survey and the US Department of Transportation are collectively involved in the final resolution of site and facility cleanup and remediation activities at these sites.

A nuance to all of this involves certain situations and specific conditions, whereby the NRC can relinquish its regulatory authority to individual States within the USA, based on their ability to adequately regulate the possession and use of certain radioactive materials within the State's border. However, neither nuclear power plants nor their related operations are included in any such delegation of regulatory authority. Additionally, to ensure that a State continues to implement adequate requirements and effective protective measures, and maintain the requisite resources and expertise for effective programme implementation, the NRC maintains oversight controls over any State to which the NRC relinquishes its regulatory responsibilities. During this conference you will continue to hear from other speakers who will address in more detail the role of regional authorities in the USA, as well as the respective infrastructure for which decommissioning and environmental restoration operations are carried out.

## 4. INTERNATIONAL FACTORS AND A NATIONAL DECOMMISSIONING STRATEGY

When developing or amending national regulatory infrastructures, one should take advantage of the available experience, data and recommendations based on the accomplishments of the international nuclear community. Utilizing this information would not only serve to help formulate a sound technical basis, but also aid in facilitating a more harmonized approach to radiation protection in general. However, existing climates, environments, resource availability and politics may result in some differences affecting the way systems are implemented. It should also be noted that differences in terminology in which the same word may lead to different interpretations could potentially affect the development of legislative and regulatory infrastructures. Although not necessarily a safety related issue, it is an implementation nuance that could be of significant importance within a given national regulatory programme, which could lead to misunderstandings among Member States. A prime example, as expressed in the Waste Convention, is the need to explicitly address both radioactive waste and spent fuel.

Approaches to conducting facility decommissioning could also vary depending on Member State interpretation and perspective. Ultimately, this may be the result of whether a national authority would adopt the international view that decommissioning is part of the overall pre-disposal radioactive waste management system, or view environmental restoration within the realm of an intervention. However, in some instances decommissioning and environmental restoration are viewed as both returning facilities and sites to uncontrolled or unrestricted use conditions, without distinguishing whether the activities are practices or interventions.

This issue becomes more noteworthy when the criteria for compliance are factored into the overall picture. For example, restoration of a contaminated land area to the ICRP 82 suggested constraint of 0.30 mSv/a (30 mrem/a), as opposed to the target for clearance of 10 μSv/a (1 mrem/a), represents a vast difference, both in the resultant doses as well as in the resources needed to achieve compliance — saying nothing of the difference in the volume of radioactive waste inventories generated for disposal.

From another perspective, separating decommissioning and restoration could prove to be counterproductive if different dose levels are utilized. For instance, different dose protection levels create a perception of non-uniform levels of protection, which in turn may be *perceived* to correspond to significantly inconsistent risk levels. Furthermore, in cases where significant efforts would be needed to comply with inordinately stringent dose constraints, alternative strategies could raise the impression of regulatory disparity or environmental inequity. The perception may be that cleanup is held hostage to economics and, as a result, national authorities would more likely rely on the use of institutional controls. If a more realistic level is used, remediation could be accomplished by utilizing the ICRP optimization approach, which would foster safe, environmentally sound and more feasible cleanup levels. As a result, the path to co-operation and consensus will need to be pursued actively from both the national and international deliberation arenas.

From the perspective of the international arena, the Waste Convention provides the prime focus in establishing the venue and mechanism for safe and environmentally sound management of spent fuel and radioactive waste. Subsequent symposia, such as the IAEA International Conference on the Safety of Radioactive Waste Management, held in Cordoba March 2000, the current conference, and the IAEA conference on Issues and Trends in Radioactive Waste Management, held in Vienna in December 2002, all provide an incremental push to achieve consensus in areas of decommissioning and environmental restoration.

Most international organizations and Member States acknowledge the role of intermediate or prolonged storage as part of the overall decommissioning strategy. Certainly, where deferred actions would result in advantages from short lived radionuclide decay, serious consideration would be merited. Although the international expert community has provided a radiological framework for individual nations to utilize for successful decommissioning, as well as to promote regulatory harmonization among Member States, we must realize that the path to global success in this area may not always be so direct or effortless.

## 5. OTHER CONSIDERATIONS

Most of you are aware of, if not already involved with, the effort to reassess how the radiological protection community addresses environmental protection. In this area, the ICRP, OECD/NEA and other organizations have established efforts leading to an evolution of how we assess the impact to the environment from practices and, for that matter, interventions (e.g. doses to biota). For example, the EC has established a requirement for environmental review and the USA has had law in place since 1969 (the National Environmental Policy Act — NEPA). Within the USA, all facets of society are bound to perform a NEPA analysis in cases where the proposed activity may impact the environment. Even a majority of US Federal agencies have NEPA obligations and are required to conduct a NEPA analysis to accompany the promulgation of their regulations. Another milestone in the unfolding role of environmental protection includes the ongoing ICRP effort to provide a framework for protection of 'Non-Human Species from Ionizing Radiation'.

So far, I have primarily addressed what is needed, or I should say desired, purely from the approach, strategy and consistency stand points. However, the fundamental complement that is most essential in linking progress toward any decommissioning final end state is disposal capacity availability. Without such availability there is no final end state. On this front, progress has been made in moving toward increasing the feasibility of such availability within the next decade or so. Specifically, with the DOE Yucca Mountain site recommendation being approved by President Bush and both of the US Houses of Congress, complemented with the progress made in Finland towards the licensing phase of the geological disposal of spent fuel wastes, these decisions have created more optimistic climates regarding the future of nuclear power. Removing this barrier brings forth options for resuming a balanced energy strategy for some countries and the only reliable energy strategy for others. This is most favourable for the decommissioning of ageing nuclear power reactors; however, decommissioning also requires access and capacity for the disposition of low and intermediate level radioactive wastes. Progress in many countries, such as France (L'Aube), Sweden (Forsmark), Germany (Konrad) and the USA (Barnwell, Nevada Test Site), in this area makes the accomplishment of successful decommissioning more feasible.

Due to issues such as limited or unavailable disposal capacity, decommissioning and environmental restoration are often exacerbated by uneven or disrupted regulatory control. Additionally, if the regulatory framework fails or is inconsistent in its function, the scope and extent of decommissioning or cleanup becomes more complex. The control of sources is a ready example of this situation. The problems, such as in Goiânia and many other examples, remind us of how the scale of decommissioning is often directly related to the degree of control of the spread and dispersion of radioactive materials.

Up to this point, the focus has been on the regulatory community — both international and national. A very important factor in the successful implementation of a national decommissioning framework is to provide access to and to gather input from stakeholders such as the general public. In this area, national authorities have generally had more exposure and experience than international organizations, most of this being attributable to the fact that an international organization such as the IAEA would face much difficulty in lending a formal voice to the general public living amongst its Member States. However, international organizations do acknowledge the importance of providing a path for stakeholders into the deliberations of a nation's nuclear energy policy development, but providing advice on the international level is difficult due to the range of cultural and geographical diversity. What works in one country may not serve as the appropriate template for another, which brings forth the realism that consensus and uniformity may need to be tempered with reality and geographical equity.

## 6. SUMMARY

Although my remarks addressed the progress made in decommissioning and environmental restoration in the broad conceptual sense, there is also an underlying theme of flexibility for national implementation. For example, and to reiterate a prior point, although terminology may differ from country to country, the focus of maintaining consistent levels of radiation safety and protecting the environment remains the same. Regardless of one's preferred nomenclature, the concept of transforming contaminated sites or facilities into ones that are clean and safe clearly is in the best interest of all of us, as well as of our future generations. In ending, let me offer the words of Albert Einstein in stating: "The significant problems we face today cannot be solved by the same level of thinking that created them."

# REGULATORY CHALLENGES IN THE DECOMMISSIONING OF NUCLEAR FACILITIES IN THE UNITED KINGDOM

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**Abstract**

The UK nuclear industry has, since the 1940s, worked extensively on the development of nuclear technology, both civil and military, and this activity has left a significant legacy of ageing nuclear liabilities for the present generation of operators to manage safely. On the older nuclear sites these liabilities include hazardous quantities of radioactive waste, and other material, stored within a decaying building infrastructure. As time passes more of the older commercial nuclear power stations are ending production and adding to the overall decommissioning task. The safe decommissioning of this historic legacy is presenting a unique challenge to operators and regulators alike. The Health and Safety Executive's Nuclear Installations Inspectorate (NII) is responsible for the regulation of safety and radioactive waste management for the UK's 40 licensed nuclear sites. The nuclear licences the NII grants place responsibilities on the operators that continue, throughout operation and decommissioning, until a site is cleaned up to the extent that it can be delicensed and released for unrestricted use. In the last few months the UK Government has outlined its intention to make radical changes to current arrangements through the formation of a new body, the Liabilities Management Authority, which will take ownership of the bulk of the UK's nuclear liabilities and manage the decommissioning programme. The programme for decommissioning will run for more than 50 years and will need the provision of a very large amount of public money. It will also require effective strategic planning and project management if it is to be carried out successfully. At the same time there will be changes in the industry's organization and workforce, and different skills will be needed. The paper describes the nature of the challenge these changes are presenting to the NII, and how it is responding. Above all the NII recognizes that it must work together with the other organizations, and contribute to achieving the common goal of making the UK's nuclear sites safe for future generations.

## 1. INTRODUCTION: THE DECOMMISSIONING CHALLENGE

Thank you for giving me the opportunity to share with you my view of the regulatory challenges arising from the decommissioning of nuclear installations in the UK. The UK's nuclear industry dates back to the 1940s; in those days it concentrated primarily on the development of nuclear weapons. Later, in the 1950s and 1960s, nuclear power stations began to be built to supply electricity to the national grid. At that time there was a considerable research and development programme for new nuclear technology, including the construction of several prototype nuclear reactors and fuel reprocessing plants. The first generation of commercial nuclear power stations were based upon the gas cooled military reactors, now known as the Magnox reactors. This was followed by a second generation of more efficient advanced gas cooled reactors. The last nuclear power station constructed in the UK was the single pressurized water reactor at Sizewell B, which went critical in 1994.

In more recent times, we have seen a decline and virtual halt in large scale research to support nuclear power, but over 50 years of nuclear operations has left the UK with a legacy of ageing and redundant facilities on its nuclear sites. The focus of the nuclear industry, including the UK Atomic Energy Authority (UKAEA) and British Nuclear Fuels plc (BNFL) in particular, is now turning increasingly to decommissioning and clean-up work. This is challenging work because most of the facilities were designed, and operated at a time when operational priorities and regulatory requirements were different to those that apply today, and little thought was given as to how they would be decommissioned in the future. Many of the redundant facilities are unique in design and their clean-up and decommissioning pose significant technical challenges. These facilities contain considerable quantities of radioactive waste and other radioactive material that need to be managed safely until decommissioned.

In July 2002, the UK Government published a White Paper that outlined its intention to make radical changes to the arrangements for the management of the extensive public sector nuclear liabilities and the clean-up of the nuclear sites. These changes are intended to reflect the scale of the technical and managerial challenges that this task involves and the Government's priority that it should be carried out safely, securely, cost effectively and in ways which protect the environment. These changes will inevitably lead to further structural change within the nuclear industry and the arrangements for carrying out work on the nuclear sites.

The Health and Safety Executive's Nuclear Installations Inspectorate (NII) is responsible for regulating safety and radioactive waste management on the licensed nuclear sites. The difficulties and changes outlined above demonstrate how the decommissioning and clean-up activities will continue to present significant challenges to the NII in fulfilling its regulatory role. In the rest of this paper I will describe the nature of the challenges in more detail and indicate how we are changing to face them. Above all we recognize that we must continue to carry out our regulatory duty to ensure safety, but that we must do it in a manner which contributes towards the achievement of the common goal of making our nuclear sites safe for future generations, so that our children and grandchildren will not have to face the difficulties we are facing today.

## 2. FRAMEWORK FOR SAFETY REGULATION

The Health and Safety at Work Act 1974 and the Nuclear Installations Act 1965 (as amended) together give the NII considerable powers to regulate safety on nuclear sites. The Health and Safety Executive (HSE) has delegated to Her Majesty's Chief Inspector of Nuclear Installations the power to grant licences [1] to operators for the purpose of installing or operating any nuclear installations. Once a licence has been granted the licensee's responsibility under the Act continues throughout construction, commissioning, operation, and decommissioning, until HSE is satisfied that there is no longer any danger from ionizing radiation from anything on that site. There are currently 40 licensed nuclear sites in the UK.

At any time NII may attach conditions to the site licence if it believes they are in the interest of nuclear safety or the handling, treatment or disposal of nuclear matter, which includes radioactive waste. The standard licence conditions are essentially goal setting and many of them require the licensee to make and implement adequate arrangements to address safety and, consequently, the conditions apply equally well to the decommissioning phase of nuclear facilities. The NII keeps the licence conditions under review and does make changes if it believes they are needed to maintain and improve standards of safety. Although all 36 of the licence conditions apply during decommissioning, I would like to discuss three of the conditions that are particularly relevant to the subject of this paper in more detail.

Firstly, there is Licence Condition 34, which requires operators to ensure that radioactive material and radioactive waste on the sites is at all times adequately controlled, or contained, so that it cannot leak or escape from control. In terms of the radioactive waste that results from decommissioning, and for which there is no immediate disposal route, operators can comply with this condition by placing the material in a passively safe form suitable for long term storage.

The penultimate condition, Licence Condition 35, requires operators to produce and implement decommissioning programmes. Under this condition the NII has the option of approving the programmes, which then cannot be changed without further approval. It specifies that, where appropriate, decommissioning shall be divided into stages, and the NII has the power to specify that a licensee shall not proceed to the next stage without its consent. Furthermore, it gives NII the power to direct an operator to commence, or halt, decommissioning if it is in the interests of safety. This condition, therefore, gives the NII appropriate regulatory control over the planning and implementation stages of decommissioning projects.

The pace of organizational change in the nuclear industry, and the effect it may have on safety, led NII to introduce the most recent condition, Licence Condition 36, in 1999. This condition requires operators to justify the safety of any proposed change to its organization's structure or resources. This is very relevant when decommissioning programmes begin and the extent and type of work on a site can lead to significant changes in the workforce. The NII expects an operator, who is the licensee, to remain in control of operations on its site at all times, and to do so it must retain the necessary resources and competence to understand the hazards and how to manage them. NII has no objection to the use of contractors, but it does become concerned if a licensee proposes to contract out its core functions. The basic premise is that a licensee must retain the ability to act as an intelligent customer [2] for work that is procured.

For relatively new facilities, those designed and built over the last 20 years, NII has insisted that the needs of decommissioning be taken into account at the design stage. The consideration of the choice of materials, decontamination, access, and the treatment of waste arisings and the preparation of an outline plan, at this stage should ensure that when these facilities are decommissioned the industry will not encounter the same problems it is facing today with the legacy facilities.

In general terms, NII's regulatory policy is that risks to the public and workers from operations on nuclear sites should be reduced as low as is reasonably practicable, and this includes decommissioning work. In some instances it is unavoidable that decommissioning work will lead to temporary increases in risk, while radioactive material is retrieved, or plant is dismantled. NII is prepared to sanction these temporary increases in risk, as long as they are adequately assessed and controlled, and if the completion of the work will lead to a reduction of the hazard on a site and lower overall risks in the longer term.

NII works closely with the other regulators in the UK, who have the responsibility for regulating nuclear security and the protection of the environment. The Environment Agency in England and Wales, and the Scottish Environment Protection Agency in Scotland, regulate the disposal of solid radioactive waste and the discharge of radioactivity in liquid and gaseous effluent from nuclear sites, under the Radioactive Substances Act 1993. The Government has published its strategy [3] to implement the objectives of the OSPAR radioactive substances strategy agreed at the 1998 ministerial meeting of the OSPAR Commission. The strategy aims for progressive and substantial reductions in the radioactivity in discharges from nuclear sites. However, experience has shown that in some instances the decommissioning of facilities may only be practicable if temporary increases in discharges are allowed, and this has been recognized in the Government's strategy. As a result, recognizing their different responsibilities, the safety and environment regulators are making strenuous efforts to work together to regulate activities such as decommissioning in a robust and co-ordinated manner. The NII has a similar relationship with the Office of Civil Nuclear Security, which is the regulator for the security issues concerning civil nuclear sites.

We recognize that as a regulator facing a changing world we must adapt our regulatory approach to match the changes and we are fortunate that the Nuclear Installations Act gives us the flexibility to do this. We strive to be aware of the needs and views of our stakeholders, including the public, and to be open in our regulatory work. Wherever possible important outcomes, or decisions in our work are published, either as reports or by placing documents on the Internet. Increasingly, we are seeking to place the guidance we produce for our inspectors on the Internet so that anyone who wishes to can better understand our expectations. Specific guidance on decommissioning, radioactive waste management, and safety cases [4–6] has been at the forefront of this initiative.

## 3. RADIOACTIVE WASTE MANAGEMENT

I have already described how the historic military and nuclear power development programmes have left the UK with a legacy of nuclear liabilities. The redundant facilities that are part of this legacy contain significant quantities of radioactive waste and other material. Some of this waste has been treated and is stored in passively safe conditions but a considerable amount is accumulated in a raw form in facilities which are likely to deteriorate with time. In 1998, NII published a review [7] of the state of radioactive waste storage conditions across the nuclear sites in the UK. It concluded that, although the current situation was adequately safe and areas of immediate concern were being dealt with, many of the stores did not meet modern standards, and have limited lives. In the future a programme of retrieval and processing of radioactive waste and replacement, or refurbishment, of the stores will be required to ensure ongoing safe storage.

As the older facilities are decommissioned the radioactive waste they contain will be retrieved and arrangements will need to be made to manage it safely in the future. Some facilities also contain quantities of new and spent fuel and other fissile material, including separated uranium and plutonium. Whatever the outcome of the UK debate as to whether these materials should be classified as waste, or whether they will be reused at some time, they too will need to continue to be managed safely. Finally, demolition of the facilities themselves will produce further quantities of radioactive waste.

Although these wastes and materials exist as a result of the actions of the past, the responsibility for managing the legacy has fallen on our generation. There are a number of reasons why this is so. Firstly, in earlier times, priorities were very different to those that apply today, and less thought was given to how the by-products of the programme would need to be managed for the future. Secondly, for the last 20 years or more there has been a preference to not foreclose future options when managing radioactive waste, which encouraged a ‘wait and see’ approach to dealing with the problem. The main reason behind not foreclosing future options was the anticipation that an underground disposal facility would be constructed soon after the turn of the century that would be able to receive the radioactive waste. However, the developments of the last few years have made it clear that there is no prospect of such a disposal facility becoming available in the foreseeable future. As a result managing radioactive waste has become an intergenerational issue, and there is recognition that the present generation has a duty to take action to avoid leaving future generations with an undue burden.

Although low level wastes can be sent to the Drigg disposal site, and NII encourages this, there is no reasonable prospect of a disposal route for the more radioactive wastes. These wastes need to be put into a state of safe interim storage for an extended period. It is likely that this period of interim storage will last for several decades and NII believes it is prudent for the nuclear operators to assume a period of at least 100 years. To reduce the hazard it presents, radioactive waste that is in a mobile form needs to be retrieved and processed into a passively safe form. In most cases this means immobilizing it in a waste form that is physically and chemically stable, such as a cement matrix inside stainless steel containers, or another equivalent product, and placing it in a suitable storage building. Wherever possible the arrangements should minimize the need for active safety systems, monitoring and maintenance to achieve safety, although they should facilitate inspection and retrieval. Due consideration should be given to making waste forms that, on the basis of today’s knowledge, are likely to be acceptable for disposal in the future. This will reduce the possibility that future generations will have to rework, or repackage, the waste in order to dispose of it.

However, the perpetual storage of radioactive waste is not a sustainable practice and it does not offer a definitive solution for the future, it is simply an interim stage. In the UK the Government is reviewing its policy on radioactive waste management with the aim of developing a consensus on the long term solution to managing radioactive waste. As a first step it has consulted [8] on a programme for reviewing the options, and the nature of a decision making process which can promote public confidence. This is likely to lead on to a programme of research and public discussion, before the preferred solution is chosen. The time-scales that this process is likely to take reinforce our belief that operators should plan for a lengthy period of interim storage.

## 4. SITE RESTORATION

The NII has required all the nuclear operators to produce decommissioning strategies for their nuclear sites and to develop plans to implement those strategies. It has been assessing the operators' decommissioning strategies and plans for some years now. In some cases we have challenged the priorities and asked for the programme dates to be shortened where there are significant safety concerns.

These strategies need to cover the task from start to finish, which ideally should be to clean up the sites to the extent that they can be released for other use, although this might not be possible in all cases. They also need to be robust and flexible enough to take account of the uncertainties there might be with respect to the facilities, and to respond to external influences that may have an impact. Nuclear operators rightly strive to justify their preferred, and generally the most cost effective, solutions, but if these fail to be realized for any reason then they will need to have fallback options available.

The emptying, and dismantling, of nuclear facilities can produce significant quantities of radioactive waste and other material. It is therefore important to recognize that decommissioning and radioactive waste management are interrelated activities that must be co-ordinated, and that they will both need to be included in the strategic planning if projects are to be taken forward successfully. Experience has shown that decommissioning projects can be held up if a route has not been established for managing each of the categories of radioactive waste they produce.

## 5. DECOMMISSIONING CHALLENGES

The 40 nuclear licensed sites in the UK present a range of decommissioning challenges. In general, the smaller sites have facilities that present relatively small hazards and the regulator expects the operators to decommission them soon after operations cease. Typical facilities on these sites include low power research reactors and lightly contaminated buildings. A number of decommissioning projects of this nature have been completed and we have been able to approve the release of the land and facilities for unrestricted use.

At the other end of the scale, the main concentration of the nuclear liabilities and the greatest hazards reside on the Sellafield and Dounreay sites that are operated by BNFL and UKAEA, respectively. The development of strategies and planning for decommissioning on these sites has proved to be a complex task. Decommissioning not only involves the removal of existing facilities, it will require the design and construction of new facilities for the retrieval, processing and future storage of radioactive waste and other material. One of the major challenges has been to understand and take account of the interactions between individual facilities, both existing and planned, some of which cannot be shut down while they are required to support other parts of the decommissioning plan. Looking further than the individual sites, there may be connections between the strategies for different sites, if for example the preferred route is to process radioactive material, e.g. spent nuclear fuel, through facilities on another nuclear site. There are also situations, such as the need to manage relatively small quantities of experimental nuclear fuel, where more than one operator is facing the same kind of problem. In such cases we have encouraged the operators to consider whether it would be most effective for them to work together on a combined strategy, which could lead to them making use of a shared facility.

An example of the commitment that is required is provided by UKAEA, which has redefined its corporate objective to be the ‘environmental restoration’ of its nuclear sites. In 2000 it completed the Dounreay Site Restoration Plan (DSRP) [9], which is a major achievement, and the main vehicle for making the site safe for the future. As well as providing a strategic overview for the entire site, it includes a decommissioning plan, and strategies for managing all the radioactive waste and the nuclear fuel material on the site. Although the programme aims to complete decommissioning within a period of 55–60 years, some parts of the site will require care and maintenance for a period of 300 years. The DSRP is a major step forward, but UKAEA now needs to be focused on delivering the work, and managing the risks and uncertainties.

In the case of the Sellafield site, NII has pressed BNFL to develop comprehensive and integrated strategies that cover the decommissioning of the whole site, and that take into account the full extent of the retrieval, packaging and storage facilities that are required. BNFL is attaching a high priority to this area and is in the process of completing the strategic planning.

A further decommissioning challenge is presented by the Magnox power stations. The reactors on 5 of the 11 sites have now shut down and those on the remaining 6 sites are due to cease operation by 2010. After the nuclear fuel is transported from the site, the first stage of decommissioning is to clean out mobile radioactive material and remove plant outside the central reactor structures. The operator's intention is to place the remaining plant in an extended period of care and maintenance to take the benefit from radioactive decay reducing the hazard. After this period the rest of the plant will be dismantled and the site clean-up completed. The way the licensee will maintain safety on the site over this period, and the proposals for how long this period of care and maintenance should be, are issues that we are currently considering.

Having described some of the difficulties that decommissioning presents it is worth noting that experience in the UK has demonstrated that it can be carried out safely and in a manner that protects the environment. Two recent examples of successfully completed projects are the complete removal of a redundant nuclear fuel fabrication complex at BNFL's Springfields site, where the landscape has been restored to its original state, and the decontamination of plutonium handling laboratories at UKAEA's Winfrith site, where the buildings and land have been released for unrestricted use.

## 6. REGULATORY RELATIONSHIP WITH A LIABILITIES MANAGEMENT AUTHORITY

Implementing the decommissioning strategy to deal with the nuclear liabilities, and clean up the UK's nuclear sites, will require large measures of finance, resources and effective project management. It has been estimated that the clean-up programme will involve expenditure in excess of £40 billion, with annual expenditures of around £1 billion of public money. Furthermore, the workforce that will carry out the work will require scientific, technical and engineering expertise of a high order, together with the broader project and operational management skills necessary to undertake a task that will take many decades to complete.

Recognizing that current arrangements do not match this task, the Government has proposed the formation of a new body, a Liabilities Management Authority (LMA) [10], which will be responsible to Government, and will have a specific remit to manage the clean up of the nuclear legacy. It will be expected that efforts will be made to ensure that this work is done safely, securely, and that the public money is spent effectively. The LMA will set the framework for delivery of the programme, promote synergies between sites, encourage best practices and prioritize the deployment of resources. It will be

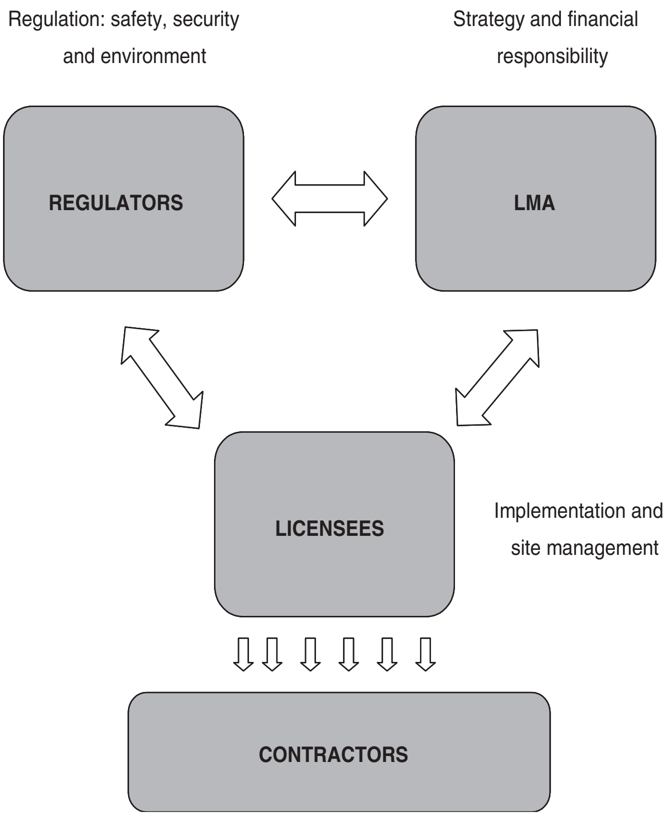


*FIG. 1. The triangle of relationships between the LMA, the site licensees and the regulators.*

a relatively small organization, with around 200 staff and it will not manage the nuclear sites. Instead, it will develop a competitive environment by setting up contract agreements, initially with the existing site licensees, for delivering the clean-up programme for each site.

Setting up the LMA will require new UK legislation, which the Government hopes to put in place by the year 2004. In the meantime, the Government has formed a Liabilities Management Unit (LMU), which is working to prepare the ground by seeking to build up knowledge of the nuclear liabilities and developing baseline strategies for the operation of the LMA. The LMU is in place and has begun its work with a staff of around 20, and the assistance of a partner–engineering contractor, Bechtel.

Clearly, these changes represent another new challenge for the regulators in the UK. The cornerstone of success will be the vital triangle of relationships between the LMA, the licensees and the regulators, as illustrated in Fig. 1, and these three different types of organizations will need to develop a common purpose to see the hazard potential on the nuclear sites progressively reduced and the safe discharge of the nuclear liabilities. To achieve this they will need to work together to set priorities and agree strategies and programmes. Licensees will be required to implement decommissioning and manage the sites in accordance with all relevant legislation and the prime responsibility for monitoring that compliance will continue to rest with the regulators, who will retain their existing powers to ensure the safety of the public, the workforce, security and protection of the environment.

The UK regulators have been closely involved in the development of the proposals for the LMA and we are committed to building the appropriate regulatory relationships. Agreements will need to be drawn up between the regulators and the LMA setting out how the relationships will work in practice. We recognize that we will need to concentrate on an open and constructive approach in order to encourage progress, rather than an adversarial approach, which can have the opposite effect. The challenge to the regulators will therefore be to develop effective ways of working with the LMA to deliver the overall joint decommissioning goals in a way that does not compromise their regulatory responsibilities or restrict their discretion in relation to regulatory or enforcement decisions. Only through effective and independent regulation will it be possible to maintain Government and public confidence.

In line with the regulatory framework described earlier, when the LMA is set up NII will seek to examine the strategy, work programmes and priorities that it defines, and to be sure that the LMA has properly qualified staff to fulfill its role. The new arrangements will stimulate changes within the organizations that act as site licensees and increased competition will lead to the use of contractors to carry out much of the work. NII will wish to be sure that safety is not compromised through organizational change and also that the licensees remain in control of their sites and act as intelligent customers for the services they procure. Normal regulatory activity will continue on the sites to ensure that operations are carried out in compliance with the site licence. The decommissioning work will need people with the appropriate nuclear and radiological skills. The regulators, industry and the Government are combining their efforts to seek ways to encourage new blood into the industry and to develop the skill sets that are required.

NII has already anticipated that it will need to change to face this challenge, and its internal structure will need to be adjusted, and strengthened. Providing a focus for the interface with the LMA and the regulation of £1 billion of decommissioning work each year on the nuclear sites will require more nuclear inspectors. This has been recognized and NII expects to expand accordingly.

## 7. CONCLUSION

In this paper I have summarized the main challenges that the decommissioning programme in the UK presents to the NII in carrying out its role as the regulator for safety and radioactive waste management on the licensed nuclear sites. The burden of decommissioning a legacy of ageing and redundant nuclear facilities has fallen on our generation and doing nothing is not an option. NII has accepted these challenges and will respond in a manner which contributes towards the common goal of making the nuclear sites safe for future generations.

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# REGULATORY APPROACH AND NUCLEAR SAFETY REQUIREMENTS FOR TERMINATION OF OPERATIONS AND DECOMMISSIONING OF NUCLEAR POWER PLANTS IN LITHUANIA

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**Abstract**

The decision to shut down Unit 1 of the Ignalina Nuclear Power Plant (INPP) was taken on 5 October 1999, when the 'National Energy Strategy' was adopted by the Seimas (Parliament). In the accession negotiations and according to the position statement, Lithuania has committed to the closure of Unit 2 by 2009. The European Union is in solidarity with Lithuania and is ready to continue to provide adequate additional assistance for the decommissioning effort even after Lithuania's accession to the European Union. The early termination of operations at INPP initiated an elaboration: of the policy; requirements; guidance; capabilities of the regulatory bodies; and technical support organizations in the area of decommissioning safety, waste management, disposal strategy, and the technology of dismantling. A legal basis has been promulgated and regulatory documents issued. Planning has been performed. However, a lack of experience specific to RBMK reactors, and limited financial and human resources, have created an environment of concern with regard to the current uncertainties. VATESI is looking forward to solving the remaining problems using the practices of other countries. The paper describes the activities of the Lithuanian authorities in the establishment of the regulatory framework, the approach for the licensing process, safety assessment of decommissioning projects, and overseeing the safety issues in the final phase of the entire nuclear fuel cycle.

## 1. INTRODUCTION

The Ignalina nuclear power plant (INPP) with its two RBMK-1500 reactors is the only nuclear installation in Lithuania. The functions of the operating organization are performed by the INPP. The regulatory body for nuclear safety is the Lithuanian Nuclear Power Safety Inspectorate (VATESI), for radiation protection it is the Radiation Safety Centre of the Ministry of Health. The Ministry of Economy, the founder of INPP, acts as the promoting organization and responsible for the elaboration of the 'National Energy Strategy'. VATESI is an entirely independent organization reporting on its activities to the Prime Minister.

The first unit of INPP went into service at the end of 1983, the second unit in August 1987. Their design lifetimes are projected to between 2010 and 2015. The ‘Preliminary Decommissioning Plan’, covering both units of INPP, was prepared in 1999 during the process of licensing Unit 1. This was the first attempt to license the RBMK reactor unit after an in-depth safety assessment using the methodology and practices of Western countries. The Preliminary Decommissioning Plan is the document setting out the actions for final shutdown and implementation of the decommissioning strategy, the decommissioning cost and the sources of financing, and the safety implications and requirements. This plan is to be updated periodically to take account of changing conditions.

After taking the decision to shut down Unit 1 before 2005, there is an urgent necessity to take additional steps in the preparation of regulatory documents in this area. The environment within which the development of the regulatory approach to decommissioning took place was:

- Early termination of the nuclear facility;
- No experience in decommissioning such types of reactor;
- Limited financial and human resources;
- Political decisions on the time of shutdown;
- Available support from foreign countries.

It was understood that the preconditions for successful decommissioning would be as follows:

- Overall priority for nuclear safety;
- Decommissioning as one of the phases of the complete nuclear fuel cycle;
- Sound financing arrangements;
- Availability of qualified staff;
- Remediation of the social impacts.

In accordance with the Lithuanian law for the decommissioning of Unit 1, a ‘Decommissioning Programme’ has been prepared. This links the legal, organizational, financial and technical measures which need to be in place to support the implementation of the decommissioning strategy for Unit 1. It also includes the preparation of laws and plans related to social and economic problems associated with shutdown and implementation of the strategy. The Decommissioning Programme forms the basis, and gives the milestones, for the preparation of the ‘Final Decommissioning Plan’.

The Final Decommissioning Plan will be a document setting out the actions for final shutdown, implementation of the decommissioning strategy, the decommissioning costs and the sources of financing, and the safety implications and requirements. The preparatory activities for the decommissioning of Unit 1 must be planned and finished before 2005. The Government will decide on the exact date for the permanent shutdown of Unit 1. This decision will consider the implementation of the Decommissioning Programme on the Final Decommissioning Plan and the possibilities of further financing from Lithuanian and international sources.

## 2. LEGAL FRAMEWORK

A number of laws and other legal acts were prepared and enacted in order to establish the appropriate legal framework for the safe use of nuclear energy. The main legal acts established since 1991 are:

— The Law on Nuclear Energy (1996);
— The Law on Radioactive Waste Management (1999);
— The Law on Radiation Protection (1999);
— The Law on Decommissioning of Unit 1 (2000);
— The Law on Ignalina NPP Decommissioning Fund (2001);
— The Law on Environmental Protection (1996);
— The Law on the Supervision of Potentially Dangerous Installations (1996);
— The Law on Environmental Monitoring (1997);
— The Law on Environment Impact Assessment of Planned Economic Activity (2000);
— General Safety Regulations for Nuclear Power Plants (1997);
— Basic Standards of Radiation Protection (1997);
— Regulations for Procedures for Issuing a License for Unit Operation at Ignalina Nuclear Power Plant (1997);
— The Regulations of the Licensing of Activities in Nuclear Energy (1997);
— General Requirements for the Decommissioning of Ignalina NPP (1999);
— Management of Radioactive Waste (for institutional radioactive waste); Regulation on the pre-disposal Management of Radioactive Waste at the Nuclear Power Plant (2001);
— Procedure of Natural Resource Exploitation Permit Issue and Setting of Norms on Natural Resource Exploitation Limits and Permitted Discharge into Environment (1999);
— Clearance Levels of Radionuclides, Conditions of Reuse of Materials and Disposal of Waste;
— Regulation on Preparation of Environmental Impact Assessment Program and Report (2000).

## 3. REGULATORY REQUIREMENTS FOR DECOMMISSIONING INPP

Under Article 25 of the Law on Nuclear Energy of the Republic of Lithuania, a licence from VATESI is required for decommissioning operations. In accordance with the same law, prior to decommissioning the decommissioning programme needs to be drawn up and approved by the Government. The programme has to deal with numerous issues arising when the plant or its unit is shut down These are technical, organizational, financial, safety, radiation protection, environmental and social issues. Each governmental institution establishes within its area of competence requirements and criteria that allow decisions on whether the decommissioning programme is adequate. As the planning of the intricate decommissioning process as a rule begins at a very early stage (usually already at the design stage of the NPP), it is desirable that the requirements and criteria be made known as early as possible.

*General Requirements for the Decommissioning of Ignalina NPP* has been issued by VATESI. This document, compiled over two years of co-operation with PHARE programme experts, identifies the key aspects of decommissioning (except social issues). These are issues related to safety assurance, radioactive waste management, organization of preliminary decommissioning work, licensing, supervision, financing guarantees and civil responsibility for nuclear damage. The VATESI document also contains general requirements for the decommissioning design and the safety analysis report, which form the basis for obtaining a VATESI licence. Although the general procedure for decommissioning licensing is the same as for other nuclear energy facilities (‘Regulations of the Licensing of Activities in Nuclear Energy’, 1997), the licensing of decommissioning has certain characteristic features. One of them is the possibility of terminating operation of a unit or the entire nuclear power plant in stages (the so-called decommissioning phases), with a licence from VATESI being obtained for each stage. This facilitates the designing and, of course, the licensing process too. The applicant is required to clearly define the state of the unit or nuclear power plant (physical and radiation criteria, organizational measures, etc.) at the beginning and end of the phase.

Such phased licensing, recognized as being effective in international practice, allows flexibility in planning the entire decommissioning (which may take 25–50 years, depending upon the strategy chosen) and, if necessary, in reorganizing the organization carrying out the decommissioning while saving funds and other resources. Another characteristic feature is that separate licences need to be secured for modifying the existing radioactive waste storage facilities or building new facilities and repositories. In accordance with the Law on Radioactive Waste Management (1999), these facilities are viewed as separate nuclear energy projects. Another essential difference between the decommissioning and operating licences is that prior to applying for the former the operating organization has to submit a final decommissioning plan (part of the decommissioning programme). The plan has to describe in a general way the decommissioning actions, the strategy chosen (direct dismantling of the installation, dismantling after a certain period of time, etc.), the possibility of using demolition, dismantling and deactivation technologies, equipment and tools, the strategy for managing radioactive waste, safety, environmental issues, emergency preparedness, physical protection measures, decommissioning expenses and financing sources. Only after the plan has been approved can work on the decommissioning design be started.

*General Requirements for the Decommissioning of Ignalina NPP* now provides answers to all of the major questions regarding safety and licensing that may arise while planning the actions related to final shutdown of INPP or its unit. Of course, much work lies ahead. Among other things, safety and acceptance criteria have to be developed for radioactive waste storage facilities and repositories as well as waste management requirements. Preparations should start for assessing and analyzing the licensing documents, beginning with the decommissioning plan/design and safety analysis reports. This will require new knowledge and skills and, naturally, numerous experts. While preparing for decommissioning licensing, VATESI is concentrating on specialist training, contacts with technical service organizations (TSOs) and co-operation with nuclear safety control institutions abroad.

## 4. SCHEME OF THE DECOMMISSIONING ACTIVITIES FOR INPP

Since implementation of the Decommissioning Plan should be co-ordinated with many actions, a schedule of activities should be considered that takes into account different ongoing projects, decommissioning phases, stages of licensing procedures, conditions of issued licenses, etc. (see Fig.1).

## 5. INPP UNIT 1 DECOMMISSIONING PROGRAMME

The decommissioning programme for INPP Unit 1 has three phases:

(1) First phase — preparation for decommissioning (2001–2004);
(2) Second phase — preparation for dismantling of equipment and long term storage (2005–2010);

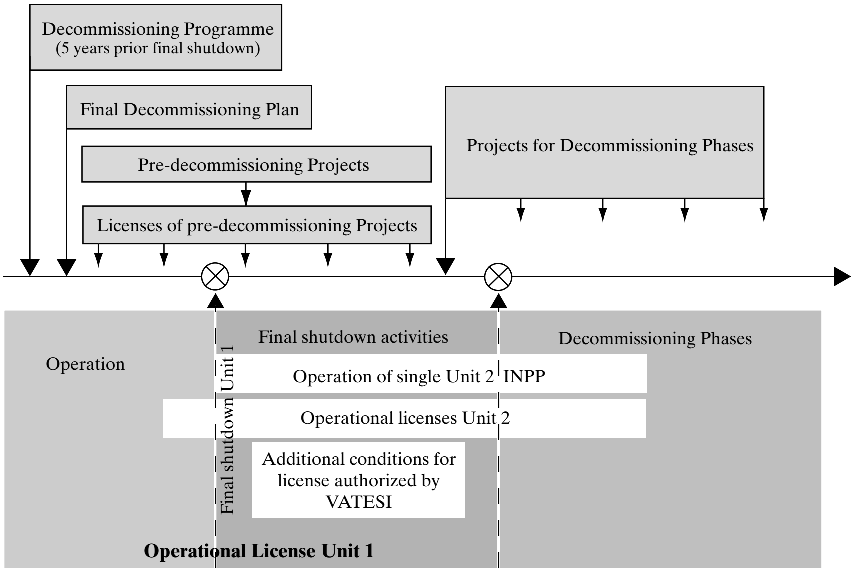


*FIG. 1. Scheme of decommissioning activities for INPP.*

(3) Third phase — dismantling of equipment and constructions after long term storage period (depending on the strategy chosen, either 2011–2030 or 2011–2080).

The main purposes of the implementation of the first phase of the programme are to:

— Ensure safe operation of INPP during preparatory work for decommissioning and during decommissioning;
— Ensure that preparatory work for the decommissioning of INPP Unit 1 is completed before 1 January 2005;
— Mitigate the negative socioeconomic consequences of the decommissioning of INPP Unit 1 for Lithuania, the Ignalina region and especially for the staff of INPP, and to create benevolent conditions for balanced socioeconomic development of this region.
— Ensure the preparation and implementation of projects, which correspond to the measures of the programme.
— Provide State support for the implementation of the measures of the programme and to encourage international aid funds.

The main purpose of the second and third phases is reloading of nuclear fuel from the reactor and pools of the unit, and dismantling of construction, equipment and buildings.

Implementation of the decommissioning programme should be performed according to the plan of action approved by the Minister of Economy. The plan is divided into two parts. One part provides a list of technical–environmental measures and the other part lists the socioeconomic measures to address jointly with INPP the economic problems resulting from the decommissioning, such as establishing a legal base, creating new jobs, rendering assistance to local municipal institutions, and encou-raging business in the region of INPP. The technical–environmental measures of the action plan comprise four aspects — organizational, legal, environmental and technical.

The final decommissioning plan must include the following:

— A description of INPP and the INPP area which could be affected by the decommissioning process.
— INPP's operating history, and the use to be made of its plant and site during the decommissioning process and thereafter.
— A list of the standards, regulations and other statutory instruments forming the legal framework of the decommissioning process.
— The decommissioning strategy chosen and its supporting argument.
— A description of the proposed decommissioning activities and their timetable.
— A conceptual safety and environmental impact assessment, including the impact of ionizing radiation and other effects on the public and the environment.
— A description of the environmental monitoring programme proposed for the decommissioning period.
— A description of the decommissioning organization: the responsibilities, resources, qualifications and the skills of its personnel.
— The opportunities for using various engineering, management and decommissio-ning methods, as well as dismantling, decontamination and cutting technologies, and an assessment of the remote control equipment which will be needed for safe decommissioning.
— A description of the proposed methods of waste management, including the sources, quantities, description and type of waste, sorting criteria, primary waste processing and the methods of its final processing, transportation, storage and disposal, together with an indication of the suitability of decommissioning residues for reprocessing or recycling, and radiation criteria; expected release and discharge into the environment of

radioactive and non-radioactive materials and the ultimate fate of the radioactive waste.
- A description of the safety and radiation safety procedures to be used during decommissioning.
- A description of the quality assurance system.
- Descriptions of other important administrative and technical requirements, such as IAEA safeguards, physical protection, and emergency preparedness.
- Monitoring programmes intended to confirm that the site complies with free release criteria, including their description, equipment and methods to be used.
- An estimate of decommissioning costs, including the cost of waste disposal, existing funds and other sources.

## 6. ENHANCEMENT OF REGULATORY CAPABILITIES IN THE FIELD OF DECOMMISSIONING

The broad spectrum of the INPP Unit 1 decommissioning projects requires reestablishment of regulatory body capabilities to sustain all necessary control of the implementation of these projects. VATESI has assessed the situation at present and has formulated a policy to strengthen its capability in this field. This involves an increase in the number of VATESI staff in some sectors, and such an increase has already started. But for better presentation of this policy three general tasks need to be formulated:

- Preparation of the necessary regulatory requirements, recommendations and other legal acts in the field of decommissioning and radioactive waste management.
- Ensuring adequate resources for the regulatory review of technical documentation presented for the licensing of decommissioning projects.
- Training of VATESI and its TSO staff.

It is evident to us, taking into account our financial resources, that implementation of this policy is difficult. Therefore, it has been decided to apply for assistance to international organizations such as the IAEA and the European Commission. As a result of the positive reaction, today we have promising projects launched by these organizations focusing on decommissioning.

### 6.1. IAEA technical co-operation programme (LIT/4/002): Assistance in decommissioning to Lithuania (2001 and extension to 2002)

In the framework of this programme, a number of expert missions were undertaken and seminars were conducted in Lithuania. A Lithuanian specialist visited some Western facilities under decommissioning and radioactive waste management facilities in Germany and France. IAEA peer reviews of safety analysis reports for INPP radioactive waste management facilities (solid and bituminous waste) were performed under these projects as well. These measures were very useful for VATESI staff as they gave a good representation of the decommissioning process in western countries. We are still planning some limited activities in the framework of this programme, since it will continue for some years.

### 6.2. EC PHARE project: Support to licensing activities related to the decommissioning of INPP to VATESI and Lithuanian TSOs PH/LI/10/99 (2002–2005)

This project will be carried out in two phases: each phase will run 18 months. Therefore, continuing assistance for VATESI is assured, which will lead to successful implementation of our decommissioning policy. The key aspect of this PHARE programme is assistance to the regulatory body, which is to be accomplished in three ways.

## 7. OBJECTIVES OF REGULATORY POLICY IN DECOMMISSIONING

The main objective is to specify the basic licensing requirements for decommissioning, to formulate VATESI’s requirements relating to the decommissioning process, its preparatory stages and its supervision, and safety assessment for the entire decommissioning process following final shutdown, and operation aimed at achieving unrestricted use of the site.

The main participants in the decommissioning process are:

- The operator (INPP)
- The regulatory body responsible for the decommissioning of INPP (the National Nuclear Safety Inspectorate, VATESI)
- Central and local government authorities.

INPP will have the following main tasks:

- To set up a suitable organization with a clear division of the functions and responsibilities of all persons involved in the decommissioning process and who are capable of retiring the facility from service.
- To ensure safe shutdown.
- To obtain a decommissioning licence from VATESI.
- To obtain the relevant permits from central and local government authorities or to comply with their requirements for decommissioning and associated activities.
- To comply with the requirements of VATESI.

VATESI will have the following rights and tasks:

- To propose to the Lithuanian Government and the Ministry of the Economy the shutting down (taking out of service) of INPP before the end of its service life, if safety is not ensured.
- To submit proposals for drafting or amending legislative instruments relating to decommissioning, the decommissioning strategy, radioactive waste handling and funding of the decommissioning process to the Government and other competent authorities.
- To specify decommissioning licensing requirements.
- To grant a decommissioning licence, or provide valid reasons for refusal.
- To suspend, prolong or revoke the decommissioning licence.
- To draw up decommissioning planning requirements, and to review and approve the plans.
- To assess safety during the final shutdown and decommissioning period.
- To draw up additional safety requirements for the final shutdown and decommissioning periods.
- To issue permits for individual decommissioning activities.
- To draw up and implement inspection programmes.
- To confirm that decommissioning has been completed and that the site can be released for unrestricted use, or permit other nuclear facilities to be installed at the site.

Before any decommissioning activities take place, sufficient funds must have been accumulated. Decommissioning costs must include all activities described in the decommissioning plan, i.e. the final shutdown, engineering design work, licensing costs, the development of special technologies, decontamination, dismantling and conducting a final survey. They should also include the cost of management of radioactive waste and of waste generated during operation and decommissioning.

## 8. PERSONNEL TRAINING

The personnel training programme should also include basic decommissioning activities, such as decontamination, dismantling, the operation of remote control equipment, basic safe working principles, the development of practical skills, where necessary, using training stands and specially prepared mock-ups simulating the basic conditions of the proposed operations as closely as possible. Both during training and refresher courses, special attention should be paid to emergency response (noting the interaction between individual employees). When training decommissioning personnel, it is necessary to explain the consequences of any errors for INPP, its employees, the general public and the environment. Before independent work starts, skills must be tested on the basis of existing standards and regulations. Periodic refresher courses are mandatory.

# DECOMMISSIONING AND THE JOINT CONVENTION

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**Abstract**

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, commonly known as the 'Joint Convention', came into effect in June 2001. The paper describes the development of the Convention, from 1992 to the present day, summarizes its current status, discusses some aspects of the scope of the Convention, and explains the review process that will be used in its implementation. The paper's main emphasis is on the Convention's implications for Contracting Parties concerning decommissioning of nuclear facilities. In describing that, the paper compares some details of the differences in scope of applicability of the Joint Convention and the Convention on Nuclear Safety, and hence explains why decommissioning came within the scope of the Joint Convention. Specific articles of the Convention are identified that are pertinent to countries engaged in decommissioning activities. A Contracting Party should ensure that each of those articles is considered during the preparation of its National Report, which is to be submitted prior to a Review Meeting.

## 1. INTRODUCTION

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (hereafter called the 'Joint Convention') came into effect in June 2001. The first Review Meeting of the Parties to the Convention will be held in November 2003, and the National Reports from those Parties are due to be submitted by early May 2003.

This paper will review the history of the Joint Convention, summarize its current status, and present some of the Convention's implications for Parties concerning the decommissioning of nuclear facilities.

## 2. HISTORY OF THE JOINT CONVENTION.

To track the origins of the Convention, one must go back to 1992, to the United Nations Conference on Environment and Development in Rio de Janeiro. At that conference, under the heading of "safe and environmentally sound management of radioactive wastes", one of the resolutions adopted called for "support efforts within IAEA to develop and promulgate radioactive waste safety standards or guidelines and codes of practice as an internationally accepted basis for the safe and environmentally sound management and disposal of radioactive waste".

At about the same time, negotiations started in Vienna that resulted in 1994 in the Convention on Nuclear Safety. One of the preambular statements in that Convention affirmed the need "to begin promptly the development of an international convention on the safety of radioactive waste management as soon as the ongoing process to develop waste management safety fundamentals has resulted in broad international agreement". That statement appears fairly insignificant in retrospect, but at the time was quite controversial. It resulted from a considerable amount of animated discussion about whether the Convention on Nuclear Safety should include radioactive waste management in its scope, and also referred to intense discussions under way at the time to attain such internationally agreed radioactive waste safety fundamentals. Later in 1994, in the light of imminent agreement on those fundamental safety principles, the IAEA General Conference invited the IAEA Board of Governors and the Director General to "…commence preparations for a convention on the safety of radioactive waste management…".

A Group of Legal and Scientific Experts was then created, which proceeded to undertake the negotiation process that ultimately resulted in the Joint Convention. The Group held seven meetings under the chairmanship of Professor Alec Baer, during which there was sometimes intense debate on various aspects of the proposed Convention. Principal among the points of contention was whether the Convention should include the safety of spent fuel management, the issue of radioactive wastes arising from military programmes, and the issue of transboundary shipments of radioactive waste. The Group completed its task in early 1997, and in September of that year the IAEA convened a diplomatic conference, which was attended by 84 States and 4 international organizations. It resulted in the adoption of the Joint Convention, which was then opened for signature.

The text of the Convention specified that it would enter into force three months after ratification by 25 States, of which at least 15 had an operational nuclear power plant. That threshold was attained in March 2001. There followed a formal Preparatory Meeting of the Parties (in December of 2001), which adopted three important documents — the "Rules of Procedure and Financial Rules", "Guidelines regarding the Review Process", and "Guidelines regarding the Form and Structure of National Reports". These three documents govern the future implementation of the Convention, including the conduct of the review meetings.

## 3. CURRENT STATUS OF THE JOINT CONVENTION

At the time of writing, there are 29 Parties to the Convention. It is hoped that this number will increase as the deadline approaches for submission of National Reports for the first review meeting. That meeting is scheduled for November 2003, with an organizational meeting scheduled for April 2003. The rules adopted by the Parties in 2001 stipulate that the organizational meeting is open to all Contracting Parties, i.e. those who have ratified the Convention. The "Guidelines on the Review Process" stipulate that the latest date at which a State can ratify the Convention in order to become a fully participating Party at the review meeting is 90 days in advance of that meeting. Thus, the identities of all the Parties for the first review meeting will only be known in August 2003.

States that are already Parties or which expect to become Parties before the first review meeting should note that National Reports must be submitted by May 2003, with an extension to August for those States that ratify between May and August 2003.

## 4. SCOPE OF THE JOINT CONVENTION

As mentioned above, negotiation of the Joint Convention was started after the Convention on Nuclear Safety was opened for signature. There was animated debate on several aspects of the scope of the Convention, some of which will be discussed briefly here.

First, through several meetings there was an impasse over whether spent fuel should be included in the Convention. Several countries argued that for them spent fuel is a valuable resource and should not appear in juxtaposition to "waste" in any convention. Eventually, since all agreed that the same principles of safety apply to the management of spent fuel and to the management of radioactive waste, it was decided to deal with both in the same document, on parallel tracks — hence the 'Joint' in the Joint Convention.

Second, there was the question of whether the Convention should apply to material arising from military programmes. That was resolved by a two part approach that appears in Article 3.3 of the Convention. The Convention does not apply to military programme material unless the Contracting Party declares that it will apply; the Convention does apply to material from military programmes if and when transferred to exclusively civilian programmes.

Third, it was eventually agreed that the Convention would not apply to naturally occurring radioactive material unless such material originates from the nuclear fuel cycle, or unless the material is in the form of a disused sealed source, or unless a Contracting Party declares that it will apply.

Fourth, the Convention on Nuclear Safety applies to a "nuclear installation", which it defines as "…a nuclear power plant…, including such storage, handling and treatment facilities for radioactive materials as are on the same site and are directly related to the operation of the nuclear power plant…". Thus, the Convention on Nuclear Safety already applied to spent fuel management and radioactive waste management in some limited cases. There was therefore some discussion about how to manage the interface between the two conventions. It was agreed that overlaps between the two conventions would be less undesirable than gaps, and that if overlaps existed, the review meetings of the two conventions would find a way to minimize the negative consequences. During this discussion, it was realized that the main thrust of the Convention on Nuclear Safety was and would be the safety aspects of operating nuclear power plants, and therefore the overlap caused by including on-site spent fuel management and radioactive waste management in the Joint Convention would not be likely to cause a significant problem.

The definition of nuclear installation in the Convention on Nuclear Safety continues from the above quotation, to say that a nuclear plant ceases to be a nuclear installation when the fuel has been removed permanently and a decommissioning programme agreed to by the regulatory body. The nuclear plant would then cease to come within the scope of the Convention on Nuclear Safety. In order to avoid a situation where such nuclear plants would no longer be subject to international review at this stage, the Group of Experts in the negotiating meetings for the Joint Convention therefore agreed to include decommissioning within that Convention. But they went further. In the Joint Convention, "decommissioning" is defined as a radioactive waste management function. In addition, "decommissioning" in the Joint Convention refers to a "nuclear facility", which is defined in that convention to be much broader than a nuclear power plant. It covers the gamut of processing, fabrication, storage, research reactor, etc., and so the Joint Convention covers the decommissioning of virtually all kinds of nuclear establishments.

Throughout the negotiations, the Group of Experts referred repeatedly to the safety fundamentals document mentioned earlier, entitled 'The Principles of Radioactive Waste Management'. That document comprised an international consensus on what constituted best practices in the field of radioactive waste management at the time when the document was drafted, and formed the basis for the numerous safety requirements that appear in the text of the Joint Convention as obligations on Contracting Parties. It is interesting that the radioactive waste management experts attached such importance to the safety principles that they agreed to elevate the status of these fundamental safety statements to obligations in an international convention.

## 5. DECOMMISSIONING OBLIGATIONS IN THE JOINT CONVENTION

In the Joint Convention, Article 26 specifically addresses decommissioning. It must be remembered, however, that in this Convention, decommissioning is but one function within the broader topic of radioactive waste management. It would therefore be inadequate if one examined only the text of Article 26, in deciding what should be included in a National Report on the topic of decommissioning pursuant to the Convention. The entire Chapter 3, on "Safety of Radioactive Waste Management", as well as Chapter 4, on "General Safety Provisions", and certain sections of other parts of the Convention, must be read carefully in order to determine the complete set of obligations.

For example, Article 7(ii), which addresses design and construction of facilities for spent fuel management, requires Contracting Parties to ensure that at the design stage, conceptual decommissioning plans are prepared and taken into account. This requirement is further developed during the operational phase of a spent fuel management facility in Article 9(vii), which requires the decommissioning plans to be updated using data obtained during the operating period. Analogous requirements are found for radioactive waste management facilities in Article 14(ii) and Article 16(viii).

Other examples stem from Articles 5 and 12(i), which deal with existing facilities for spent fuel management and radioactive waste management, respectively. The text in these articles requires Contracting Parties to review the safety of existing facilities, and take all practicable steps to improve safety if necessary. If such steps were to include the decommissioning of the respective facilities, rather than upgrading them, the details of the envisioned decommissioning would be reportable to a review meeting.

Article 19 requires Contracting Parties to "establish and maintain a legislative and regulatory framework to govern the safety of spent fuel and radioactive waste management". Since decommissioning has been defined in the Convention as a function within the overall field of radioactive waste management, this article requires the Parties to have a regulatory framework for decommissioning nuclear facilities in general. And of course the Contracting Parties are obliged to report to the review meetings on how or to what extent they meet this obligation.

Article 22(ii) requires Contracting Parties to "take the appropriate steps to ensure that financial resources are available to support the safety of facilities for spent fuel management and radioactive waste management during their operating lifetime and for decommissioning". This brief requirement is obviously of great importance in terms of long term safety and environmental protection, but can be controversial because of its financial impact.

And after all those requirements for decommissioning, one comes to the text of the Article 26 in the Convention whose title is “Decommissioning”! This article, quite brief if one counts the number of lines, again has somewhat hidden ramifications, because it calls up two other Articles. In summary, Article 26 requires Contracting Parties to:

— ensure the availability of qualified staff;
— ensure the availability of adequate financial resources;
— ensure that radiation protection measures such as the ALARA (as low as reasonably achievable) principle and dose limits are respected;
— ensure that unplanned releases to the environment are prevented;
— limit discharges to the environment;
— take corrective measures in the event of an unplanned discharge;
— have emergency preparedness plans and test them as appropriate.

Thus the Joint Convention stipulates a wide array of requirements on Contracting Parties concerning decommissioning. These requirements envision the same degree of planning and operational control with respect to safety for decommissioning nuclear facilities, as is required for their operation.

## 6. REVIEW PROCESS UNDER THE JOINT CONVENTION

The Joint Convention, like the Convention on Nuclear Safety, incorporates a review meeting at intervals not exceeding three years. Approximately six months in advance of each review meeting, there will be an organizational meeting. Both these meetings are open only to Parties to the Convention. At each organizational meeting, decisions will be taken concerning officers for the upcoming review meeting, observers that would be invited to the review meeting, the budget and timetable of the review meeting, and what groups will be created and their composition, for discussion of the National Reports at the review meeting.

These groups will primarily be groups of countries, each being composed of, for example, six Parties. Because of the diversity of topics covered by the Convention, some Parties have expressed the view that certain topics would be more effectively discussed in a group specifically created for that subject, rather than in country groups in which perhaps only one or two Parties have expertise in the particular topic. The organizational meeting must therefore decide whether there would be topic sessions in addition to country groups at the review meeting.

Each Contracting Party must submit a National Report, showing how that Party has achieved or is achieving the objectives of the Convention. The report must be submitted not later than six months before the start of the review meeting. Copies of each National Report will be distributed to all Parties for review. Any Contracting Party can submit questions on any other Contracting Party's National Report, up to two months before the review meeting.

At the review meeting, each Contracting Party in turn will present its report to the country group to which it has been assigned, and respond to the questions that were submitted. A summary of the proceedings in each country group will be presented in plenary session.

## 7. GENERAL COMMENTS ON THE JOINT CONVENTION

The Joint Convention, like the Convention on Nuclear Safety, is a so-called 'incentive convention'. That means that the Convention does not impose sanctions or penalties for violators; rather, each Contracting Party is subjected to peer review pressure, and thus encouraged to improve the level of safety in its management of spent fuel and radioactive waste.

It is a modern convention, which reflects many of today's societal expectations. High among those are the emphasis placed in the Convention on environmental protection. Other examples are the references to public information, consultation, consideration of neighbouring States, and consideration of the needs and well-being of future generations. States that have ratified the Convention are displaying a sense of responsibility by making a commitment to reporting to other States on what they are doing, and how well they are doing it.

The Convention covers a wide range of topics. Operational safety and environmental protection will be reviewed in the context of low and intermediate level radioactive waste storage and disposal, uranium mining tailings management, spent fuel reprocessing, spent fuel storage, spent fuel and high level radioactive waste disposal, management of disused sealed sources, radioactive discharges, and decommissioning of nuclear facilities. Thus, one can expect the review meetings to be complicated, with several specialists probably being in any one delegation. In addition, there is a wide variation in the size and complexity of the nuclear programmes of Contracting Parties, and therefore in the quantities and types of radioactive waste. But each of those Parties will present a National Report. So there will also be a wide variation in the complexity and content of reports to be reviewed. All this will represent an interesting challenge to those charged with the responsibility of organizing the review meeting!

The benefit to be gained from the Convention is very great, at least in theory. There is probably no greater motivating factor for individuals or even nations than peer pressure. Associated with that is the desire to be recognized as performing well, and to avoid public criticism or embarrassment. And it is hoped that peer pressure will have its usual effectiveness when applied through the Joint Convention. Of course, to achieve that, one must have a wide representation of the world's States signing on as Contracting Parties. To date that is perhaps the biggest concern, because of the 54 States that are Contracting Parties to the Convention on Nuclear Safety, only 29 are Contracting Parties to the Joint Convention at present. Since virtually all States have some radioactive waste, one would intuitively expect the Joint Convention to have more Parties than the Convention on Nuclear Safety. Perhaps that will be the case in the future. At the time of writing, however, some very prominent States are not yet Parties, and one hopes that their governments will ratify the Convention as soon as possible, preferably before the organizational meeting in April 2003 so that they can be full participants at the Convention's first review meeting in November of that year.

# STATUS AND DEVELOPMENT OF DECOMMISSIONING TECHNOLOGIES

(Session 1.C)

**Chairperson**

**V.P. Kansra**
India

# STATUS AND DEVELOPMENT OF DECONTAMINATION AND DISMANTLING TECHNIQUES FOR DECOMMISSIONING OF NUCLEAR INSTALLATIONS

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**Abstract**

The complexity of components in nuclear installations subject to dismantling or decontamination is enormous and so is the number of techniques. To choose the ideal technique and the corresponding strategy, complex limiting conditions have to be considered. The most important criteria are: costs; the amount and kind of radioactivity (contamination, activation, isotopes, spatial distribution within the object), aspects of radiation protection (segmentation, decontamination under ambient conditions/under water); the kind of material to be treated (steel, concrete, graphite, compound materials); geometries (thickness, structure); and their spatial accessibility. Based on these criteria, decontamination or dismantling processes are selected. A selection of techniques is presented and new trends are discussed.

## 1. INTRODUCTION

Through decontamination a major reduction in waste for final storage can be achieved. During selection of a suitable decontamination technique, there is a focus on the material to be decontaminated. There are metallic, organic (paint, plastic coatings and parts), mineral (especially concrete) and ceramic (tiles) objects and surfaces. In classifying decontamination techniques, the cleaning of surfaces and the removal of surface coatings have to be identified. In general, decontamination techniques are based on chemical, electrochemical, mechanical and thermal mechanisms, as well as combinations of these methods.

Analogous to decontamination techniques, there is a large variety of dismantling techniques that are state of the art and in use. They are grouped into mechanical, hydraulic, thermal and chemical/electrochemical cutting mechanisms. In addition to the above mentioned selection criteria, process safety, cutting speed, remote operated handling, and reduction of emissions will be compared.

The state of the art for decontamination and dismantling techniques, as well as aspects of research and development will be also described. Further information concerning the technologies described is available in Refs [1–13] and the proceedings of the KONTEC conferences. The proceedings of the yearly conferences 'Kerntechnische Jahrestagung' in Germany and reports from the European Commission also provide useful additional knowledge.

## 2. DISMANTLING TECHNIQUES

### 2.1. Classification of dismantling techniques

In view of the wide range of dismantling tasks, many different cutting techniques have been developed so far. In some cases, techniques already used in the sheet metal manufacturing industry have been adapted to the special requirements for the decommissioning of nuclear installations. Additionally, special techniques have also been developed exclusively for such tasks. An overview is given in Table I, dividing the techniques with respect to the physical mechanisms into mechanical/hydraulic, thermal and chemical/electrochemical techniques. With respect to the requirements for the decommissioning of nuclear installations, for example remotely controlled applications, high process safety and efficiency, reduction of emission dissemination and applicability under water, the number of usable techniques, especially in the controlled area, is smaller.

TABLE I. DISMANTLING TECHNIQUES

| Mechanical/hydraulic | Thermal | Chemical/electrochemical |
|---|---|---|
| Sawing | Oxy-fuel cutting | Explosive cutting |
| Shearing | Lance cutting | |
| Milling | Plasma-arc cutting | |
| Breaking | Consumable electrode oxygen jet cutting | |
| Grinding | | |
| Nibbling | Consumable electrode water jet cutting | |
| (Diamond) wire sawing | | |
| Microwave spalling | Oxy-arc cutting | |
| Abrasive water jet cutting | Arc-saw cutting | |
| | Contact-arc metal cutting | |
| | Contact-arc metal drilling | |
| | Contact-arc metal grinding | |
| | Laser beam cutting | |
| | Electrical discharge machining | |

As a result, electrochemical cutting techniques, electrical discharge machining and microwave spalling are used only for specific dismantling tasks and for decontamination purposes [1, 6, 13–16]. Furthermore, explosive cutting, used for example in Niederaichbach, Germany, for the delamination of activated concrete structures, has only a few applications in decommissioning tasks, for example the dismantling of the biological shield at the Elk River reactor [1, 6]. Arc-saw cutting, i.e. working with a rotating disc, was developed in the USA and used for the dismantling of different reactor pressure vessels in the USA and for the JPDR in Japan [1]. Other arc processes are discontinuous oxy-arc cutting, consumable electrode oxygen and water jet cutting [1, 13, 17, 18]. Examples of the use of consumable electrode water jet cutting are dismantling of a pressure vessel and a steam dryer housing [1].

## 2.2. Thermal cutting techniques

### *2.2.1. Oxy-fuel cutting/lance cutting*

Oxy-fuel cutting is restricted to mechanized, semi-remote as well as hand guided dismantling of mild steel or stainless steel plated mild steel structures [1, 19]. Therefore, mainly conventional cutting systems are used. Hand guided and semi-mechanized dismantling has been carried out up to plate thicknesses of 250 mm [20, 21]. With additional powder, oxy-fuel cutting is also capable of cutting stainless steel and concrete. In cutting tests, maximum cut thicknesses of 320 mm for steel and 1200 mm for concrete structures were achieved. An important disadvantage is the high quantity of aerosols produced during this process [1]. The lance cutting process can only be used for drilling and perforation cutting, for example prior oxy-fuel cutting of thick structures such as pressure vessels. Typical features of this method is a low cutting speed, a discontinuous process, lack of suitability for automation and also a large amount of aerosols produced [1]. With regard to dismantling, combined processes were developed as combinations of consumable electrode water jet gouging/oxy-fuel cutting and plasma-arc gouging/oxy-fuel cutting [1, 22]. Research and development activities are currently being carried out for high pressure oxy-fuel cutting and mechanized oxy-fuel cutting under water, especially for cutting stainless steel plated mild steel structures [19, 23, 24].

### *2.2.2. Plasma-arc cutting*

For decommissioning purposes, plasma-arc cutting is the most commonly used thermal cutting technique for activated components, especially reactor internals. The main advantages are the high cutting speed over a wide range of plate thicknesses, especially for cutting stainless steel, applicability in the atmosphere as well as under water, easy remote handling and low reaction forces. The maximum achievable cutting thickness in the atmosphere is 150 mm and under water it is 100 mm [1]. Therefore, several plasma torches based on such principles as water injection plasma-arc, dual flow plasma-arc, contact ignition, etc., were designed for fast remote controlled replacement of worn parts and modular systems [1, 13]. With regard to the dismantling of high activity core components, data on the quantity and size of emissions are available in Refs [1, 25, 26].

Research and development is being carried out to: reduce the kerf width in combination with the design of a personal guided 'steady cut system' [27]; increase the plate thickness that can be cut under water; and plasma-arc cutting up to a water depth of 20 m in Gundremmingen, Germany [28].

#### *2.2.3. Laser beam cutting*

Laser beam cutting is characterized, where applicable, by small cutting kerfs and precise cutting contours, small heat affected zones, small tolerances, little distortion of the object, stress-free treatment and high reproducibility. On the other hand, a high level of investment is necessary, while the low efficiency of lasers is coupled with high energy consumption. Laser technology can be used in many areas for the dismantling of nuclear power plants [29, 30]. For the dismantling of tanks or storage basins consisting of concrete walls lined with steel plates, cutting of the steel material is complicated. The metal sheets lie directly on the concrete, and it is rather difficult to cut them mechanically. A special nozzle technique, in combination with a hand guided laser system, was used in the nuclear power plant at Greifswald, Germany, to expel the molten material to the top surface of the sheet. Specific removal by suction of the released process emissions is also possible [31]. The mobility and flexibility of the fibre optic, hand guided Nd:YAG laser is an important reason for its application in nuclear facilities. A condition for the use of these applications is the availability of a hand-held laser processing head and characterization data, and a suction system for the aerosols produced [32–35].

Research and development is being carried out for cutting asbestos materials as well as for the design of modular laser beam cutting systems for cutting in the atmosphere and under water.

#### *2.2.4. Contact-arc metal cutting, drilling and grinding*

Contact-arc metal cutting (CAMC), drilling (CAMD) and grinding (CAMG) are electrothermal cutting techniques used to cut conductive materials with Joule and arc heating. CAMC, with a swordlike graphite electrode and a water curtain for blowing out the molten material, is a thermal cutting technique currently used for the decommissioning of nuclear facilities [36]. Using this technology, complicated components like tube-in-tube objects and components with re-entry angles can be separated with a single cut. The state of the art in CAMC is the cutting of 260 mm thick components. The kerfs show widths of 4–8 mm and the wastage ranges from 20 to 25% [36]. A special CAMC tool with a turntable drive unit and integrated process control for automatic cutting was developed for cutting tasks in Greifswald [37]. CAMD was developed as a novel technology to drill holes or pocket holes without restoring forces. Furthermore, together with a warp mechanism, an automated fixing system was built [38, 39]. Another cutting technique is CAMG, with a rotating electrode, offering new fields of application. As materials for the cutting electrode, steel or carbon fibre reinforced graphite can be used. The cutting speed is very high: For example, CAMG is capable of cutting objects of 15 mm thickness at a speed of 3 m/min. The wear of the rotating electrode can be reduced to 9% by appropriate parameter adjustments, and the maximum cutting thickness is 40–50 mm [39, 40]. Research and development is being carried out to reduce electrode wear and to increase the maximum cutting thickness for CAMG; a comparison of the abrasive water jet cutting and CAMC processes is also being carried out.

### 2.3. Mechanical cutting and segmentation techniques

Mechanical cutting techniques with geometrically defined tool angles, such as sawing and milling, are characterized by rough and easily collectable residues (e.g. chips), high reaction forces and low cutting speeds. Mechanical cutting techniques with geometrically non-defined tool angles, such as grinding and diamond wire sawing, are characterized by process products consisting of small grained dust (100–800 mm) in the atmosphere or in slurry in underwater use [13].

Grinding units are electrically, hydraulically or pneumatically powered discs, appropriate for the cutting of all types of materials (metals, concrete, reinforced concrete, etc.). They may be used in atmospheric as well as in underwater conditions. The maximum cutting thickness for metallic components is limited to 150 mm; mobile grinders used for dismantling tasks are not suitable for cutting stainless or mild steel thicker than 30 mm. Grinders can be operated by remote control using video equipment. Problems include induced vibrations and reaction forces of the cutting disc, as well as contamination control due to a continuous stream of sparks in the atmosphere and the wear of the disc [1, 41, 42].

According to its definition sawing is cutting with a multitooth tool of small kerf width. Sawing can be carried out in the atmosphere and under water.

The tool is moved and supported by a feed unit. Different tools vary in performance, the wear of tools and in the accumulation of secondary wastes. Fret saws are mainly used without coolants and lubricants for cutting depths up to 100 mm. Bow saws are suitable for thin walled components with dimensions of up to 1 m cutting length. Band sawing is used for large dimension components up to 3 m [43, 44]. With circular saws a cutting depth of up to 200 mm for metal and 500 mm for concrete structures is achieved [45]. Taking into account the time for operation, the thickness that one would cut with hack saws is limited to 100 mm [1]. Diamond wire saws have been successfully tested for thick concrete and reinforced concrete structures (biological shielding) up to 1000 mm [46] and for metal structures up to 300 mm [47]. The main problems are the cutting kerf width and the resulting dispersion of contamination [1].

Shearing is used for cutting metals in the form of sheet steel, pipes, bars and concrete reinforcements. In comparison to other mechanical cutting techniques, a compensation of the reaction forces in the cutting tool can be achieved. Shearing processes can be divided according to lever shears, circular shears, parallel shears and 'nibbling' for plate thicknesses between 1 and 30 mm and for cutting lengths up to 4 m [1, 48–50]. Milling and orbital cutting tools are mainly used in the atmosphere and underwater for cutting cylindrical objects, such as pipes, tanks, etc., of diameters between 0.15 and 6 m [1, 45].

Research and development activities were carried out for the breaking of graphite structures using a straddling tool as it is widely used by emergency services. After drilling a hole the graphite structures are broken in a defined way. The generation of particles during the breaking process is very low. The technology has been successfully tested at VKTA Rossendorf, Germany [9, 12, 48].

### 2.4. Hydraulic cutting techniques

One of the first examples of dismantling by abrasive water injection jets (AWIJ) was the biological shield of the JPDR in Japan. The first use of an abrasive water suspension jet (AWSJ) was at the VAK Nuclear Power Plant in Kahl, Germany. With a maximum water pressure of 200 MPa, plate thicknesses up to 132 mm were cut. The advantages of abrasive water jet cutting are the small amount of aerosols produced, applicability to a wide range of cutable plate thicknesses, multifunctional uses including for kerfing and delamination tasks, applicability in the atmosphere as well as under water, easy remote handling and low reaction forces. A disadvantage is the secondary waste emission. Only a very small amount of waste is spread into the air as aerosol, with most of the waste being sedimentary particles [51–56].

Actual cutting operations using AWIJ in the atmosphere have been carried out for dismantling the dome of the reactor pressure vessel at the nuclear power plant in Würgassen, Germany. Research and development activities were conducted to reduce the secondary waste, as well as to design a process monitoring system and a modular, hand guided unit for AWIJ cutting.

## 3. DECONTAMINATION TECHNIQUES

### 3.1. Classification of decontamination and removal techniques

Different physical and chemical effects can be distinguished. These effects may be classified into chemical/electrochemical, mechanical and thermal effects.

*(1) Chemical and electrochemical:* Chemical removal techniques are based on a reaction or solution of a substance with the material.

*(2) Mechanical:* Mechanical processes may be classified as cutting technologies and impact technologies. Cutting technologies excavate the material with a cutting edge. Impact processes are based on particle or jet impact to crack material and remove it.

*(3) Thermal:* Thermal processes may be classified according to methods that apply heat or that remove heat from the material (cryogenic methods). Both use changes in material properties, such as brittleness at low temperatures or, with regard to multilayer systems, differing coefficients of thermal expansion. Heat may be applied to facilitate a chemical reaction or to degrade the material.

Many removal applications combine these mechanisms. Abrasion and impact mechanisms typically occur simultaneously in technologies emphasizing one mechanism over the other. The major effects and some corresponding techniques are presented in Fig. 1.

The objective of this paper is not to provide an overview of all decontamination and removal/excavation techniques, but to describe the major mechanisms used in decontamination and excavation and the capabilities of some new techniques. A presentation of state of the art decontamination techniques is given in Refs [57, 58].

### 3.2. Chemical and electrochemical processes

The effect of the chemical processes is based on a reaction with the material. The solvent stripping chemical may be wiped off or spread onto the component. The attacked material and solvent sludge are then wiped, scraped, or flushed off. In many applications, several repetitions are needed in order to guarantee satisfactory surface removal. A water rinse often is used for final cleaning of the part.

Alternatively, the whole part may be immersed within the liquid where the material may be dissolved in the chemical or, in the case of anodic (electrolytic) stripping, is plated out on the cathode. The bath may be operated at ambient temperature or be heated up to 70°C.

In *electrochemical stripping,* a fixed voltage is applied between the part and the cathode that is placed in the bath, close to the part. Thus, the oxidizing process is accelerated. Electrochemical stripping requires additional equipment if compared with chemical immersion stripping. Complex shaped parts may be stripped, non-uniform parts must be racked and passivation may occur on some substrates.

In *molten salt bath* technology, the part is immersed in a bath of molten salt. The salt is chosen according to the material. Molten salt baths operate at 200–500°C and offer high reaction velocities and low operation times. Due to the strength of the bath, only a few metals can resist molten salt baths, apart from platinum, niobium and tantalum.

For all chemical methods, the processing time to remove the surface varies greatly according to the material and the thickness of the layer to be

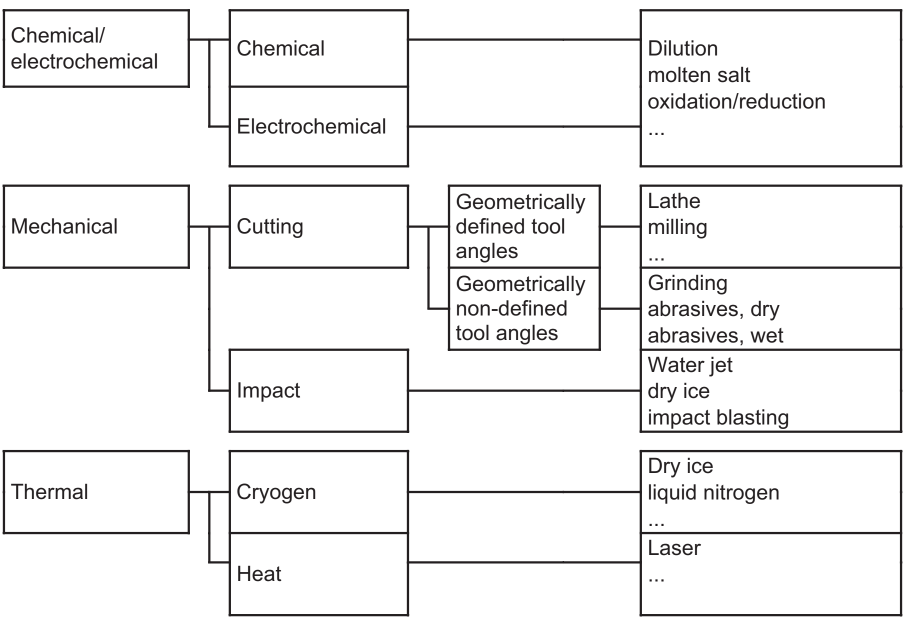


*FIG. 1. Classification by physical effect of removal technologies.*

removed, and may vary between some seconds in the case of salt baths up to several days for 'cold' chemicals. Chemical strippers generate organic vapours and sludges containing solvents and reaction products. These may be hazardous to staff and the environment. The life of the chemicals used varies up to several years. The chemicals and sludges represent a significant expense factor in waste disposal, and the handling of the chemicals implies safety hazards. Economic advantages due to low investment costs might easily be lost by the often high costs of waste treatment and disposal.

In decontamination and for the removal of metal layers, chemical techniques are of great importance. A table, listing tasks for stripping metallic coatings by coating material and substrate and indicating the applicable chemicals, as well as comments with occurring problems and instructions for application, is given for example by Rosenstein and Hirsch [59].

### 3.3. Mechanical processes

Mechanical processes are classified in terms of cutting with geometrically defined tool angles, cutting with geometrically non-defined tool angles and in processes with impact mechanisms. Cutting processes with geometrically defined tool angles are used to remove thick layers greater than 0.5 mm, e.g. with a lathe or mill.

A frequently used cutting technique with non-defined tool angles is machining, usually grinding. The method can only be used on parts with simple geometry. As in the removal of coatings, the process is difficult to adapt for automation and is usually applied manually.

Another mechanical coating removal technique is abrasive blasting, which uses abrasive grains that are accelerated towards the coating to be removed. Acceleration may be achieved by a gas stream (usually compressed air) or a rotating wheel. During blasting processes, a part of the blasting media breaks up, but some media may be used up to 30 cycles on average. The waste produced by blast processes consists of coating debris and degraded blast media and often is disposed together. The amount of degraded blasting media causes secondary waste, and subsequent cleaning of the parts of the blasting media and coating debris is often necessary.

#### *3.3.1. Abrasive water jet process*

To avoid dust production, wet abrasive coating removal may be used. The abrasive media is accelerated by water jets, with pressures usually less than 100 MPa. The liquid jet allows more precise guidance of abrasives than in dry abrasive blasting. For precise operation, automation is necessary. There are two methods for the generation of the abrasive water jet: in the water abrasive injection jet (WAIJ) technology, the abrasive is added to the high pressure water jet in an injection chamber. In water abrasive suspension jet (WASJ) technology, high pressure water and a high pressure abrasive suspension are mixed. In WAIJ technology large amounts of energy are dissipated within the injection chamber and air is absorbed by the water jet. During relaxation of the jet, the air expands and causes breakups of the jet. The WASJ technique demands higher efforts in equipment.

The absence of dust production may confer economic advantages on abrasive blasting, although the wastewater to be purified means extra cost. The used abrasive usually is not recycled.

#### *3.3.2. High speed water jet process*

The water jet technique uses supersonic jets of water to remove the material. The kinetic energy of the water jet causes the material to fracture and spall according to the mechanical impact mechanism. The jet is formed by a laser drilled sapphire or diamond like orifice. Diameters vary from 0.05 up to 0.5 mm. Pressure to reach the necessary velocities varies between 150 and 400 MPa. Velocities are in the range of 500 to 1000 m/s. Nozzle stand-off length may vary by about ±10 mm; the distance must not exceed a certain characteristic length where the jets break up (usually about 175 diameters [60]). Due to the high precision of the jet, manual manipulation is not effected. According to the geometry of the part to be stripped, one or more orifices are mounted in a nozzle. Because of the small diameter of the water jet, the removal rates of single nozzles are low. For large planar surfaces, rotating nozzles may be used which raise the removal rate [61]. Due to the uneven dwell of the rotating nozzle, the traces produce an uneven wear. By placing multiple orifices on the rotating nozzle, this problem may be reduced [62].

With the high speed water jet, excavation of concrete, organic and some metallic and ceramic components is possible. Extensive experience exists for the removal of thermal sprayed coatings [63]. Solid metal structures usually cannot be damaged by a high speed water jet.

### 3.4. Thermal processes

#### *3.4.1. Dry ice blasting*

Dry ice blasting has been in use for several years for the cleaning of surfaces and the removal of coatings without damaging the base materials' surface. The blasting media consists of carbon dioxide snow compressed to pellets of

1–3.5 mm diameter and length of 2–10 mm. The pellets used are at phase equilibrium solid–gas at a temperature of –78°C. They are accelerated by a gas stream and projected onto the surface. The gas jet reaches velocities of the order of 300 m/s, pellet velocities are between 190 and 300 m/s [64]. In contrast to other blasting techniques, dry ice blasting is not a proper abrasive due to the lower Mohs' hardness of the dry ice pellets of 2–3 [65, 66]. Dry ice blasting is based on the following effects: on contact, the cold carbon dioxide takes heat energy from the material to be treated. According to measurements by Haberland, the temperature of the surface of a sheet of metal is cooled down to –60°C, while at a depth of 0.5 mm only –10°C is reached [67]. As a result, thermostresses are induced onto the material. For coatings with thermal expansion coefficients other than the base material, additional stresses between coating and substrate are produced.

On impact, a part of the kinetic energy of the carbon dioxide pellets is transformed into sublimation energy. Through the phase change from the solid to the gaseous state, volume expansion by a factor of 700 takes place. This expansion generates a shockwave right at the surface to be treated. These very fast alternations in pressure induce the desired impact on the material. The third effect is the kinetic energy of the pellets. Due to the low pellet density, the effect of kinetic energy is low compared to other blasting processes. Dry ice blasting alone yields good results in the removal of organic coatings and cleaning. In the decommissioning of nuclear facilities, dry ice blasting has been used for the decontamination of surfaces [58, 68]. Some organic coatings with high mechanical resistance, such as powder coatings or decon coatings, cannot be removed by dry ice blasting. Additionally, the excavation of solid materials of a metallic, ceramic or mineral nature is not possible. The resulting gaseous carbon dioxide is sucked off together with the coating particles. The filtered gas stream may be discharged to ambient air; no secondary waste is produced.

### *3.4.2. Dry ice laser beam process*

The dry ice laser beam process is a new technology which combines dry ice blasting with heat supplied to the treated material by a laser beam. By heating the surface surrounding the area of the dry ice pellet impact using laser beams, the effect of thermal stress is maximized and, for several materials, a weakening is obtained. Different from laser ablation techniques, the material is not heated up to decomposition of the material, but only up to some 100°C. The creation of a plasma in the laser zone or melting and evaporation of the treated material is avoided to keep the cleaning effort of the sucked off gas stream low.

Tests involved a 2 kW diode laser and standard dry ice blasting equipment. A diode laser was chosen due to its compact size and comparably low investment costs. Poor beam quality is not a limitation in this application [69].

### *3.4.3. Application*

Excavation of concrete and ceramic tiles may be accomplished by the dry ice laser beam process. The great heterogeneity of concrete, which consists of cement and aggregates, does not lead to the selective excavation of only one phase. In any case, in concrete as well as in ceramics the excavation depth varies by up to 50% of the average due to the removal of the material in splinters of size up to 0.5 mm. A more detailed presentation of an experimental set-up and results can be found in Ref. [69]. For concrete volume removal, rates of 1500 $cm^3/h$ and 650 $cm^3/h$ for ceramics are reached, while the excavation depth is up to 5 mm and 3 mm, respectively.

Removed particles may be separated from the gas stream by mechanical separation (cyclones, filters). Measurements of the particle size in the gas stream by cascade separators show that 98% of the solid particles are greater than 0.5 mm and 99.9% are greater than 0.06 mm. Studies of filter residues by scanning electron microscopy showed that the mineral particles are only broken mechanically and any melting of the material could not be observed.

Recontamination of the material by removed material, which can be observed in many mechanical techniques like milling, is greatly reduced with the dry ice laser beam process. Organic coatings that cannot be removed with dry ice blasting alone can be removed with the dry ice laser beam process. The organic coating may be weakened by the laser beam or thermally disintegrate. Experiments on a thermoplastic and duroplastic powder coating that could not be removed by dry ice blasting alone proved the feasibility of organic coating removal by the dry ice laser beam process [69]. While the thermoplastic coating (polyethylene) was not disintegrated by the laser beam, the duroplastic coating (epoxy/polyester) was thermally disintegrated.

Solid metal components usually cannot be damaged by the dry ice laser beam process. Therefore, this process is suited for the removal of a non-metal coating from a metal substrate without damaging the metal component. In addition to the organic coatings discussed, ceramic coatings produced by thermal spraying may also be removed from metal substrates.

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# STATUS AND DEVELOPMENT OF NUCLEAR POWER PLANT DECOMMISSIONING TECHNOLOGIES

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**Abstract**

The dismantling of more than 20 nuclear power plants has now been finished or is continuing toward completion of decommissioning. This experience has matured many technologies and clarified technological issues that remained to be solved. The paper reviews the status of the major decommissioning technologies used for large light water reactors throughout the world and the main development efforts in Japan. These cover decontamination, dismantling and remote operation, radiological characterization, waste processing and recycling, and systems engineering. Certain important issues, however, still remain, and require co-operation from a broad spectrum of various specialized fields. Intensified international co-operation will, therefore, be necessary for the safe and rational implementation of nuclear facility decommissioning.

## 1. INTRODUCTION

There were 440 nuclear power plants (NPPs) of over 10 MW(e) as of the end of 2001 in operation in 31 countries which have established nuclear power as a main electric power source. To date, approximately 80 NPPs have been shut down. Approximately 10 of these have been totally dismantled and the rest are in safe storage or in various stages of dismantling.

JPDR (Japan Power Demonstration Reactor), Niederaichbach, Shippingport, and Fort St. Vrain are examples of completed NPP dismantling. BR-3 (Belgium Reactor–3), Gundremmingen A, WAGR (Windscale Advanced Gas Cooled Reactor) and Greifswald in Europe, and nine NPPs such as Yankee Rowe, Trojan and Big Rock Point in the USA are examples of NPPs under dismantling and approaching completion.

Recently, however, due to plant life extension strategies, the number of decommissioning plants has not increased as anticipated. Another trend is a move toward early dismantling, as seen in the USA, France, Germany and the UK. This trend is caused by factors such as safety and security, cost increases during safe storage, the use of personnel familiar with the plant, avoidance of imposing undue burdens on future generations, as well as mature technologies to safely implement NPP decommissioning.

This does not mean that all rational and economical decommissioning techniques have been established. Decommissioning experiences have, however, clarified the availability of some techniques, while also clarifying the technical issues still to be solved. In the above mentioned examples, even major strategies may not always have a common evaluation. Reactor pressure vessels in Europe were cut into pieces. In the USA, however, they are removed in one piece without cutting. This is because the selection of the decommissioning strategy depends on such factors as the plant condition (number of units in the site, reactor type, operating period and history), decommissioning condition (safe storage period, future site usage, labour cost, and radioactivity inventory), and waste treatment and disposal policy (clearance system implementation, disposal facility availability, disposal cost).

In the middle of this century, when NPP decommissioning becomes a more common practice, society will be more advanced industrially and in age. The available labour force will also have decreased. It is, therefore, important to rationalize decommissioning further by mitigating the influence on the environment and by reducing undue burdens on society and individuals. From these perspectives, techniques such as wasteless decontamination, more autonomous remote operation, more effective and economic dismantling, environment friendly recycling, and systems engineering making full use of the database of previous decommissioning experiences assume more importance.

Regarding decommissioning technologies, there is an enormous amount of documentation related to development and application, including prominent reviews [1] and handbooks [2]. This paper focuses on the status of techniques applied for large light water reactors (LWRs) throughout the world and the important development work done in Japan.

## 2. DECONTAMINATION TECHNIQUES

Decontamination, a process in which contaminated materials are separated from non-contaminated materials, is an important factor in minimizing radioactive waste. This section deals with decontamination techniques for the hard and fixed contaminants of metal employing chemical, physical, electrochemical methods. Decontamination techniques for loose contaminants is omitted because such contaminants are easily removed, are commonly used and are various in type. Volumetric decontamination for metal is discussed in Section 5.2.2.

Before dismantling, systems and large components may be decontaminated to decrease their dose rate and the occupational exposure during dismantling, in order to ease the progress of the work. This form of decontamination may not, therefore, require complete removal of all contaminants. After dismantling, segmented parts of components may be decontaminated to attain 'below the CL' (clearance level) or the required recyclable level. Another important aspect is to minimize waste originating from decontamination.

## 2.1. Closed system decontamination

Decontamination has a long history in reducing the working atmospheric dose rate and has been used in in-service decontamination. The main feature of decontamination for decommissioning is that it is free from restrictions to prevent damage to the base metal, while in-service decontamination has such restrictions.

The HP/CORD (Permanganic Acid/Chemical Oxidation Reduction Decontamination) process developed by Siemens has often been used for the in-service decontamination of many NPPs. The process dissolves the oxide film through oxidizing chromium oxide by $HMnO_4$ and then reducing the ferric oxide by oxalic acid with only one filling of water. Manganese and dissolved iron collected by the ion exchange resin is the only waste, while the excess oxalic acid is decomposed into $CO_2$ and water by $H_2O_2$. For decommissioning, HP/CORD DUV (Decommissioning Ultra-violet light), an improved process to solve the base metal, was used in the German Mult-purpose Research Reactor (MZFR), Würgassen, Connecticut Yankee and so on. The DF (decontamination factor, i.e. the ratio of radioactivity before to after decontamination) was 10 (for carbon steel)~500, and decontamination waste was reduced [3].

The DfD (Decontamination for Decommissioning) process developed by the Electric Power Research Institute (EPRI) in the USA and Bradtec Decon Technologies is a process to dissolve ferric oxide film and base metal by $HBF_4$ (fluoroboric acid) and to dissolve chromium oxide film by $KMnO_4$. This process was used at Main Yankee and Big Rock Point. The resulting DF and waste volume were almost competitive with the CORD process [4].

As processes that focus more on solution of the base metal rather than the oxide film, cerium and ozone based SODP (Strong Ozone Decontamination Process) and strong mineral acids such as nitric acid and hydrochloric acid were tried to increase the DE. SODP, developed by Studsvik [5], was effective in demonstration tests for the steam generator (SG) tubes of Agesta, Dampierre and Greifswald, and actually used on the SGs of Agesta and

Ringhals-2. NUPEC demonstrated, using actual plant specimens, that hydrochloric acid with a reducing agent for BWRs and a kind of diluted SODP for PWRs achieved a DF of more than 100 [6]. Electrolytic dialysis was seen to reclaim hydrochloric acid, which is effective in reducing waste generation.

### 2.2. Large component decontamination

Decontamination of large components tends to generate large amounts of excess waste when it is fully filled by the decontamination agent. The spray method, foam method and strippable paint are the solution to this issue.

A gas cooled reactor's (GCR's) SG is a large component with low contamination and contains large areas of finned tubes. NUPEC carried out demonstration tests using Tokai SG tubes [7]. There are two types of oxide film: thick breakaway oxide at a higher temperature zone and thin protective film at the lower temperature zone. Their major components are $Fe_3O_4$ with $^{60}Co$ dominant. In comparison with blasting, chemical decontamination and their combinations, a combination of steel blasting and hydrochloric acid proved most effective in achieving the required CL. A combination of zirconia blasting and formic acid can also be a competitive method. Repetitive use of the blasting media, recovery of hydrochloric acid and the decomposition of formic acid were confirmed to decrease decontamination waste.

### 2.3. Decontamination of segmented parts

After dismantling, segmented parts may be decontaminated to attain 'below the CL' or the required recycling level. There are various methods to achieve this, depending on the contaminant involved, such as oxide film, adherent and base metal. Combinations of various methods could also prove effective.

Blasting was used in Würgassen, Fort St. Vrain and Trojan. Electropolishing with $H_3PO_4$ was used in Gundremmingen. In the USA, waste processors such as Duratek decontaminate segmented parts in their own facilities using the same type of methods mentioned above.

Typical blasting media are steel, aluminium and zirconia. Steel and aluminium, granular crushed particles (grit blasting), provide good grindability and provide fast, hard oxide removal. They are, however, easily degraded with repetitive use. Zirconia, a spherical particle (shot blasting), provides slow hard oxide removal but has less degradation in repetitive use.

Electropolishing and REDOX (Reduction and Oxidation) decontamination are effective for segmented parts. In the electropolishing process, as the superficial base metal is dissolved due to the electric current between the metal and the electrode, the polished surface comes close to being flat. In chemical decontamination such as a REDOX process (cerium 4 valence in nitric acid), the surface is dissolved, depending on the concentration of the agent even within crevices or gaps. The dissolution rate in a deep gap with a 0.02 width/depth ratio was seen to be a half that of a flat surface [8].

Ordinary electropolishing (monopolar type) involves manually connecting a power supply anode to the radioactive metal waste. This handling process is time consuming and results in radiation exposure for the operators. NUPEC and Toshiba have developed a bipolar electropolishing technique in which the anode is not directly connected to the metal waste. Instead, the waste is set in a basket equipped with an insulator and anode (Fig. 1). While the dissolution rate of the bipolar electropolishing is half that of ordinary monopolar electropolishing, it does save a great amount of time for plates and piping [9]. The decontamination of tritium demands a different approach. Heating is known to be an effective decontamination method for tritium existing in metal as a solid solution. JAERI reported [10] that drying (100°C) lowered the adhered tritium of the samples taken from tritium contaminated piping. The drying could be easy and effective enough for parts with less oxide film and low tritium contamination to achieve below the CL, though the heating method (over 250°C) could reduce this more drastically.

## 3. DISMANTLING TECHNOLOGY

The main components in NPP dismantling are the reactor pressure vessel, the reactor internals (or core internals), and the concrete structures such as the biological shield wall (BSW).

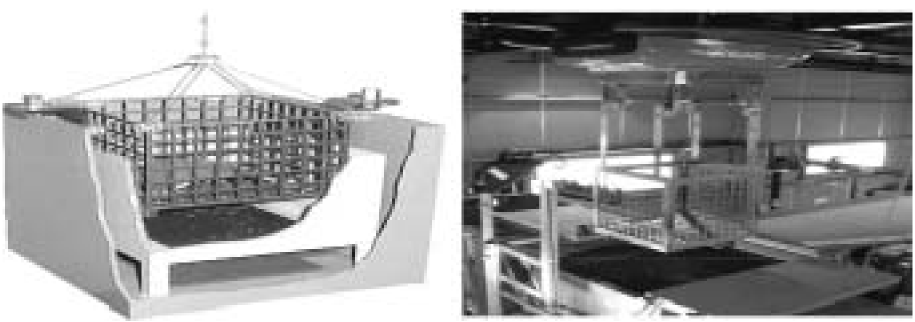

*FIG. 1. Bipolar electropolishing.*

### 3.1. Reactor pressure vessel dismantling

A reactor pressure vessel (RPV) is a thick steel component that contains peak radioactivity after a long period of operation. Therefore, segmenting an RPV requires a reliable cutting method that generates less secondary waste, remote operation to minimize worker exposure, and measures to minimize radioactivity scatter during normal cutting operations or in the event of an accident.

In the USA, one piece RPV removal without segmentation is a common practice. While it looks like a simple, cost effective removal method, transportation and its acceptance by the disposal facility are basic prerequisites for its adoption. For the application of one piece removal, it is vital that regulatory issues be cleared. These include the radioactivity concentration averaging in the RPV that allows the one piece to be low level waste (LLW), and mitigation of the drop height for reliability analysis according to the actual transport condition, as approved by the United States Nuclear Regulatory Commission.

Reflecting on the history of one piece RPV removal without segmentation, the first instance was JAERI's JRR3 research reactor wherein the RPV and surrounding BSW were removed in one piece in 1986 [11]. In the USA, subsequent to Shippingport (1988–1989), the RPVs of Yankee Rowe and Trojan were removed in one piece. However, only at Trojan was the RPV removed with its core internals intact [12]. Following dismantling, plants in the USA prepare to remove the RPV as one piece. In Finland, Loviisa plans to remove the RPV in one piece [13], as the repository is on-site. One piece removal can decrease transportation risk and may not require transportation vessels for the RPV. It does not, however, always have economic merit when the waste disposal unit cost is high, since the volume of the RPV is so large. An approach to solving this problem is to fill the RPV with radioactive metal and concrete waste.

The experience of large RPV cutting has been quite limited throughout the world until now. The RPVs of LWRs are mostly formed from CS (carbon steel) with SS (stainless steel) cladding. For these, two types of cutting method have been used, mechanical cutting and thermal cutting. Employing mechanical cutting, a submersible band saw and milling cutter were used for BR-3 [14]. Mechanical cutting is feasible because of the easy treatment of the secondary products. There is some difficulty in adapting it for large NPPs due to the large diameter and thick material of the RPVs. JPDR was cut using an arc saw [15]. NUPEC demonstrated underwater arc gauging/flame cutting using a simulated large RPV (420 mm CS with 10 mm SS cladding) [16].

### 3.2. Dismantling reactor internals

It is a common concept that the reactor internals of an LWR should be cut under water to ensure shielding and to minimize radioactivity scatter. Plasma arc cutting was reported to be good for small reactors such as JPDR and MZFR. However, there still remain such problems as transparency loss, high soluble activity and so on [17]. The abrasive water jet method was applied to Main Yankee, Connecticut Yankee and San Onofre 1. This method also extends problems such as transparency loss and high abrasive waste generation.

For the WWER reactors in Greifswald, the non-contaminated reactor components of Units 7 and 8 were transported to Unit 5 in the trial operation and were cut there as a model dismantling. The highest activity core internals, such as the cylindrical jackets of the core basket, were cut with an underwater band saw in the cutting pool, while the RPV was cut by an aerial band saw in the dry cutting area [18].

Regarding GCRs, although few reactor internals have ever been cut as part of actual decommissioning, they are planned for aerial cutting because a GCR area cannot retain and drain the water filled in the RPV. Flame cutting is planned as one option because the GCR RPV is formed from CS.

Using models simulating actual reactor internals in terms of size, shape and material, N1JPEC demonstrated LWR reactor internal cutting by laser that provides good cutting performance with narrow kerf breadth. A 20 kW CO laser could cut SS up to 150 mm under water and to 300 mm in air [19]. The CO laser is transferred by a mirror, while the YAG laser and COIL (Chemical Oxygen Iodine Laser) can be transferred by optical fibre. A 10 kW YAG laser was seen to cut CS up to 90 mm in air and a complex of CS (80 mm) with insulator (200 mm) in air [20]. RANDEC (Research Association for Nuclear Facility Decommissioning) and Kawasaki Heavy Industries confirmed that a 7 kW COIL could cut 80 mm SS under water [21].

### 3.3. Biological shield wall and activated concrete

As the inner layer of the BSW is activated by neutrons from the core, cutting to separate the activated part is necessary in order to minimize the radioactive waste volume. The building's contaminated concrete surface also needs to be cut to the depth to which contamination extends. A large excavator with a hydraulic shear or hammer was used for demolition of the BSW and all concrete structures in the containment of Trojan, as well as for reducing it to rubble.

A diamond wire saw was used for cutting the highly active concrete of the BSW of Fort St. Vrain, Niederaichbach and other sites. The advantages of this technique are less dust generation and more accurate sizing. Where the active concrete is classified into more than two waste categories, accurate sizing is more important to minimize the volume of the higher level waste. RANDEC and Takenaka demonstrated dry diamond wire saw cutting using an actual BSW model. Cutting without cooling water is an important advantage in 'no-liquid' radioactive waste generation [22]. Taisei improved the BSW cutting operation with a diamond wire saw and core boring to allow workers access from only one side of the wall.

### 3.4. Remote robotics

Various working and inspection robots have been developed and applied to the high dose areas of NPPs. Beyond the conventional robots used in regular work such as refuelling and inspections, robots for decommissioning must be able to cut and handle heavy components and also be able to constantly change position.

NUPEC has installed a GCR RPV replica (approximately 1/12 division) and has demonstrated remote dismantling for the GCR RPV and reactor internals using a 6-axis mast type manipulator (Fig. 2). Gripping and transferring large components (payload 1000 kg), cutting and transferring tube bundles are included in the demonstration tests [23].

Based on the JPDR dismantling experience, JAERI has developed dual arm manipulators for future dismantling activities [24]. This unit consists of two electrically powered manipulators, end-effectors and a control system with image feedback and force feedback. Using the control system, the manipulators are able to efficiently carry out remote dismantling activities such as cutting, radioactivity measurement and decontamination.

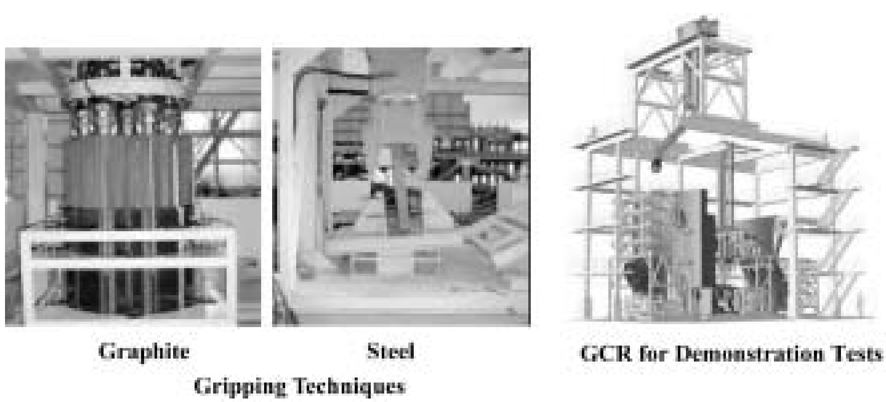


*FIG. 2. Demonstration tests for GCR dismantling.*

# 4. RADIOLOGICAL CHARACTERIZATION

Characterization is a key issue for decommissioning planning and implementation. Overall characterization can be roughly assumed based on design (reactor type, output, structure, material composition), operational history (operational period, troubles) and previous experiences. Detailed characterization needs sampling and measurement for precise evaluation of the radionuclide distribution in the facility [25]. This section deals with the radiological characterization necessary for decommissioning planning, the works plan and waste disposal.

## 4.1. Pre-dismantling radioactivity measurement and material release

Radioactive materials can be divided into two categories: activation and contamination. Activity caused by activation can be evaluated depending on the neutrons and elements in the reactor components. Regarding neutron data, a wide range of operational data are available for core areas, but very little data are available for outside the core area, which needs to be measured. Core drilling and slicing procedures for concrete sampling and in-laboratory analysis have been established.

The neutron flux during reactor operation for outside the RPV core area is an important factor in deciding whether or not the material is below the CL. Boner Ball detectors are normally used for this purpose. JNC (Japan Nuclear Cycle Development Institute) reported [26] that gold foil detectors during operation helped to estimate more accurate activated activity concentration on the CL.

Contamination occurs during reactor operation as radioactive materials transfer and deposit depending on various factors such as the prevailing water chemistry. Therefore, sampling and measurement are necessary for precise evaluation to determine the nuclide composition and concentration. After determining the full radionuclide composition for a certain area, the measurements can be limited to key radionuclides, for example $^{60}Co$, or the gross activity. Full radionuclide composition can be estimated based on relative factors (nuclide vectors or scaling factor). Tritium and $^{14}C$ need to be evaluated separately because their behaviour may not be related to the other major nuclides. Both of them need laboratory analysis for ‘difficulty’ in direct measurement.

Regarding free release or clearance for buildings, soil and solid materials, regulatory authorization has often been given on  case by case bases. Recently, some countries have established regulatory authorization based on dose rate per year. In Germany, for example, the Radiation Protection Ordinance amended in 2001 provides radionuclide specific clearance values for material, buildings and sites, and German standard (DIN 25457) provides the procedure. In the USA, the Radiological Criteria for License Termination (10CFR20.1401 1406) provides release criteria for buildings and soil, and the MARSSIM (Multi-Agency Radiation Survey and Site Investigation Manual, NUREG 1575) provides a manual to judge release of the buildings and soil according to the DCGL (Derived Concentration Guideline Level). In Japan, the Nuclear Safety Commission issued the radionuclide concentrations for clearance level (1999) and the clearance concept (2001). On the basis of these, RWMC (Radioactive Waste Management Funding and Research Center) drafted a manual of regulatory authorizations for clearance (2002). The legal framework of the clearance release is still in preparation in Japan.

### 4.2. Building radioactivity measurement

Generally, the buildings in the radiologically controlled area (RCA) are demolished after removing contaminated equipment and after confirming that no contamination exists. When the JPDR final confirmation survey was implemented in 1992–1995 [27], the CL system was not established yet. Therefore, 100% of all RCAs were scanned by portable survey meters and many samples were measured in a laboratory using a germanium detector. As this confirmation survey is very time consuming, covering hundreds of thousands of square metres for a large NPP, it must be done in a rational manner.

Trojan's Final Survey for the Containment Building was finished by manual survey in 2002 according to the DCGL derived from a dose analysis model (D&D) and the MARSSIM, this being the first case of an NPP in the USA. The manual provides ways to classify the impacted area into three classes and a non-impacted area to determine the appropriate scanning area and number of measurements for rational assessment.

Electricité de France carried out zoning and dismantling of a building of Brennilis (Monts d'Arree) in 2002 and released the non-contaminated concrete according to a cleanup procedure, which was based on a study of actual plant contamination and agreed by the French safety authority. While in principle the zoning is described as being without radioactivity measurement, it actually includes confirmation by measuring the object after the cleanup.

NUPEC developed scanning and static semi-automatic measuring devices and demonstrated them at Tokai [28]. The scanning device is provided with two layers of plastic detectors to decrease background influences, combined with wavelength shift plates to detect 10 cm × 10 cm units of contamination. A fully automatic scanning robot, which mounts this scanning device on the Mobile Automated Characterization System (MACS) developed by ORNL, was demonstrated at Tokai (Fig. 3) [29]. For a final confirmation survey, a static device equipped with a high efficiency germanium detector was seen to detect 1 m × 1 m units efficiently.

### 4.3. Solid material radioactivity measurement

The radionuclide concentration of solid materials must be measured prior to their release, disposal and/or recycling. Because the background may influence accuracy around the CL very greatly, the measurement needs to be accurate and effective.

A shielded bulk chamber with 24 plastic detectors was used for an accurate measurement of the CL at Würgassen [30], with 12 liquid detectors in Niederaichbach, and 2 large plastic detectors in Marcoule G2. For this, specialist manufacturers offer special measuring devices for the decommissioning wastes.

NUPEC developed a device that consists of two plastic detectors to accurately measure large volumes of waste [31]. In this unit, objects are placed in a cage with a 50–100 cm breadth between the detectors. The ratio of the scatter ray/direct ray compensates for self-absorption errors caused by the waste itself. The performance of this device was demonstrated to measure the CL of waste (1 $m^3$ max.) in 10 minutes at Tokai.

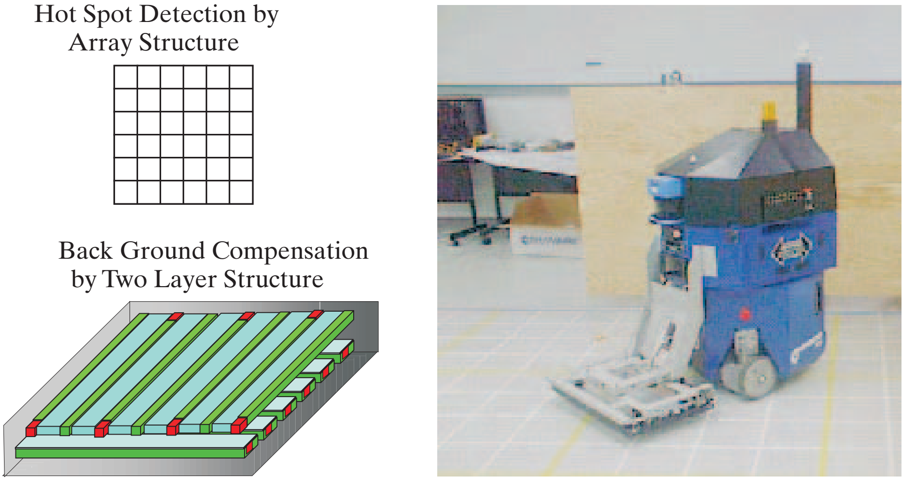


*FIG. 3. Scanning device and automatic scanning robot.*

# 5. WASTE PROCESSING AND RECYCLING

NPP decommissioning generates a large volume of concrete and metal waste. Waste processing such as stabilization, compaction and volume reduction may be used for safe and economical disposal. Recycling of dismantled material contributes to conservation of natural resources and protection of the environment. Some innovative recycling techniques may provide a final solution for sustainable use of the material for the future. Life cycle assessment may support their adoption. This section covers waste processing and recycling of concrete, metal and graphite.

## 5.1. Concrete waste treatment and recycling

Radioactive concrete waste is usually crushed and packaged into containers, and disposed of in a waste repository. Non-radioactive or CL concrete has been used for roadbeds and backfill, or disposed of as industrial waste. The concrete from Niederaichbach was used for roadbeds in the vicinity of the site [32]. That from the JPDR was used as backfill for the site where the buildings stood. Duratek disposes its concrete waste as industrial waste when it passes a specially authorized device named GIC (Green Is Clean) [33].

### *5.1.1. Radioactive concrete for mortar filling*

In many countries, radioactive concrete waste is solidified in the containers as required by the disposal facility. In Japan, waste containers to be disposed of as LLW in repositories must be solidified by mortar into one single piece to provide sufficient strength specified for the disposal facility. Until now, LLW concrete rubble is pre-placed in the containers and solidified with mortar containing ordinary fine aggregate. This method provides approximately 50 vol% of LLW concrete fill ratio per container. Increasing the radioactive waste fill ratio, which is inversely proportional to the disposal volume, is an important factor in cost saving.

NUPEC has developed a process to utilize radioactive concrete as the fine aggregate for the mortar filled in waste containers [34]. Dismantled concrete, blocks and rubble are crushed and sieved for recycled aggregate (Fig. 4). Mortar containing the recycled aggregate was seen to provide sufficient strength at the proper mixing proportion (water/cement ratio and recycled aggregate ratio). It was confirmed that this process could increase the radioactive fill ratio by up to 75 vol%, which is equivalent to approximately 40 vol% of waste reduction. Similar approaches have been studied in SCK-CEN [35] in Belgium.

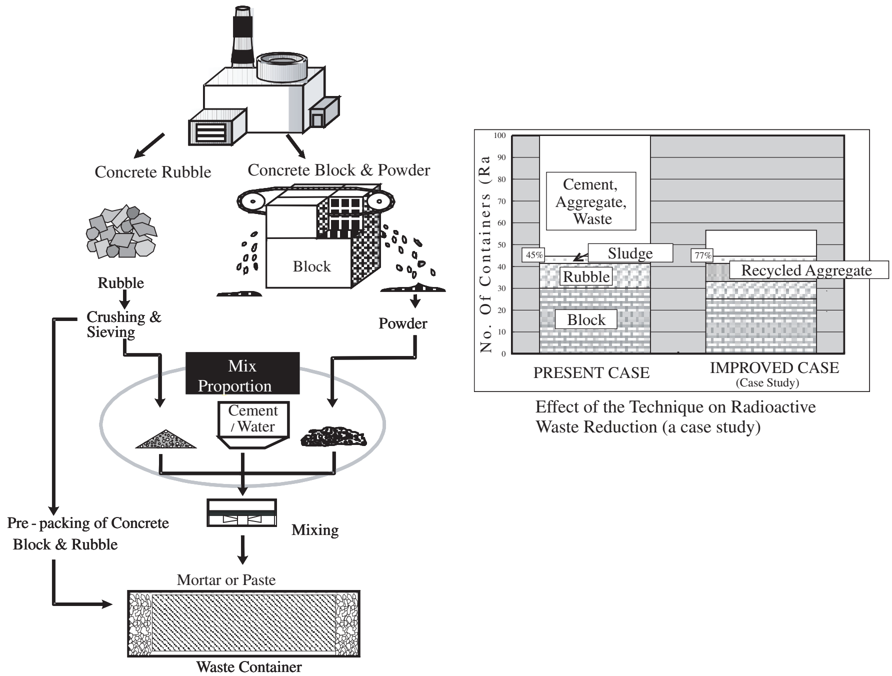


*FIG. 4. Use of radioactive concrete for mortar filling.*

### *5.1.2. High quality recycled aggregate from concrete*

Concrete disposal into an industrial disposal site will not be a solution, especially in the future, because of decreasing site availability. It is therefore important to find general recycling options that do not limit the use of concrete to roadbeds or backfills. Such recycling options could provide decommissioning operators the best choice in meeting the site specific decommissioning case.

NUPEC has developed techniques for high quality aggregate reclamation and byproduct powder usage for the concrete occurring from NPP dismantling. With regard to reclamation techniques, the heating and grinding method showed that the reclaimed aggregate achieved the nuclear facility grade aggregate standard (density: 2.5 g/cm$^3$ min; absorption: 3.0 weight % (wt%) max.) and mechanical grinding methods achieved the aggregate standard (density: 2.5 g/cm$^3$ min; absorption: 3.5 wt% max.) for general building structures in Japan [36]. The concrete using the recycled aggregates has been tested for its strength, durability, construction, etc. For demonstration purposes, a model building (50 m$^2$) was constructed using the recycled aggregate concrete in 1999 (Fig. 5). Thus far, the results show that the performance of the recycled aggregate concrete is equivalent to ordinary aggregate concrete.

The byproduct powder could be a source of waste if it is not properly utilized. Therefore, for effective usage of the powder. NUPEC demonstrated the maximum powder availability for such products as cement raw material (50 wt% to cement), cement admixture (20 wt% to cement), paving block (30 wt% to the block), soil reformation material and others.

### 5.2. Radioactive metal waste treatments and recycling

Radioactive metal waste is usually treated for volume reduction, then packaged and buried at waste disposal sites. Very low radioactive metal has been recycled for waste containers and shielding blocks. The recycled containers were manufactured for trial or actual use at GNS/Siempelkamp, Marcoule, and Manufacturing Sciences Corporation (no facility now). Duratek has manufactured shielding blocks of over 80 000 t, but has now reduced production.

Non-radioactive or CL metal waste has been released as scrap without restrictions. For slightly contaminated metal, Studsvik offers melting service for unrestricted release of ingots in Sweden that includes storage to allow for radioactive decay over a maximum of 20 years. When unnecessary equipment to be discarded meets a user's need, it can be reused. Making a list of such equipment and seeking users from a broad area is an effective method for reutilization commonly practiced in many countries.

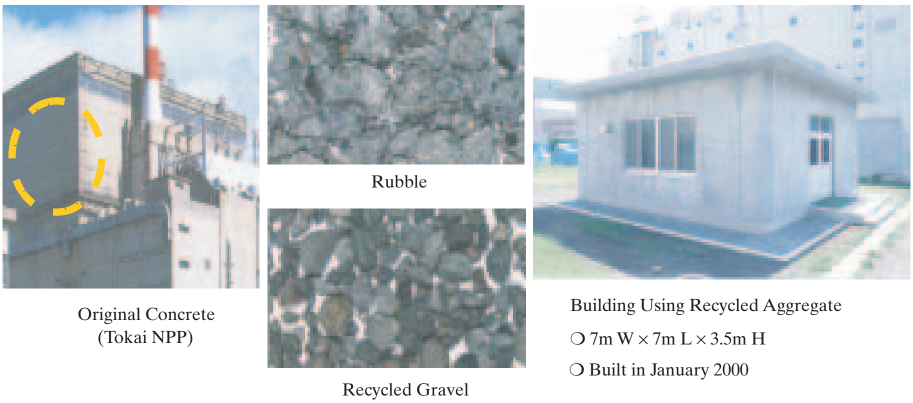


*FIG. 5. High quality recycled aggregate.*

*5.2.1. Molten metal casting*

Mortar may be used as filler to solidify radioactive metal in waste containers. This method attains 10–20 vol% of the radioactive metal fill ratio. Melting can also minimize the metal volume.

The method that 'pre-places' relatively higher radioactive metal without melting and fills lower radioactive molten metal as shield material is another rational process. Pre-placing the reactor components of Gundremmingen A, GNS and Siempelkamp confirmed this method. A monolith container showed good filling performance [37].

NUPEC studied the thinner waste container to increase the radioactive fill ratio as an improvement to the monolith container. When the container material is thinner, the container becomes wider and needs a larger amount of filler metal and more heat protection against container damage. A half-scale test showed that the thin container (6 mm) with a proper layout of the heat removal blocks suffered no harmful distortion when the molten metal is poured at the proper temperature. This improved method would substantially increase the radioactive metal fill ratio per container (1.8 times in a case study) [38].

*5.2.2. Pyro-metallurgical separation*

Decontamination is applied to surface contaminated metal, while decontamination to volumetrically contaminated metal is very limited. Separation of LLW metal to obtain a lower radioactive category of waste would be feasible when the cost for the separation is lower than the cost for waste avoidance.

NUPEC developed a pyro-metallurgical separation technique to separate cobalt and nickel from iron. This technique oxidizes the radioactive metal and then reduces the oxidized metal, based on the principle of different oxygen affinity of each element. Prototype scale tests using 10 kg of metal specimen showed that cobalt could be separated with DF 100 and a recovery factor of 70 wt% [38].

## 5.3. Graphite waste treatment

Graphite used in a GCR moderator and reflector is one of the highest radioactive wastes occurring from dismantling. Generally, graphite is assumed to be removed from the RPV, its volume reduced, packaged and disposed. Most of the graphite used for GCRs is still stored in the core structure after shutdown. The WAGR's graphite is stored in a storage facility on the site. That of Tokai will be removed from the core from 2013 onwards.

### *5.3.1. Safe handling of graphite waste*

Graphite is non-combustible. The Brookhaven National Laboratory (BNL) experimentally confirmed [39] that the block is the least probable to cause a fire or powder explosion during handling because it does not burn or continue combustion unless heated to over 650°C and is also provided with an adequate air (oxygen) supply. NUPEC confirmed BNL's results as appropriate under indirect heating, while graphite does not continue combustion below 1500°C under direct heating [40]. With due regard to combustible tendencies provided by its irradiation and the impurities it contains, graphite will not burn or explode during decommissioning.

### *5.3.2. Graphite crushing and filling*

When the graphite used for the moderator and reflector in the GCR is packaged, as it was without treatment, the fill ratio in the waste form is approximately 30 vol%. Disposal costs will be lowered by volume reduction, when it is paid by volume. NUPEC confirmed that the graphite fill ratio can be increased to 70 vol% by filling the cut pieces and the crushed pieces into the remaining void, this being followed by grouting to achieve good filling and solidification as a waste form [41].

### *5.3.3. $^{14}C$ separation for graphite incineration*

Incineration is an optional graphite treatment. It provides an advantage of solid waste volume reduction, but also the disadvantage of $^{14}C$ (half-life 5730 years) release into the atmosphere. NUPEC has been developing a $^{14}C$ isotope separation and retrieval technique [41]. This is an absorption process that uses Na-X type zeolite, targeting a 1/100 $^{14}C$ release rate, assuming concentrated $^{14}C$ to be solidified as carbon by the Sabatier-Senderens reduction method. Until now, the concentration ratio per one column (1000 mm in length) is 2.5, according to small column tests ($^{14}C$) and bench scale tests ($^{13}C$). This is a feasible value to materialize a graphite incineration process.

## 6. SYSTEMS ENGINEERING

As seen above, there are currently no technical issues that prevent NPP decommissioning. There are, however, issues regarding systematic rationalization, through proper combination of techniques, to implement safe and effective decommissioning of NPPs There are several aspects of rationalization. First, cost reduction is the most important aspect to be rationalized. This relates to labour (person-hour and unit cost), waste (quantity, unit cost, the CL system), timing of dismantling (immediate or deferred), techniques available, administrative procedures, etc., because these are the major cost drivers. Individual exposure and environmental impact are also important aspects which relate to decontamination, protection of radioactive material release, waste minimization and recycling. For NPP decommissioning planning, the first step must be to learn from past experiences. Much data have been gained and collected [42] from past technical developments and practices on NPP decommissioning, which are summarized as a database together with evaluation tools [43].

In Japan, JAERI developed COSMARD (Computer System for the Planning and Management of Reactor Decommissioning), including a database of JPDR, an expert system for decommissioning planning, and an evaluation code for worker exposure, together with a dose rate display program (Fig. 6) [44]. JNC is developing a database for the Fugen decommissioning as well as a 3D CAD program [45]. RANDEC has been renewing the decommissioning database that contains 4000 items of literature and the decommissioning experiences of 104 NPPs and 90 research reactors [46]. CRIEPI (Central Research Institute of Electric Power Industry) has developed a computer code, the Decommissioning Recycle Simulator, to find the most feasible recycling options for site specific decommissioning waste [47].

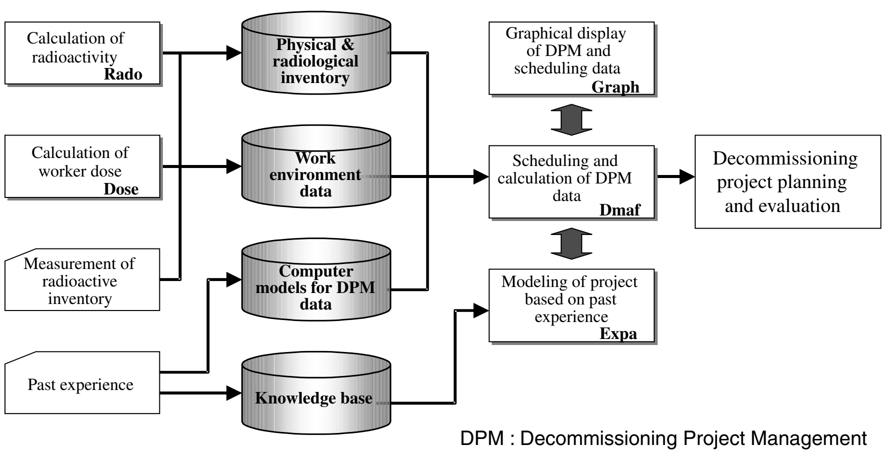


*FIG. 6. Computer program and database in COSMARD.*

## 7. SUMMARY

The status and development of NPP decommissioning technologies have been summarized, focusing on the status of techniques applied to large NPP decommissioning throughout the world, together with various key techniques developed in Japan. As seen in NPP decommissioning activities as well as upgrading works in operating plants, techniques are available for all needs. Some issues, however, still remain, especially with regard to systematic rationalization. Important development work relating to these issues is ongoing. The following are examples of the issues:

— Reactor internals cutting,
— RPV one piece removal,
— Regulatory authorization on the CL,
— Radioactive waste minimization,
— Waste recycling.

Solutions to the issues may depend on the conditions specific to the plant in question. However, there are some similarities that require co-operation from a broad spectrum of specialty fields to find common evaluations. International co-operation and collaboration will, therefore, become increasingly necessary for safe and economical plant decommissioning.

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# DECOMMISSIONING OF URANIUM–GRAPHITE NUCLEAR REACTORS AND RADIOACTIVE WASTE HANDLING

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**Abstract**

In accordance with the agreements between the Russian and US Governments on completion of weapons plutonium production, ten powerful industrial reactors were unloaded and decommissioned in the Russian Federation. Three such reactors, I1, E2 and ADE3, were decommissioned after 30 years of operation. The decommissioning concept started in the middle 1990s, comprising the dismantling of low-activity structures, sealing of all reactor outlets, and filling of all reactor spaces with special compounds of concrete and betonite. All these arrangements ensured multi-level protection with a number of safety barriers between the reactor and the environment. As a result, the suggested decontamination and decommissioning concept allowed qualification of the structure under the IAEA's Stage 2 and ensured its safety for over 300 years. The presence of radiation and restricted access to the reactor components led to the development of remote controlled equipment and for electrical contact or mechanical cutting methods, for welding and remote sampling of radioactive metal and other items. The paper also discusses the cost of the work that has been performed, personnel exposures, the quantity of filling materials consumed for the support structures, as well as the handling of radioactive wastes (i.e. reactor products). The ways they were unloaded, their selection, how they were contained, their transport and termination are described. Particular attention is paid to the use of special compounds with betonite ingredients as a protection against radiation, which ensures multi-layered protection for radioactive waste on the basis of the 'matrix–isolation–coat' principle. This allows the radioactive waste to be stored at a decommissioning site.

## 1. INTRODUCTION

The decommissioning of reactors includes organization and engineering activities for dismantling, deactivation, removal and safe disposal of radioactive materials and wastes, parts and components, in order to achieve the desired reactor condition while observing safety measures and criteria during the performance of the work [1, 2]. Decommissioning work has the aim of reducing the radiation danger of the reactor. The final condition of the reactor should be characterized by a minimum of danger from radiation, or a high level of radiation safety, while striking it off the plant's inventory.

Methods of reactor decommissioning differ on the basis of the scope and duration of dismantling, decontamination, removal and disposal of radioactive waste, parts and components. There are two basic methods of decontamination and decommissioning (D&D) for uranium–graphite reactors:

(1) Decommissioning of the reactor in the vault and dismantling of components after previous (long or short term) conditioning of the reactor and components contaminated by radionuclides.
(2) Decommissioning of the reactor in the vault and dismantling of components without previous conditioning of the reactor and components contaminated with radionuclides.

The engineering aspects of closed site rehabilitation will be considered within the framework of these D&D methods,. These aspects mainly comprise the means of handling radioactive waste located at the site. Attention will also be paid to the actual D&D activities for three industrial power uranium–graphite reactors.

## 2. BACKGROUND AND BRIEF DESCRIPTION OF THE WORK

### 2.1. Background

As mentioned above, in accordance with the agreements between the Russian and US Governments on completion of weapons plutonium production, ten industrial uranium–graphite reactors (IUGRs) were unloaded and decommissioned in the Russian Federation. Three such reactors, I1, E2 and ADE3 commissioned in 1955, 1957 and 1961, were decommissioned in 1989, 1990 and 1992, respectively. After decommissioning and fuel removal, the main problem was that of radioactive waste. All radionuclides were produced during the operation of the IUGRs. Their production was a result of both radioactive material fission and of the structures' neutron exposure. Nuclide forming occurred not only in the reactor's core, but also in the closed support protective structures. In addition, during the service period a lot of radioactive waste was accumulated in the storage facilities — replacement reactor parts, tools, etc.

## 2.2. Description of the reactor structures

A brief review of the design of these reactors shows, that they include a heavy graphite stack, aluminium tubes charged with fuel elements made of metallic natural enriched uranium and control system elements. The closed support and protective structures are made of carbon and corrosion resistant steel. The protective structures are filled with a sand and iron ore mixture, and the side structures are filled with water. The overall mass of the metal structures is over 3000 tonnes. The water coolant used was: refined river water for the I1 reactor, and purified, chemically condensed water (95%, 99%) for the E2 and ADE3 reactors. After the reactors' shutdown the systems for humidity, temperature and radioactivity monitoring continued to operate.

## 2.3. Methods of decommissioning

The problem of the reactors' decommissioning has two aspects:

(1) The nuclear facility itself after its shutdown;
(2) Radioactive waste storage facilities (reactor products).

For the D&D of specified types of reactors a method of low activity reactor structure dismantling was chosen and implemented. The remaining structures were left in the vault and all reactor outlets were sealed to the environment. The support structures were secured, and the biological shield tanks, the reactor space and some of its cavities were filled with a special compound of concrete in a betonite base. All these arrangements ensured multi-level protection, with a number of safety barriers between the reactor and the environment. As the first barrier all the cavities in the core material were filled with natural materials in a concrete base. The second barrier is metal and hermetic, using as a basis the metal structures that form the reactor's surroundings, and improved by sealing and filling the biological shield tanks with concrete. The third barrier was the vault itself based on the structures surrounding the shaft. Concrete walls were formed and the lower structures were concreted, etc. The fourth barrier was the surrounding strengthened building structures. Additional safety barriers were also provided [3, 4].

As a result, the suggested D&D concept allowed qualification of the structure under the IAEA's Stage 2 and ensured its safety for over 300 years [5]. The concept of safe conditioning of reactor facilities, isolation from the environment and radioactive waste disposal is the first and main task in developing a D&D strategy and bringing an area to a partially usable condition.

### 2.4. Technology and equipment

A high radiation level and inaccessibility of the reactor components demanded that special technologies be developed for remote cutting of the channel pipe over the protective plate, as well as methods of remote cutting of holes in metal structures to fill them with special compounds, remote welding of seals to isolate the reactor from the environment, and technologies to cut specimens out of the material after neutron exposure in order to study its changed properties [3]. In order to develop these technologies, the following special equipment was developed: remote controlled equipment for plasma, electric-contact and machined cutting; remote controlled welding machines for sealing of the channels and other pipes; transport arrangements; cutters for pipelines of the humidity/temperature monitoring systems and for other structural parts. Special betonite based compounds were also developed whose fluidity guaranteed complete filling of any reactor cavity in the project. Special technologies and equipment were needed to apply about 2200 $m^3$ of the compound to each reactor thorough the above mentioned remotely cut holes. Great attention was paid to quality inspection of the filling and welding operations. For this purpose special optical and TV systems were used.

Work on two reactors of the Siberian Chemical Plant has just reached the final phase. The total exposure of the personnel is within permissible limits. A complex engineering–radiation study was performed on the A, AB1, AB2 and AB3 reactors in the NPO MAYAK Enterprise, the results of which should help to define the scope of the work. The decommissioning principle will be the same.

### 2.5. Financial conditions

In 1993, work started on the Siberian Chemical Plant for decommissioning of two, and later three, uranium–graphite reactors, which also included review of the project development and manufacture of equipment and accessories. The financial plan became the basis of the Branch Programme accepted by the Ministry, and the consolidated resources developed on the basis of this plan were used for the Branch tasks.

During the research, project, manufacturing, and reactor maintenance stages the expenses exceeded 3 billion rubles. By 2010 over 8 billion rubles will be needed for all the work on three reactors and storage facilities on the plant's site, depending on the method of decommissioning, inflation rate, personnel salaries, etc.

### 2.6. Radioactive waste handling in storage facilities

The most important problem both in the Russian Federation and in the rest of the world is the problem of radioactive waste handling, in this case of reactor products. The quantity is tremendous. Solid radioactive wastes include over 90% of all wastes. There are three groups of radioactive waste based on their activity. Based on potential danger, the waste is defined as short lived and long lived. The short lived comprise low and medium waste containing mainly beta and gamma radionuclides with a short half-life (up to 30 years), with the potentially dangerous period extending to 500 years. The long lived waste comprises radionuclides with a long half-life (over 30 years), mainly transuranium and transplutonium elements. The potentially dangerous period, after which the waste does not need inspection or any restrictive/protective measures, is assumed to be 8–10 half-life times. As was mentioned, the largest group of waste is the solid radioactive waste group (up to 98%). The main D&D task is therefore the solution of the solid waste handling problem (Table I).

The solid wastes are considered to be radioactive if they meet one of the following criteria:

(1) Gamma dose capacity is over 1 μSv/h at a distance of 0.1 m from the surface.
(2) Specific activity for beta sources is over $7.4 \times 10^4$ Bq/kg; for alpha sources it exceeds $7.4 \times 10^3$ Bq/kg.

TABLE I. SOLID RADIOACTIVE WASTE CLASSIFICATION FOR GAMMA, BETA AND ALPHA EMITTERS

| Radioactive waste category | Specific activity (kBq/kg) | | |
|---|---|---|---|
| | Beta radionuclides | Alpha radionuclides (except transuranium) | Transuranium radionuclides |
| Low active | to $10^3$ | to $10^2$ | to $10^1$ |
| Medium active | from $10^3$ to $10^7$ | from $10^2$ to $10^6$ | from $10^1$ to $10^5$ |
| High active | over $10^7$ | over $10^6$ | over $10^5$ |

(3) Fixed surface contamination for beta sources is over 500/cm$^2$ min for alpha sources: over = 5/cm$^2$ min.

There is no necessity to detail the radioactive waste conditions, since they are obvious to everyone. These include the radioactive waste comprising reactor parts and components after in-service neutron exposure. Their contamination results mainly through radiated activity and surface contamination; their volume is about 13 000 tonnes. There are also wastes from in-service contact with the coolant, or of contact with surfaces of contaminated parts. The mass of this waste is over 15 000 tonnes.

Taking into consideration other waste (building, repair or protective waste, etc.), the total quantity should be about 50 000 tonnes. The radionuclide composition of the radioactive waste is known. The most studied is the composition of both the graphite stack and its parts. Depending on their locations, the specific activity can be varied up to 400 times. The main radionuclides are $^{3}$H, $^{14}$C, $^{60}$Co, $^{137}$Cs and $^{90}$Sr. The full analysis of the graphite condition is for another report. In this area there is some interesting work from our English colleagues.

*2.6.1. Direction 1*

Minatom in the Russian Federation has made an effort to create a technological centre for the development and implementation of low cost innovative technologies. The goal is to create the conditions for the long term safe storage of radioactive waste. Two main directions have been defined: radioactive waste unloading from storage facilities, partial selection, fragmentation, containment, filling of loaded containers with concrete compounds, transportation and storage in special premises of ‘terminated’ reactors.

In pursuit of this, special technologies, systems and equipment were developed. They comprised remote controlled grasping, holding, cutting and transport machines, ventilation systems for radioactive waste, selection, containment, filling of loaded containers with betonite base compounds, transportation of containers and storage at sites provided by the project. At the present time this work has not started yet. It should be noted that the performance of this work will lead to the contamination of territory and to a high level of personnel exposure, even after the observance of safety requirements.

### *2.6.2. Direction 2*

The second direction for radioactive waste handling is to extend the method used for reactor decommissioning itself, that is waste isolation using the model of radioactive waste localization by geochemical barriers in the natural environment. A practical capability of waste treatment with fluid clay solutions was studied. Laboratory studies showed that application of the clay cementing mass could guarantee non-release of radionuclides, both in gas and ion solution forms beyond the concrete protection for the storage.

In order to substantiate the selected decision, research work is being performed for definition of the composition of the clay filling material, and the means of its supply to the storage facility. At present, such a storage facility has been chosen and the necessary equipment and methods of reliable filling are being developed. Testing of this method and evaluation of the results are planned in the next few years.

## 3. CONCLUSIONS

The following conclusions can be drawn as a result of the data presented above:

— The D&D concept ‘termination on site’ for uranium–graphite reactors has been accepted and implemented in the Russian Federation for the I1, E2 and ADE3 reactors, with the capability to dismantle the rest of the equipment at the same time.

— A system of protective barriers (multi-level protection) is being developed in order to avoid environmental pollution from disposed radioactive waste and to protect the other reactor components from external natural or technical influences.

— A special monitoring system has been provided for the inspection of storage parameters, including measurements of temperature, humidity, gas composition, radioactivity, and location of support metal structures. A system of special environmental drill holes is provided on the site for inspection of the conditions.

— Unique technologies and equipment were developed for dismantling some of the structures and for the safe and successful performance of all works.

— The experience obtained by application of the technologies and equipment can be used, after relevant adjustment, for the decommissioning of all channel type uranium–graphite nuclear reactors.

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# VIRTUAL REALITY TECHNOLOGY AND NUCLEAR DECOMMISSIONING

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**Abstract**

During past years, an important activity at the Halden VR Centre (HVRC), Institute for Energy Technology (IFE) in Halden has been the development of virtual reality (VR) software for use in the decommissioning of nuclear facilities. It is hoped that use of VR technology in the planning process may prove beneficial both with regard to minimizing workers' radiation exposure, as well as in helping to achieve the efficient use of human resources. VR can also be a valuable tool in the dismantling phase. In addition to this, VR provides the decommissioning project team with an effective medium in presentations to the public, as well as for communicating with relevant engineers and licensing authorities. The most extensive IFE VR decommissioning project is at present the VRdose project, conducted in co-operation with the Japan Nuclear Cycle Development Institute (JNC). VRdose will be used in the decommissioning of one of JNC's reactors, the Fugen Nuclear Power Station. The paper describes the present and planned versions of the VRdose system, but also briefly describes other related activities at HVRC.

## 1. INTRODUCTION

Virtual reality (VR) is a way of visualizing, interacting with and navigating through an environment described by a 3-D computer model. A commonly accepted definition is "A computer system to create an artificial world in which the user has an impression of being in that world and with the ability to navigate through the world and manipulate objects in the world" [1].

A standard example of VR is the flight simulator. The user has controls to enable him or her to navigate in the virtual world. In the case of a flight simulator, the goals will be to perform tasks such as landing and take off in a safe way for both aircraft and passengers, to handle unforeseen situations and so forth.

Just as a flight simulator enables a pilot to practice without risk to himself or herself, the passengers or the aircraft, a VR tool for nuclear decommissioning can enable, say, a group of engineers to test plans and procedures for various tasks involved in dismantling a nuclear facility. Instead of measuring and displaying factors such as fuel consumption, speed and altitude, these VR tools will calculate and display dose rate, contamination and individually estimated doses through different phases of the process.

In nuclear installations, in service and after service, some areas are inaccessible because of high radiation and surface or air contamination. VR technology can be a very useful solution for the planning of operations in such restricted areas.

When planning the decommissioning of a nuclear power plant (NPP), it is very important to balance cost reduction and safety. It is our belief that having access to planning tools using computer simulation technology such as VR can be very effective for optimization of these kinds of projects. Since 1999, Japan Nuclear Cycle Development Institute (JNC) and the Institute for Energy Technology (IFE) have been developing a VR software tool, 'VRdose', for the simulation and planning of dismantling work in an environment where radioactivity is present [2–5]. It is also important to note that many of the VR tools that may prove useful in the decommissioning process also have applications for NPPs that are still in production, for maintenance and training for operations, or even for crisis management.

This paper is organized as follows. We start with a brief description of the Fugen decommissioning project and some of the motivations for employing a VR tool in this process. The VRdose system is more closely described, focusing on its different interfaces for desktop use, as well as the immersive mode and the new VR facility at Fugen. This is followed by some general reflections on the application possibilities of VR decommissioning tools. The contributions from IFE's human factors specialists in the development and testing are then described, and we will also touch on some other related VR projects at IFE. Before concluding, future plans and possibilities are discussed.

## 2. VRDOSE

### 2.1. The Fugen decommissioning project

The JNC aims to use VR for the decommissioning project of the Fugen Nuclear Power Station (Fig. 1), which ends its operation in March 2003. In order to prepare an optimized dismantling plan for their decommissioning project, JNC has adopted a system called COSMARD (Code System for Management of Reactor Decommissioning) [6] developed by the Japan Atomic Energy Research Institute (JAERI) based on the experience of decommissioning the Japan Power Demonstration Reactor (JPDR).

COSMARD permits evaluation of workload, radiation exposure dose and waste mass, as well as the schedule of the dismantling process. In order to produce a reasonable method and an effective process, it is necessary to carry out detailed dismantling planning in advance. It is possible to evaluate the workload of the dismantling of the general equipment by COSMARD, based on the experience of decommissioning of existing plants. However, equipment such as the reactor core or heavy water system, which is unique to Fugen, requires a special evaluation. Moreover, intensive training before the real dismantling process is effective for reducing radiation exposure dose, workload and for the enhancement of safety. For example, mock-up training can be replaced with a computer simulation system.

For this reason, JNC decided that they needed to develop a dismantling work simulation system based on VR technology and 3-D CAD data. At the Halden VR Centre (HVRC), this started out with a prototype that was ready in March 2000. This work still goes on, and version 4 of the system will be delivered to JNC in March 2003. VRdose is a simulation system of human movements which evaluates workload and exposure dose. A set of virtual humans, ‘manikins’, can move around in VR space, which in the Fugen case has been derived from 3-D CAD data. The manikins can perform sequential work operations, interacting with and waiting for each other. The manikins and their operations may be recorded as work scenarios. Based on a work scenario, the system outputs work time and exposure dose for each worker. Scenarios may be played back, discussed and edited, helping to arrive at a reasonable work process.

The present version has features for scenario recording with from 1 to 25 workers involved in each work scenario. The system can visualize and play back recorded scenarios from any angle of view, and can also visualize distribution of radiation exposure rate in various ways. VRdose also provides real time stereoscopic animation.

*FIG. 1. View of the Fugen Nuclear Power Station.*

### 2.2. Different ways of using VRdose

In the default set-up, VRdose comes with four work areas for use in the standard mode of the program, representing different sets of windows interfacing with the VR model of the work environment, and with sets of radiation information. In addition, VRdose has a full screen demonstration mode, allowing for use in an immersive VR facility.

#### 2.2.1. The navigation area

For most users, the first approach to VRdose will be the set of tools available in the navigation area. The main window in this workspace is the 3-D navigation window, to the right in Fig. 2. Virtual environments (VEs) described on the Virtual Reality Modelling Language (VRML, ISO/IEC 14772-1:1997) format can be loaded and a set of navigation functions allows the user to move through and explore the selected VE in various ways. The navigator has a 3-D radiation visualization tool, and in Fig. 3 this tool has been activated. It also has a tool for selecting objects or positions. In later versions, other functions such as measurement tools may be added.

Inside the VR model, separate objects can be identified and selected. Any pre-defined object in a model may be movable. In scenario recordings, manikins can access these objects, and they can also be moved to different locations. When generating a VR model, the user decides which objects should be moveable.

The navigator, as well as the rest of VRdose, has been developed using Java *(http://java.sun.com/)* and the Java 3D API *(http://java.sun.com/products/java-media/3D/)*. The geometries are made in VRML.

Dose rate visualization is an important feature of VRdose, and various ways of visualizing the radiation situation are available. In Fig. 2 an example is shown. The circled area at the bottom left of the main window (bright green in the display) indicates that some source of high radiation is present somewhere on the reactor top (actually, we have put a fake radioactive 'pellet' here). The same can be extracted from the overview map (black circle in upper left window). The dosimeter surface plot, at the bottom left in Fig. 2 and as a close-up (slightly different angle) in Fig. 3, shows the dose rate level at chest height of the virtual spectator on a 50 × 50 m$^2$ area. The pole indicates the position of the VR camera through which the scene in the navigation 3-D window is viewed.

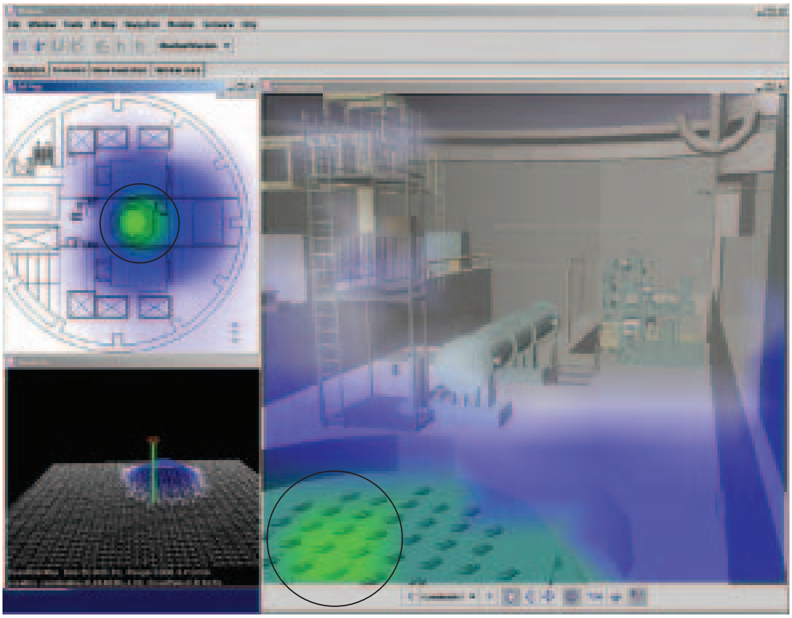

*FIG. 2. User interface in the navigation work area.*

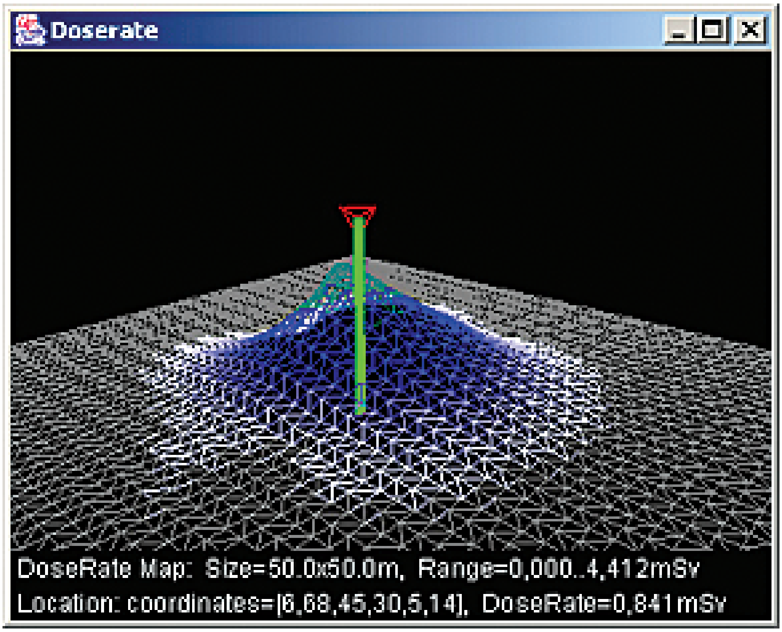


*FIG. 3. Dosimeter surface plot.*

### 2.2.2. The scenario recording area

Planned work operations can be recorded in the Scenario work area, shown in Fig. 4. The user may record work scenarios on selected locations in the VE. A scenario consists of a collection of participants, each with a work task that can include walking routes, simplified work animations and operations, as well as co-ordination of the different actions with the other participants in the work scenario. Scenarios can be recorded, edited and stored in XML (Extended Mark-up Language) files.

In Fig. 5, the list of work actions of the two participants in a demonstration scenario is shown. For this demonstration, one manikin is given the assignment engineer and the other is a mechanic. The user can switch between the manikins or participants while recording, and a pointer always indicates the selected manikin.

After the scenario has been recorded, its various tasks can be assigned to real staff whose relevant data have previously been entered into the system database. For each work task in the scenario, the estimated dose rate is computed, and the workers' accumulated dose in the task can be visualized as graphs and tables.

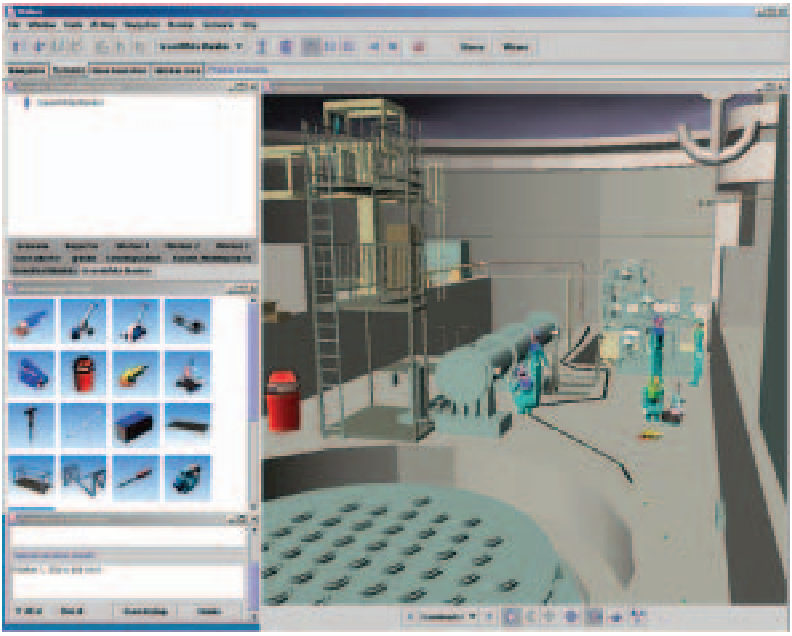

*FIG. 4. The scenario work area.*

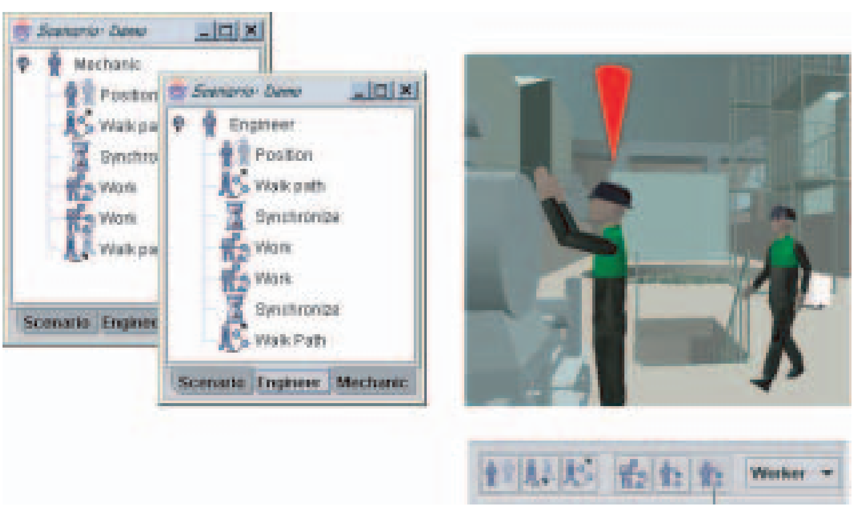


*FIG. 5. Two workers and a scenario.*

The manikin workers need dismantling tools. A selection of pre-defined dismantling tools such as a band saw, cutting torch, dust box, scaffold, etc., have been modelled and can be inserted into any VE from the “Virtual storage house” (see Fig. 6). A manikin can pick up a tool, carry it around and use it in work operations. This function gives the user a realistic impression of the dismantling process.

The user can build work scenarios step by step. This may require much effort if the scenario consists of many actions and tasks of many workers. A ‘scenario wizard’ is therefore being developed, and can be applied for all or part of the scenario creation. The scenario wizard utilizes templates or libraries of tasks to produce the scenario semi-automatically. The templates for the decommissioning are configured based on the work breakdown structure from COSMARD.

#### 2.2.3. The dose evaluation area

When a scenario has been recorded, it can be examined in the dose evaluation area shown in Fig. 7. This area has dose and dose rate graphs of each of the participants in the scenario, as well as a combination of radiation visualization tools. It will often be useful to move between the dose evaluation area and the scenario area while establishing the best way to perform the work.


*FIG. 6. Virtual storage house.*

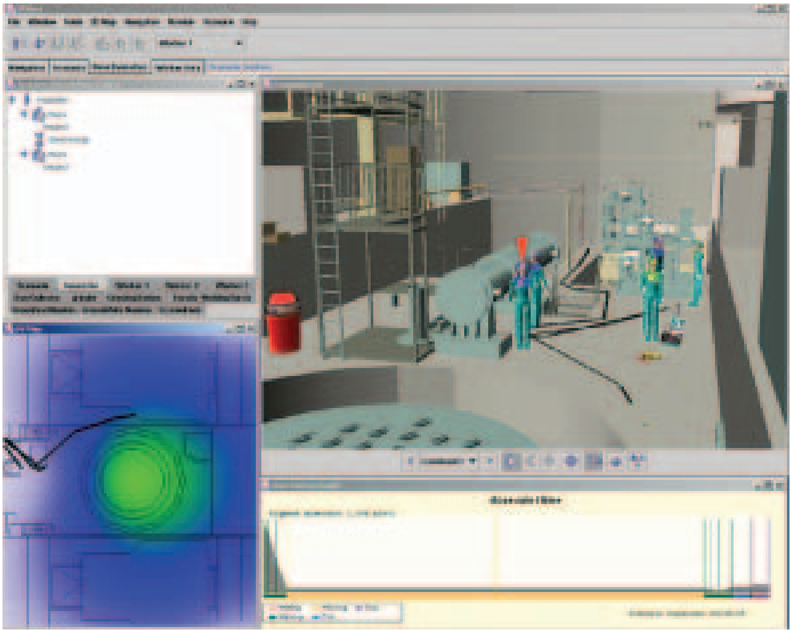

*FIG. 7. The dose evaluation area.*

### 2.2.4. The worker data area

The fourth area is the interface to the underlying worker database. From here information on real life workers can be inserted into the database, and recorded scenarios can be assigned to them.

The database may record real life doses as well as assigned computer generated doses, and general staff information can be entered. For every task that has been assigned to a real worker the occupational dose and dose rate is stored. This information is displayed as tables and graphs in the worker data work area, as illustrated in Fig. 8. From this worksheet reports can also be automatically generated, stating workers' dose history or giving an overview of the dose rate exposure associated with a certain task.

For use in the VRdose system, an Oracle *(http://www.oracle.com/)* database has been selected.

### 2.3. Stereoscopic projection system (VENUS)

Even though for many purposes, the VR models and animations of VRdose can and will be viewed on normal office PCs and laptops, the extra

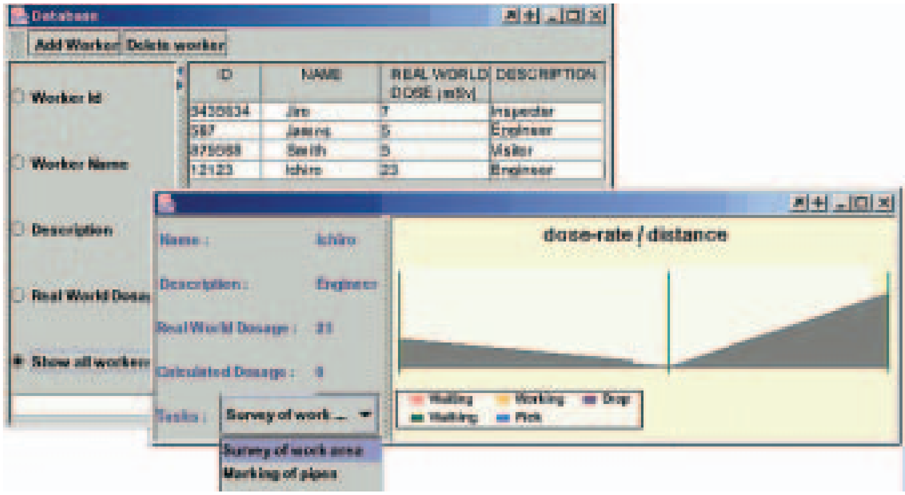


*FIG. 8. The database interface.*

3-D effects of a stereoscopic system with large screen projection are sometimes required. In a stereoscopic view, the left and right eye get different visual inputs, e.g. through the use of polarized glasses. This adds depth to the VE, and gives the spectator an increased sense of presence in the virtual world.

VRdose is now available on a multipurpose visualization system at Fugen named VENUS (Virtual Engineering and Navigation with a Universal Visualization System), which was installed in March 2002. It is possible to have a stereoscopic view by using four high resolution projectors and polarization glasses. This system is at present used both in the evaluation and testing of VRdose, and in actual applications of the system. One present application is in the briefing of engineers, as shown in Fig. 9. VENUS will also be used in contacts with the public.

## 3. APPLYING VR DECOMMISSIONING TOOLS

There are several application areas for VRdose in a decommissioning process. A VR illustration of a scenario has several advantages over that of a picture or a video.

A VR decommissioning tool can offer radiation visualization inside a model of the NPP. This may contribute to an increase in the radiation awareness as well as provide a better estimation of radiation conditions in the work areas. In addition, radiation computations are performed for all recorded work scenarios.

*FIG. 9. Projectors for VENUS and discussion of the dismantling plan.*

In VRdose, all work operations are represented as scenarios including a number of participants. Each of these participant’s actions in the scenario may later be linked to a selected real life worker previously entered into the database.

Based on these dose rate scenarios, the sequence of dismantling and work operations can be planned with regard to minimizing the radiation exposure involved. Further, the use of staff can always be planned according to the expected dose connected to the work task, aiming both at keeping the staff’s doses as low as possible and at efficient use of working power.

Once a work plan has been made, VRdose also provides an effective tool for briefing of the staff involved. Unlike videotapes, it is possible in VR to move around during playback, allowing the spectator to view the scenario from any angle. In VRdose, a 2-D map is also available to make orientation and precise movement easier.

Once the work plan has been confirmed, VRdose can be used for training purposes. One may rehearse and demonstrate complex scenarios without exposing the persons being trained to any radiation. Safety critical operations can be performed in a secure environment, and expensive or high radiation operations can be performed at any time and as frequently as necessary.

The possibility of training for the work tasks in advance, along with better planning and briefing, should lead to an optimization of the radiation dose and minimization of workload, and consequently results in cost reduction. JNC is expecting that the economic benefit gained from using the VRdose system will compensate for the cost of the development and introduction of this software. The results could be reflected in the work plan itself.

VRdose can also provide the public with illustrative and comprehensible information of the decommissioning process. This will help to prevent misunderstandings about the decommissioning process. The minimizing of radiation exposure is also an important issue to both the public in general and the environmental organizations in particular. Briefings to authorities and the press can be made much clearer, direct and convincing when using the VR tool.

## 4. USABILITY AND EVALUATIONS

At Fugen, JNC has now started to use the system both for test scenarios and demonstrations. Figure 10 shows a screen shot from the recording of piping removal work that has been performed at Fugen.

In addition to the testing and evaluation performed by JNC, human factors specialists at IFE have evaluated the system in different ways. In the second year of project work, modules from VRdose were used in a training

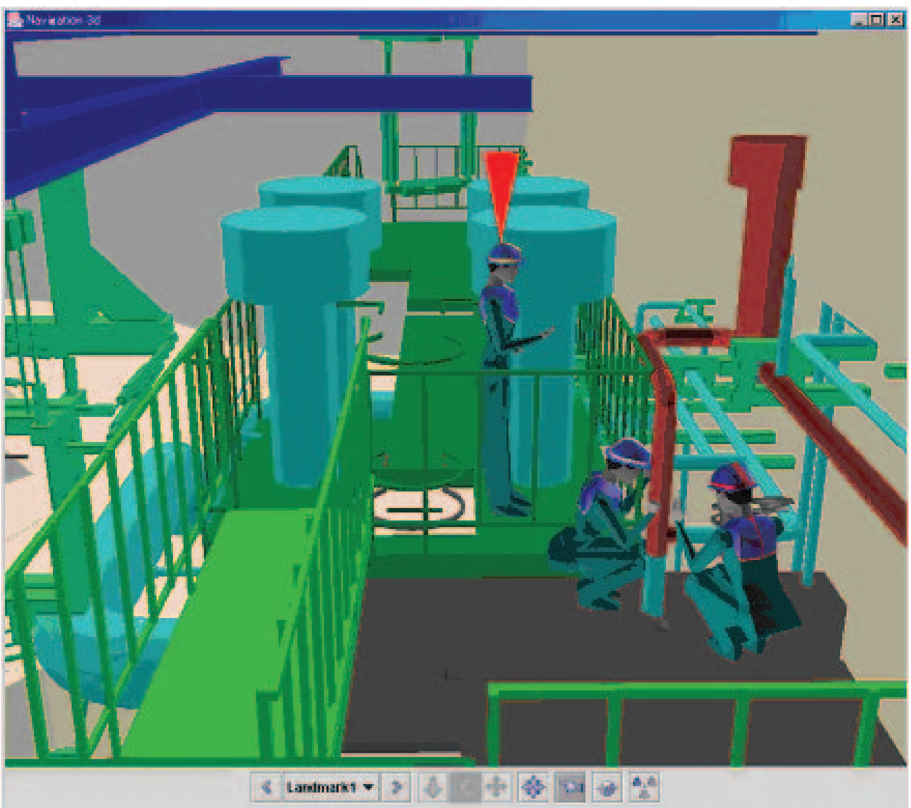


*FIG. 10. Simulation of piping removal work at the Fugen Nuclear Power Station.*

experiment under the Halden Project Programme [7] evaluating, among other aspects, the effects that VR training had on the test subjects' radiation awareness.

The project team investigated three types of training conditions and a set of navigation (route knowledge) and measuring tasks in the reactor hall (RH) of the Halden Boiling Water Reactor (HBWR) in Halden, Norway. The three training conditions — a map condition (not in VR), a guided VR condition (passive learning: subjects were shown the route to follow), and a non-guided VR condition (active learning: subjects had to find their own route) — allowed study participants to familiarize themselves with the layout of the RH. In all three conditions, subjects had a map of the radiation field in the RH and were asked to follow the practiced route and take equipment measurements at specified points. They were also queried about the radiation profile of particular areas (this provided a measure of radiation awareness).

The findings were that subjects in the non-guided VR training conditions had higher radiation awareness in both the training (VR) and the testing (RH) conditions. Though the same subjects did not have improved route knowledge for measuring task performance over the other two training groups, non-guided VR training seemed to offer more opportunity for exploration, and thus the chance to develop a more complete mental representation of the radiation field in the area.

In the third project year this has been taken further. A human factors specialist has been involved in the design process, conducting usability evaluations [8]. The purpose of a usability evaluation is to identify problems in the existing design that need to be fixed so that the final product will be easy to learn, easy to use and will reduce the possibility for human error.

Participants in the usability tests were representative users from the HBWR plant. All usability test participants attended a brief (15 minute) familiarization programme and a one hour training session. The participants then performed various tasks using the system, making comments about how they expected tasks to be done and what they thought of how the system was designed. Throughout the session, the human factors specialist took notes of particular problem areas (as well as tasks that were easily accomplished). Following the session, subjects were specifically asked to provide comments on various aspects of the system.

Based on these studies, a number of areas for improvement were identified. Briefly summarized, these include improving navigation, providing clearer guidance and/or additional support for performing tasks, and supporting comparisons between dosage information and scenario occurrences. Particularly usable features of VRdose were also identified during these evaluations. As a general rule, these features were usable because they clearly presented to users the available control options. They helped the user to get an understanding of what could be done and how it could be done.

Using the results of this evaluation, the design team is currently making modifications to VRdose. These changes are expected to improve usability, since many of them specifically address issues identified in the usability report. Further usability tests will be conducted as future versions of VRdose are developed. In addition, because VRdose is a complex system, intended for long term use by personnel who are trained in its use, a training programme is also being developed.

## 5. RELATED PROJECTS AT IFE

As the host of the Halden Reactor Project, IFE is active in several research areas concerning the safety of nuclear facilities. Among these are the projects concerning the use of Augmented Reality (AR) to visualize the radiation conditions in radioactive environments [9] (Fig. 11). The results are promising, and further research is scheduled for the next three year programme of the Halden Reactor Project.

In the Leningrad RMS VR Project [10], conducted in co-operation with the Leningrad Nuclear Power Plant and the Kurchatov Institute, an advanced simulator for a refuelling machine is being developed (Fig. 12). The fuel is often changed during full power, and the process has a high level of safety requirements. The simulator is used for training staff in procedures and for emergency situations. This project is financed through the Norwegian authorities and co-ordinated by the Norwegian Radiation Protection Agency.

## 6. FUTURE PLANS AND POSSIBILITIES

The present version of VRdose just simulates external exposure dose. In the next version, radioactive tritium (beta emitter) intake will be considered, as cutting of the heavy water or helium system may release vapour with tritium, derived from heavy water. The intake exposure will be calculated based on the concentration of tritium in air and on the efficiency of the protection gears.

Moreover, in the dismantling process, some radioactive materials or shielding materials might be moved. This leads to changing of the radiation dose rate in the work area. Simulation of dynamic radiation transition is still challenging, mainly because of the required computing power. However, the situation is improving due to a favourable price/performance ratio in hardware technology.

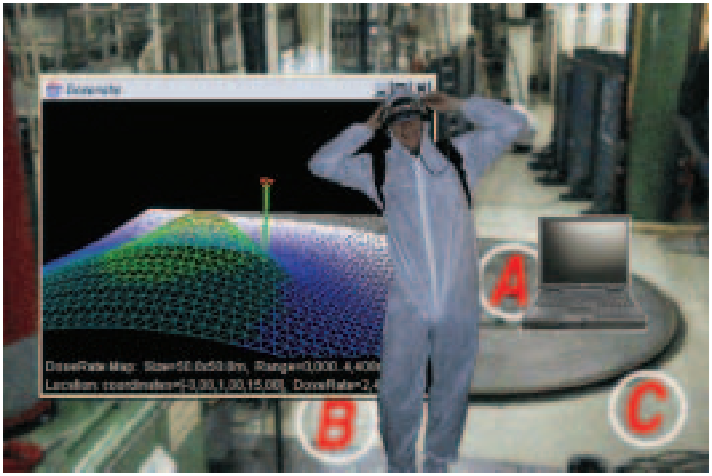


*FIG. 11. Experiments with AR in the reactor hall at the Halden Boiling Water Reactor.*

The scenario wizard is still limited. The wizard will, after a number of tests in realistic situations, be extended to know more about the dismantling work. The final outcome of the workload estimates should later be reflected in COSMARD for more accurate evaluation.

In the near future, this system will include some of the functionality mentioned above and will be applied to real cases of dismantlement planning and training. We believe this may lead to a reduction of the total cost of decommissioning as well as to safety improvements during dismantlement.

VRdose and similar systems have applications not only in nuclear decommissioning. VR technology could be used as an effective planning and training tool for maintenance work. Just like in the decommissioning situation,

*FIG. 12. The refuelling machine at the Leningrad RMS VR Project in real life (left) and in VR (right).*

work operations are planned, personnel are assigned to work tasks and briefings are held. VR also provides a possibility for training for expensive operations or operations involving high dose rates, and can be a very helpful tool in training for handling extreme situations.

## 7. CONCLUSION

We have discussed use of VR tools in the decommissioning of nuclear facilities. VRdose and similar tools may be of significant assistance in planning and managing a decommissioning process. Another important aspect of using VR in such processes is the gain in documentation possibilities. Virtual reality technology also provides training tools for both daily work and safety critical operations.

VRdose is not only applicable to a nuclear decommissioning process but has potential for application in the management and documentation of productive nuclear power plants as well.

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# DECOMMISSIONING STRATEGIES AND REGULATIONS

(Session 2.A)

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# REGULATORY METHODS AND ISSUES IN DECOMMISSIONING

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**Abstract**

Successful decommissioning of nuclear facilities depends not only on an operator having a sound decommissioning plan and programme in place prior to beginning decommissioning, it also requires that the regulator have a sound regulatory infrastructure in place to both provide guidance and monitor the facility during decommissioning. A regulatory infrastructure includes both regulations and compliance strategies. Regulations in some Member States include criteria for: (1) site release for artificial radioactive material with and without restrictions; (2) site criteria for technologically enhanced naturally occurring radioactive material; (3) radioactivity that may be present in building materials and on equipment that are released from a site during decommissioning (i.e. clearance); (4) public outreach; (5) environmental reviews; and (6) source control. In addition, the roles of regulators and developers must be firmly established and it is recognized that the responsibility for safety ultimately is the responsibility of the operator. Strategies for decommissioning materials facilities include cleaning the site to allow any use after release, terminating the licence with restriction on future site use and perpetual licence (nuclear parks with no site release envisioned). Strategies for decommissioning reactor facilities include DECON, SAFSTORE, or ENTOMB. Issues associated with decommissioning include the on-site storage of high level waste, storage of low level waste, materials requirements versus the reactor decommissioning approach, and ensuring that realistic scenarios and modelling techniques and tools are available and being used. To aid licensees and regulators in the decommissioning of nuclear facilities, the IAEA and some Member States have developed safety standards and guidance documents. Each of these activities will provide support for Member States in meeting the obligations under the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

## 1. INTRODUCTION

Successful decommissioning of nuclear facilities depends not only on an operator having a sound decommissioning plan and programme in place prior to beginning decommissioning, but on the regulator having a sound regulatory infrastructure in place to provide guidance to the operator and regulatory staff, and to monitor the facility during decommissioning. This infrastructure should be based on a widely accepted foundation such as the one created by the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (Joint Convention). The need for global comparability of this infrastructure is balanced by the Member States' regulatory and compliance characteristics and needs. Thus, it is incumbent upon each nation to develop its own regulatory standards, inspection and enforcement programmes.

However, the approaches and strategies in a national decommissioning regulatory infrastructure need to go beyond the specific processes of decommissioning such as decontamination, dismantlement and demolition. Issues important to other areas of nuclear facility regulation also need to be addressed (e.g. disposal of decommissioning wastes, storage, institutional controls). This is a theme that I believe will be mentioned often at this conference; that is, that decommissioning cannot stand alone, but should be planned for and integrated into a 'cradle to grave' regulatory compliance approach for all nuclear activities or facilities.

## 2. REGULATIONS (STANDARDS)

The IAEA's standards for decommissioning are treated as a subset of the regulatory structure of predisposal management of radioactive waste. Under this approach, the decommissioning of nuclear facilities is viewed as those actions leading to removal of some or all of the regulatory controls on a facility. Inherent in this approach is the view that decommissioning is the last component of the operational life of the site. As such, it should be part of the early overall planning and, like conventional predisposal considerations (treatment and conditioning of the waste form), constitutes a suite of activities that should be considered well before the termination of the licensed activity.

However, many in the international community treat environmental restoration in a different context than decommissioning. In some cases, the regulations and guidance for the environmental restoration of lands affected by prior nuclear activities are kept separate from decommissioning and are addressed in the same context as the clearance and recycle of materials. Our experience to date indicates that decommissioning of contaminated legacy sites has proven to be more challenging than expected and the application of international clearance dose constraints as decommissioning standards would be problematic, if not impracticable.

Under the Atomic Energy Act (AEA) of 1954, as amended, the US Nuclear Regulatory Commission (NRC) regulates the decommissioning activities at civilian commercial and some defence related sites not under the control of the US Department Energy (DOE). The DOE manages the cleanup of the facilities it controls. The NRC regulates environmental cleanup and restoration of licensed and formerly licensed facilities, and those possessing licensable quantities of source, special nuclear and by-product material under a comprehensive decommissioning programme. The NRC is implementing a risk informed, performance based approach in regulating nuclear activities, including the decommissioning of licensed facilities. The License Termination Rule (LTR) in the USA is the governing regulation for both materials and nuclear reactor decommissioning. The LTR specifies a dose constraint of 0.25 mSv/a (total effective dose equivalent (TEDE) for unrestricted release), and requires that all doses be as low as reasonably achievable (ALARA). The NRC regulations also provide for the releases of facilities and sites with restrictions on future site uses [1].

Although a sound regulatory infrastructure is an essential component of safe operation and decommissioning, the ultimate responsibility for safely decommissioning a site rests with the operator or licensee. To achieve this, the roles of the regulator and the operator or licensee should be clearly identified in the standard or regulation. Furthermore, the regulator should provide guidance, which is not necessarily binding, that allows the operator to gauge where resources should be allocated in terms of establishing a compliance protocol. This approach is recommended in international standards (e.g. IAEA Safety Series No. GS-R-1, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety) and is also the practice in the USA.

The regulator should not be a passive partner in this process. There is an active and confirmatory role for the regulator in the form of inspections, confirmatory monitoring and radiation surveys. The regulator should have an effective inspection and enforcement programme to ensure that the licensee or operator is correctly conducting the decommissioning of the facility, as well as co-operating with the operator in dealing with the inevitable surprises that occur during dismantlement and decontamination. It is important that the regulator and the operator/licensee have good records and staff with the institutional knowledge essential to a risk informed protocol for the conduct of decommissioning.

This approach ensures that: (a) attention is focused on the most important activities; (b) objective criteria are established for evaluating performance; (c) measurable or calculable parameters are developed for monitoring system and licensee performance; (d) flexibility is provided in meeting the established performance criteria in a way that will encourage and reward improved outcomes; and (e) regulatory decision making is results oriented.

One of the unique aspects of decommissioning, as opposed to operations, is that the incentive for profit or to obtain a product is no longer a consideration for the licensee or operator. Rather, for the operator the facility has now become a potential resource drain and the operator can no longer balance the costs for regulatory compliance against the profits resulting from the operation. This presents an additional challenge to the regulator to recognize the operator's motivation to limit costs where there is no longer a tangible profit. Moreover, this consideration is an important factor in ensuring that there is a regulatory mechanism to guarantee that there are adequate resources planned for eventual licence termination. In some Member States, the national government may vouchsafe the ultimate decommissioning and disposition of radioactive waste therefrom. In other cases, financial mechanisms, referred to as 'financial assurance', are established as early as possible in the operational planning to allow the accrual of the funding to pay for the decommissioning of the operation at the end of its useful life.

### 2.1. Non-AEA radioactive materials

It should be noted that there are other categories of sites in the USA which would, in some other countries, fall under the jurisdiction of the radioactive materials regulatory authority. In the USA, these sites and facilities include DOE defence facilities and private sector entities regulated by other Federal or State agencies. The DOE performs the regulatory function at many US defence facilities undergoing what would otherwise be termed decommissioning. Technologically enhanced or naturally occurring radioactive material (TENORM) is regulated by the individual States acting under a broad US Environmental Protection Agency (EPA) mandate to set generic standards for the radiation in the environment. Examples include operations associated with petroleum production (oil sludge and pipe scale), phosphate rock processing and similar mineral processing activities.

### 2.2. Accountability of sources

The EPA is funding the first national programme to systematically address the problem of 'orphan radioactive sources'. The Orphan Sources

Initiative is a co-operative effort with the Conference of Radiation Control Program Directors (CRCPD) — a group of State radiation protection officials — that is designed to assist States in retrieving and disposing of radioactive sources that are discovered in non-nuclear facilities, particularly scrap yards, steel mills and municipal solid waste disposal facilities. The goal of the programme is to establish a nationwide system that provides quick and effective identification, removal and disposition of orphan sources, which, if undetected, can present a health hazard and can cost facilities millions of dollars in lost production and decontamination expenses. Disposition may include recycling, reuse, or disposal. The NRC has also been dealing with the problem of unwanted and uncontrolled radioactive materials, including orphan sources, for more than ten years. This issue is marked by complex jurisdictional relationships involving all 50 States and at least 11 Federal agencies. The NRC has signed a Memorandum of Understanding (MOU) with the DOE on the management of certain types of materials. Under the MOU, the NRC and DOE will consider radioactive materials in other forms on a case by case basis. The agreement specifically excludes reactor incidents and other radioactive material incidents where agreements or procedures are in place to address the situation.

### 2.3. Waste disposal

One of the important considerations in the selection and timing of facility decommissioning is the availability of and access to radioactive waste disposal of the decommissioning generated radioactive waste. The waste disposal option must be diverse, because the nature of the waste from nuclear facilities includes high level waste (HLW), low level waste (LLW) and by-product radioactive waste. Although regulatory bodies may not have direct authority over non-radioactive waste materials, the radioactive and non-radioactive waste generated by dismantlement, demolition and decontamination will mostly be dealt with concurrently, at least during active decommissioning. The inventories of these different waste forms are determined by the type of operation and can range from small quantities of discrete LLW from laboratories to millions of tonnes of slag and tailings from uranium milling operations.

### 2.4. Clearance

The term ‘orphan sources’ generally refers to sealed sources of radioactive material contained in a small volume — but not radioactively contaminated soils and bulk materials. Disposition of these other materials falls under the topic usually referred to as ‘clearance’. The international community has been quite active in working to establish acceptable and enforceable criteria for the release of low activity contaminated materials (metals, rubble, etc.). Currently, there is a need to develop a technical basis for establishing the radionuclide concentrations in surface and volumetrically contaminated materials which might be suitable for clearance. During the past several years, the NRC has been developing a technical basis for releasing these types of materials, either for unrestricted use or with certain restrictions (e.g. shielding in nuclear facilities).

The NRC is currently deliberating on the course of action to take with respect to any decision on modifying the current, case specific approach to clearing material such as low activity metals. Feedback from stakeholders (industry, the public, academic institutions, etc.) and recommendations from the US. National Academy of Sciences (NAS) [2] on the current approach to the control of such material are being weighed in the NRC's deliberations.

The NRC and other Federal agencies have been very active in the international arena in terms of clearance and the control of radioactive sources. The IAEA has been in the process of developing guidance for the control of materials and goods made from recycled metals and other products used in nuclear facilities (e.g. medical laboratories) in a safe and responsible manner. Experts from the NRC and other agencies have participated in technical meetings to develop guidance and technical protocols for addressing this subject.

If it is determined that rulemaking to establish criteria for clearance should be initiated, the NRC would evaluate the environmental impacts and cost–benefit of rulemaking alternatives. Specifically, the NRC would evaluate the implications of a rule with regard to the National Environmental Policy Act of 1969 (NEPA). Such an evaluation would consider both radiological and non-radiological impacts associated with the criteria for the release of materials for unrestricted and restricted use. The NRC would also publish regulatory guidance to provide licensees with information on how to demonstrate compliance with the regulations. Guidance would be provided on, for example, measurement methods for low concentrations of volumetrically contaminated material that may exist in various equipment and material types, shapes and sizes that are anticipated to be available for release. As in the other topical areas I have discussed, the public participation and stakeholder involvement component would again play a significant role in the decision making process.

## 3. STRATEGIES FOR DECOMMISSIONING

Currently, there are 20 nuclear power reactors undergoing decommissioning or in long term storage. The commonly cited strategies for the decommissioning of power reactor facilities are:

— **DECON (Decontamination).** A method of decommissioning in which the equipment, structures and portions of a facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations. This is complete and prompt decommissioning, enabling the facility to be released for generally unrestricted access. It involves the decontamination and removal of all equipment, structures and other parts of the facility that had become radioactively contaminated. Under this option the principal advantage is that the responsibility for the decommissioning is not transferred to future generations, because the site is available for unrestricted use promptly. But immediate decontamination may lead to generally higher worker doses, because there is little opportunity for radioactive decay of short lived radionuclides. Of the nuclear power reactors in the USA in decommissioning, five are in the DECON stage.
— **SAFSTOR (Safe storage).** A method of decommissioning in which the nuclear facility is placed and maintained in such a condition that it can be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use. As the name implies, this usually involves placing the facility in a safe, stable and monitored condition and keeping it in that state until a decision is made to DECON. Readily removable contaminated material (e.g. the fuel, radioactive liquids, stored materials) is removed during the initial dismantlement and decontamination phases, but the facility structures are generally left in place. A surveillance and maintenance programme is put into place to ensure that the facility remains in a safe and stable condition, meanwhile taking advantage of a significant reduction in residual radioactivity and therefore reduction of the radiation hazard during dismantlement. SAFSTOR minimizes the initial commitments of time, funds, radiation exposure and waste disposal capacity, while complying with requirements for the protection of public health. Another advantage is in the case where there are other operational nuclear facilities at the same site or where there is a shortage of radioactive waste disposal capacity. The remaining nuclear power reactors (15) are in some form of SAFSTOR.
— **ENTOMB (Entombment).** A method of decommissioning in which radioactive contaminants are encased in a structurally long lived material, such as concrete. The entombment structure is appropriately maintained, and continued surveillance is carried out until the radioactivity decays to a level permitting unrestricted release of the property. This strategy eliminates the need for total decontamination by proceeding

directly from deactivation to encasing radioactive contamination in a structurally sound material such as concrete. Then it should be appropriately maintained and monitored until the radioactivity decays to a level permitting release of the property. This approach entails keeping the facility under an appropriate level of surveillance and maintenance, until the radioactivity has decayed to a safe level that would allow release of the facility for restricted or unrestricted use. The advantage is for use at sites where residual radioactivity will decay to levels permitting unrestricted release of the facility within longer, yet reasonable, time periods (of the order of 100 years). Disadvantages may include the apparent propagation of 'interim storage' sites and local perceptions that permanent disposal is intended.

The NRC is currently in the process of evaluating the entombment option for decommissioning power reactors. Additional study of this option has been proposed, prior to initiating any changes to the current regulatory approach; public input has been solicited on this option. Industry is also evaluating the feasibility of the entombment option.

Approximately 300 NRC material licences are terminated each year. NRC regulations for the decommissioning of materials facilities do not address either the SAFSTOR or ENTOMB option. Rather, materials licensees must inform the NRC of their decision to cease licensed operations and either begin decommissioning or submit a decommissioning plan to the NRC for review and approval within one year of permanently ceasing operations. If a facility includes buildings or outdoor areas that have not been used for licensed operations for a period of two years, the licensee must inform the NRC and either begin decommissioning or submit a decommissioning plan to the NRC (timeliness regulations).

In the preceding discussion there has been mention of restricted and unrestricted release. The decision strategy whether to decommission to release for unrestricted use or limited use must be based on a logical and defensible decision paradigm, which can be applied in cases involving a facility nearing the end of its useful life. An integrated approach, which addresses safety, public protection, public participation, the cost of remediation, potential post-operational uses, and environmental considerations and available technology should be utilized to arrive at a balanced decision on the fate of a facility at the end of its usefulness.

An important means to achieve this paradigm is the establishment of guidance that will aid the regulator, the developer/operator and the stakeholders in facilitating the implementation of the regulations. The NRC has developed guidance in the form of a Standard Review Plan that provides licensees, regulators and the public with valuable information on the requirements for, and strategies to comply with, the NRC's release requirements for materials licensees [3].

The international community is well acquainted with the IAEA's Safety Standards publications programme. Among the documents published in this programme, the Radioactive Waste Safety Standards (RADWASS) publications include safety requirements and guides in the area of predisposal radioactive waste management including decommissioning. These provide regulators in Member States with a benchmark with which to establish their own country's regulations and guidance needed to address decommissioning. Moreover, the IAEA is preparing requirements and guidance in the area of environmental restoration [4]. Together, these documents provide a foundation for the regulator and stakeholders to use to establish a decommissioning strategy, as well as a gauge by which the success of this can be strategically evaluated.

### 3.1. US regulatory infrastructure for decommissioning

As in other Member States, the USA can issue regulations for controlling the commercial use of nuclear materials under the provision of law. The controlling legislation for most of the NRC's regulatory responsibilities lies in the 1954 AEA, as amended. As the nuclear fuel cycle evolved in the USA, the AEA was modified and augmented using legislative instruments such as the Uranium Mill Tailing Radiation Control Act (UMTRCA) of 1978, as amended, which not only served as the legal vehicle to establish the regulatory basis for uranium and thorium milling, but also established the mechanism for addressing the remediation of the uranium processing sites for the Manhattan Project.

Decommissioning had the legislative vehicle in place, but trailed somewhat in the establishment of the regulatory infrastructure. Since the 1970s, changes in the regulatory and industrial situation in the USA have led to revisions to the scenarios of the NRC's original decommissioning alternatives [4, 5]. In the reactor sector, two principal changes were: (1) the delay of major decommissioning actions for at least five to seven years following reactor shutdown because of a DOE requirement to cool the spent fuel in the reactor pool to avoid cladding failures in dry storage; and (2) the assumption that decommissioning will be completed within 60 years, as required by current regulations. The delay resulted in increased decommissioning costs while the spent fuel pool continues to operate. Changes in cumulative occupational radiation dose could also result from the decommissioning scenario changes.

The regulatory evolution began in the late 1980s and can be traced as our experience with bringing ageing facilities to termination also increased:

— June 1988: Technical and financial criteria for decommissioning licensed nuclear facilities;
— July 1993: Additional record keeping requirements for decommissioning;
— July 1994: Time frames and schedules for the decommissioning of licensed nuclear facilities;
— July 1995: Clarification of decommissioning financial assurance requirements;
— July 1996: Decommissioning procedures for nuclear power reactors;
— July 1997: Radiological criteria for license termination.

As can be seen from the preceding list, the NRC has been revising and adjusting its strategy and guidance ever since the initial steps in the late 1980s to construct a decommissioning infrastructure. In conjunction with these early regulatory steps and reflecting the experience acquired over these years, the diversity of facilities necessitated the development of a significant amount of decommissioning guidance. Previous guidance on decommissioning was dispersed among many different documents and regulatory guides, and the need for revision, updating and consolidation had been long recognized. The materials programme began the process of formalizing the decommissioning process for materials facilities in 1996 with the publication of NUREG/BR-0241, NMSS Decommissioning Handbook. This effort was furthered in 2000 with the publication of the NMSS Decommissioning Standard Review Plan mentioned previously. The principal purpose of the SRP is to provide guidance on the review of decommissioning plans. In addition, the SRP guidance supplements that in NUREG-1700 (Standard Review Plan for Evaluating Nuclear Power Reactor License Terminations Plans) in such areas as site characterization, dose modelling, final radiation survey and institutional controls. The NRC staff has also initiated a decommissioning guidance consolidation project. The project involves review and consolidation of all existing NMSS decommissioning guidance documents, decommissioning technical assistance requests, decommissioning licensing conditions and all decommissioning generic communications issued over the past several years. The goal is to produce consolidated NMSS decommissioning guidance that allows the NRC staff to evaluate information submitted by licensees in a timely, efficient and consistent manner that protects public health and safety. The end result will be a streamlined, multi-volume document grouped into decommissioning functional categories. Further ease of use will be realized by making this a web based document. The project is scheduled to be completed by the end of fiscal year (FY) 2003 [6]. The updated, consolidated guidance will be available to all users, both NRC and licensee, in hard copy and/or electronic media. Because each group will have access to the same guidance, the expected results are more complete licence documents that will expedite the approval process for both applicants and reviewers. As a result, it is expected that this project will serve to improve the overall decommissioning process.

### 3.2. The stakeholder and outreach dimensions

Although technical challenges remain, the ability to achieve substantial progress in decommissioning depends on the level of confidence that the public has in our actions. The NRC has invested substantial resources over the past several years in an effort to open up the regulatory process and improve our efforts at public outreach. In the decommissioning arena, this has meant implementing a number of new activities, including broader participation in public meetings at sites undergoing decommissioning, developing site specific communications plans for each site undergoing decommissioning and adopting a new approach in the development of the SRP for decommissioning.

For example, the development of the SRP included a series of public workshops on various review plan topics and placement of part of the review plan on the NRC's web site so that stakeholders could participate in the developmental process.

These efforts at public outreach and several efforts in other programme areas demonstrate the NRC's commitment to involve the public in our decision process. Nonetheless, we recognize that success in decommissioning nuclear facilities is linked to our ability to demonstrate that actions taken by both licensees and the NRC are protective of the public health and safety.

Accordingly, we will continue to stress the need to build public confidence as a key component of our decommissioning effort. We have taken steps to open our regulatory process to allow the states, industry, and the public to aid in defining acceptable approaches to address the key issues. Although progress has been made, there appear to be no near term, easy solutions for the challenges that decommissioning presents. Flexibility on the part of licensees, the NRC and our other stakeholders is needed to foster development of innovative solutions.

## 4. SUMMARY

Successful decommissioning of nuclear facilities depends not only on an operator having a sound decommissioning plan and programme in place prior to beginning decommissioning, it also requires that the regulator have a sound regulatory infrastructure in place to both provide guidance to the operator and monitor the facility during decommissioning. Decommissioning should be considered during the operational life of the facility and eventual site restoration needs to be an integral part of all operational activity plans. Mechanisms need to be established by the regulator for developing and establishing appropriate site release criteria, the clearance of materials as well as public involvement in the decommissioning process. The major components include: a timeliness criterion; a provision for adequate record keeping; mechanisms for ensuring adequate resources to complete the decommissioning (financial assurance); access to and availability of waste disposal and in some cases long term storage; provisions and legal structures for institutional controls and a regulatory fabric that weave these components into a clear and flexible mechanism to bring ageing facilities to safe and secure termination. Without these components, regulators will find it difficult to ensure facilities are being decommissioned safely, while ensuring that stakeholders have confidence in the regulator's ability to protect public health and the environment, without unduly burdening the regulated community.

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NRC web page for reactor decommissioning:
*http://www.nrc.gov/reactors/decommissioning.html.*
NRC web page for materials decommissioning:
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# SAFETY ISSUES IN DECOMMISSIONING, STRATEGIES AND REGULATION

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**Abstract**

Many plants throughout the world are undergoing decommissioning. There are some differences in the safety issues associated with decommissioning as compared with operations. These pose challenges to operators, regulators and those responsible for developing policies and strategies. The paper aims to set the scene for future discussion by identifying these issues. This includes regulatory systems, regulating the changing situation and factors that need to be taken into account in developing decommissioning strategies. In particular, the situation in the absence of a disposal route for waste and issues associated with care and maintenance periods are discussed. A key point that is identified is that well considered and justified strategies need to be developed to act as the basis for detailed decommissioning plans.

## 1. INTRODUCTION

As the nuclear industry matures, many plants are being taken out of operation and being decommissioned. Although there are a number of similarities to the operational phase, decommissioning has significantly different features, which pose challenges to those responsible for developing policies and strategies and for regulating the industry. This paper examines safety issues associated with decommissioning with the aim of stimulating discussion rather than offering solutions.

Policy makers, regulators and industry recognize that decommissioning poses different challenges and there are a number of international groups set up under, for example, the OECD/NEA and European Union. The membership of these groups is widely drawn and they serve as a forum for information exchange with the aim of making improvements and producing agreed documents. The IAEA also, of course, has a programme of developing guidance and other documents. This paper draws heavily on experience in the United Kingdom and also on the experience of such groups.

## 2. ROLES IN DECOMMISSIONING

The roles of most organizations during decommissioning are, in principle, very similar to those during operation. Governments set legislation, policy and strategy, regulators enforce the legislation and the operator, who will hold some form of licence, is responsible for safe operation and decommissioning of the plant. In some countries a special organization has been set up to decommission nuclear facilities and this has taken over responsibility from the original operator. The licence may be held by this organization or by contractors undertaking the work on its behalf.

Having said that, the relationships between the organizations may be somewhat different during the decommissioning period. During operation the operator has a strong incentive to gain the necessary regulatory permissions so that the plant can be operated to its full potential. Here the regulatory role is to ensure that the operator fully considers the safety issues before proceeding; so essentially it is a case of allowing the operator to start running a plant or stopping it from operating. The drivers for taking forward decommissioning are not always so clear since there is not a direct benefit from the activity. Once most of the radioactive material has been removed from the plant, conditioned or placed in a suitable long term store, then the safety drivers for further work are also weaker. The regulator may consider that the best course of action is to remove the residual hazard as soon as possible but this may not be seen as cost effective by the operator. This is particularly true if the plant is government owned and there are other demands on the public purse. In these circumstances the regulator's best approach may well be to influence the development of strategies and plans to ensure safe management and decommissioning of the plant. This may mean a less adversarial and more co-operative approach and early dialogue with the relevant parties, which may include government as well as operators. Such discussions must not prejudice the freedom of the regulators to take any necessary regulatory action that may be needed as the project progresses.

## 3. REGULATION OF DECOMMISSIONING

### 3.1. National regulatory systems

Nuclear installations are subject to a special legislative regime because of the nature of the hazard, international requirements on third party liability and the IAEA conventions. These regimes continue to apply as the plant moves into the decommissioning phase. The type of legislation which is developed to implement these requirements depends very much on the legal system in each country. In some systems legislation is generally goal setting. More detail may be given in guidance which explains how the requirements can be met but it is left open to operators to develop their own systems. In other cases legislation is very detailed and prescriptive. There are also specific regional requirements. For instance, within the European Union relevant Directives on radiological protection and environmental impact assessment must be incorporated into the legislation of member States. Again, the way that this is done will depend on the individual State's legal system.

The structure and remit of regulatory bodies also varies depending on the constitutional arrangements in various states. Regulatory powers may be shared by the central government and federal states. Separate regulatory bodies may be responsible for different aspects of decommissioning such as nuclear safety, radiological protection, general health and safety of workers, radioactive waste disposal and environmental protection. In some countries some or all of these functions are combined. Where these functions are separate, close liaison between the regulatory bodies is necessary in order to facilitate the best decommissioning options.

Therefore it is clear that the regulatory regimes in different countries may vary markedly; however, they will all share the overall aim of safe decommissioning.

### 3.2. Regulatory control of transition from operation to decommissioning

In an ideal world, plant closures are planned well in advance so that decommissioning plans are complete, the necessary financial arrangements are made and legal requirements are met before shutdown. But in reality, the regulatory system has to be flexible enough to cope with unplanned closures for technical, economic or political reasons. The regulatory system may also have to cope with the situation at complex sites where some plants are being decommissioned whilst others are fully operational. These plants may share the same physical services such as steam, electricity and waste disposal and certain staff may work on several of the plants. Such situations require good safety management to ensure continued safety of all plants.

### *3.2.1. Licences and regulatory style*

Operating nuclear installations will hold some form of licence from the regulatory body. In many regulatory systems there is a specific licence for operation and when the facility is closed for decommissioning the operating licence is revoked and another licence or a series of licences is granted for decommissioning. In other systems the same licence continues to apply but the requirements of the licence may change or, as in the UK, the licence remains the same while the operator's arrangements for compliance may change.

Clearly different regulatory styles have and will continue to be used successfully to regulate decommissioning. One of the features of decommissioning is that the situation at the plant is continually changing as work progresses. This means that under the first system the process of granting new licences has to be well-managed. Otherwise there could be uncertainty as to which requirements apply, which could result in the system falling into disrepute and a loss of public confidence in the regulatory regime. The second system where the licence remains the same is more flexible but the regulator needs to ensure that the operator has appropriate arrangements and safety cases in place at all times. The first system has the advantage of more transparency to the public and this is an issue that will need to be addressed in cases where the licence remains the same.

### *3.2.2. Safety cases*

The requirement for safety cases will continue during decommissioning. Many of the principles for the well established systems for producing construction and operational safety cases can be applied to decommissioning safety cases. However, there are some differences as a result of the changing extent of the hazard as the project proceeds. The process of decommissioning may continue for some time and the plant state will be continually changing. A safety case or a systematic series of developing safety cases will be required for this period. It is also important to note that some activities that are essential to enable decommissioning to take place may increase risks temporarily, for example, remedial work, plant installation or waste retrievals. Such activities need to be fully considered, substantiated and monitored.

*3.2.3. Regulating the change in risk*

Once the bulk of radioactive material such as fuel or process liquids has been removed from the plant the risk of a significant radioactive release is reduced. However, the work of cleaning out contaminated plant and dismantling will pose new hazards, particularly if, as may be the case, for old plants, complete plant information is not available. Workers may be exposed to higher radiation doses and more industrial hazards, and the potential for spills and leakages is higher.

The transition from operation to decommissioning and the decommissioning process is usually accompanied by significant organizational change. The operator will probably wish to reduce staff numbers as production ceases and staff will often leave of their own accord for better prospects elsewhere. There may be drives to make more use of contractors to undertake specific projects or provide certain services. Problems arise where the operator does not retain sufficient in-house resources and knowledge so it can take proper responsibility for the work. For this reason, some regulators have sought and obtained powers to control organizational change.

There will be different challenges for the remaining workforce and some may find it difficult to adjust to the change. Staff may have to be retrained to undertake different tasks. Work will be undertaken on parts of the plant which were not generally accessible. This must be carefully planned and contingency plans made if the situation is not as envisaged. It needs to be recognized that the drawings and records for old plants may be poor compared with modern expectations.

One question is whether the regulator should put less effort into the regulation of decommissioning sites. On the basis of the reduced risk it would seem that regulatory resources should be transferred to the operating plant. However, as indicated above, many changes are taking place at the site both to the plant and organization and different operations are being undertaken. The experience in the UK is that decommissioning sites, particularly complex ones, still need significant regulatory attention during the more active phases of decommissioning.

## 3.3. Environmental impact assessment

Many countries have a requirement for an environmental impact assessment before decommissioning starts and this is now a specific requirement for reactors in the European Union. The expectation is that the local environment will be significantly improved after the facility is decommissioned. The aim therefore is to ensure that the decommissioning process itself does not lead to adverse environmental impacts and that appropriate mitigation measures are implemented during the process. The process for producing environmental impact assessment is generally an opportunity for the public and interested parties to become involved in the decision making process.

An important feature in these assessments is the long time scales for some decommissioning projects, which may be many decades. In that time there may be changes, either human made or natural, to the local environment over which the operator has no control. Another aspect is that environmental statements are generally expected to give an analysis of the options considered and the reasons for the preferred option, and discussion of options is part of the process. This is more difficult if the operator is constrained by government policy, as may well be the case where the government has decided to shut down a nuclear programme or the facilities are government owned. In addition, if some phases of decommissioning are to be deferred, the detailed methods for undertaking the task may not be fully developed. This makes it difficult for the operator to make a comprehensive case although it should be able to demonstrate that it has a viable plan. It should be noted that if there is a substantial change to the project there may be a requirement for a new assessment.

## 4. STRATEGIES FOR DECOMMISSIONING

### 4.1. Developing strategies

One of the keys to successful decommissioning and site restoration is the development of robust strategies and plans. This will include a consideration of options and usually the use of some form of decision aiding technique to decide on the best strategy. A large number of factors need to be taken into account and these are discussed later. A strategy may be developed for one plant, or one site, or a group of similar sites or for the national programme.

The strategy may need to take into account complex interactions between different decommissioning projects on site, plants that continue to operate and possibly interactions with plants on other sites. It will need to be consistent with the operators own and the national radioactive waste management strategy, as well as any national decommissioning strategies. It may need to take into account specific government policies on, for example, sustainable development and levels of radioactive discharges, as well as being consistent with regulatory requirements.

The end point of decommissioning needs to be identified. Is the aim to release the site for other unrestricted use or to keep it available for future nuclear use or perhaps as a disposal site? Is it possible to release the site for unrestricted use in the foreseeable future? This topic will be discussed in another session of this conference.

A strategy for decommissioning will generally identify a number of stages or activities, including:

— removal of fuel, process liquids, etc;
— decontamination of plant;
— conditioning waste for disposal or storage;
— dismantling of plant;
— dismantling of buildings;
— restoration of the site/release from regulatory control.

These activities may follow each other closely or there may be intermediate periods of care and maintenance between stages of the work. As well as scoping the work the strategy will also need to identify and justify the time scale and length of any care and maintenance periods. The outcome should be a strategy that is practical and well justified which will form the basis for more detailed planning. Experience has shown that problems occur if strategies are not developed early enough and these days the expectation is that some planning for decommissioning is done when the plant is designed.

Relevant stakeholders, including the public, have a legitimate interest in the strategy for decommissioning a nuclear plant, particularly if the projects are government financed. The way that the public is involved in decisions will depend on the legislative system and culture of each country. Finding ways for a meaningful public discussion is always a challenge. In some countries the environmental impact assessment process is used to facilitate this debate. Under this system the operator or some other body is expected to consult widely on options before producing a formal environmental statement with the aim of finding a consensus. In other countries the strategy for decommissioning is a matter of government policy and so other processes are used for involving the public. Where many decommissioning projects are under the control of a single organization, then there may be merit in holding a debate on the national strategy. This would identify priorities so that resources could be used most effectively. Such resources would include funds and also technical expertise and skills which may be in short supply, particularly in the absence of a programme of nuclear build.

### 4.2. Factors influencing the choice of a strategy

A large number of factors will influence the choice of options within a strategy. Specific safety related issues include radiation exposure to the work force and public, the potential for a release of radioactive material, conventional hazards and hazard from non-radioactive chemicals. There is also the issue of how radioactive waste is managed and this is discussed below as a special topic in the context of the lack of a disposal site. The operator also needs to estimate costs and ensure the availability of funds. Whether there is pressure for re-use of the site is another factor which may have a significant effect on the strategy. There are also less quantifiable factors such as governmental policy on sustainable development and public attitudes which need to be taken into account. If it is planned that a decommissioning project will last for many decades, then the risks and uncertainties in the project increase.

#### *4.2.1. Radiological safety*

The property of radioactive substances to decay has led to the suggestion that there is some advantage in leaving plant or buildings in care and maintenance for periods of time on the grounds that this will make eventual decommissioning safer and easier. This argument may be valid for short lived radionuclides in situations where the material can be contained and physical deterioration will not make the decommissioning task more hazardous. An example is structures contaminated with nuclides such as cobalt-60. On the other hand, many chemical process plants are contaminated with long lived nuclides such as plutonium, and here there is no benefit from decay but clear 'disbenefits' from the in-growth of daughter radionuclides.

If periods of care and maintenance to allow for radioactive decay are included in the strategy, then containment of radioactive material and integrity of structures become key safety issues to protect both the workforce and public. In particular, water ingress must be avoided. This means that the operator has to carry out a surveillance and monitoring programme and have contingency plans to remediate the position or decommission early if problems occur.

#### *4.2.2. Decommissioning in the absence of a final waste management route*

Decommissioning of a plant or site will lead to the production of a wide range of radioactive wastes. Any remaining operational wastes will need to be conditioned at this time, decontamination of plant and buildings will result in wastes and parts of the plant and buildings which cannot be decontaminated will also be classified as radioactive waste. The quantity and type of waste will vary depending on factors such as the type of plant and national practice on clearance of material which has been on a nuclear site. The issue is then how best to manage the situation where disposal routes are not immediately available and whether it is a reason to delay decommissioning.

First there is the question of spent fuel and high level waste from reprocessing, for which no country has an established disposal route. The strategies adopted for spent fuel are continued storage on-site, or storage in a central site, or reprocessing. The advantage of a central site is that the shut-down site can be decommissioned completely providing the rest of the waste can be sent off-site. High level waste from reprocessing is generally being incorporated into glass matrix and stored on the reprocessing site, but may be returned to another country in due course. This will not affect decommissioning in the short term where, as is often the case, the reprocessing plants are still operating and in practice decommissioning of such sites will be carried out over extended periods.

Next is the issue of intermediate level waste, where the type and amount is very plant-specific. In countries such as the UK, where the civil programme developed from the weapons programme and there was extensive research into different reactor types, there is a significant legacy of intermediate level wastes. Much of this is in raw form and was accumulated as it arose with little thought of segregation or retrieval. The existing stores may not meet modern standards. The previous policy in the UK was not to foreclose options for the treatment of waste, unless there were overriding safety reasons, with the aim of being confident that when the waste was eventually conditioned it would be suitable for final disposal. This policy was developed in anticipation that a disposal route would be available within a decade or so and so it seemed reasonable, subject to being able to justify continued safe storage, to plan to condition waste just before disposal. The present situation is that a solution for intermediate level waste is a very long way off. The UK regulatory response has been to press the operators to treat their wastes so they can be in a passive safe form in stores which are designed for around 100 years. The aim therefore is that the old stores should be emptied and decommissioned.

Raw waste is also stored at reactor sites, in a variety of facilities, old and modern. If the waste is in old stores then there is a strong argument for early treatment to ensure that it does not become mobile. On the other hand it might be appropriate at a site where there are only limited quantities of raw waste stored in modern stores with robust containment to continue to store it until a disposal route is established. The actual practice varies according to the circumstances.

Some plant components or parts of structures may be designated as intermediate level waste and cannot be decontaminated down to low level waste or free release levels. If the state of these components of structures is such that the waste is most unlikely to be mobilized, then there is an argument for leaving them on-site until a disposal route is available. Indeed, the alternative may simply be to cut them up and place the waste in containers surrounded by grout in a purpose-built store at the site with a possible increase in the volume. The graphite in UK reactors is an example, as is activated steel. Leaving short lived contaminated material in situ for a while will have the advantage of allowing some of this material to decay to low level waste.

Much of the material from the structures of plant and buildings will be categorized as low level waste or have the potential for free release after careful monitoring and decontamination, if necessary. Although low level waste disposal facilities are generally available, they may not be adequate to take large volumes of decommissioning wastes. New facilities may need to be planned and put into operation, which can be a lengthy process. Similar arguments for delay to those above may therefore be reasonable. However, another response to the lack of disposal facilities could be to put much more effort into decontaminating to levels that are acceptable for free release and recycling.

There is also the question of how to deal with contaminated soil on-site arising from leakage or spills that is above levels at which it can be left on the site when it is cleared. If the activity is still reasonably low, then it is questionable whether it is a good use of resources to dig it up and place it in a low level waste disposal site. Possibly, in situ disposal could be a better option. However, it should be noted that nuclear sites were not selected using the same criteria as disposal sites so the geology and hydrology may be less suitable than a specially selected disposal site and this could result in more rapid mobilization of material. It is unlikely, therefore, that contaminated soil could be left on-site without some form of surveillance programme. There is also the general question of how and when waste disposal sites can be released from regulatory control, of which this is a specific example. The matter is discussed later in this conference.

Entombment of the plant may also be considered as an option in the absence of a disposal route. In many respects the issues are similar to those raised by contaminated land.

In cases where early treatment of wastes is the preferred strategy, the risk is that the conditioned waste may not be suitable for the disposal route when it is eventually established. The need for repackaging of waste is clearly undesirable. However, it should be possible to derive some basic waste conditioning and packaging specifications linked to particular disposal options which would give a reasonable assurance that conditioned waste will eventually be acceptable for disposal.

Therefore there are a number of strategies which can be used to manage decommissioning in the absence of a disposal route. In some cases it may be a factor in deciding to delay some part of the decommissioning work, in other instances the result will be longer term storage of conditioned waste or more strenuous efforts to make material suitable for free release or recycling.

#### *4.2.3. Care and maintenance*

A decommissioning strategy may include periods of care and maintenance for a number of reasons. As discussed earlier this may be to allow for radioactive decay or because a disposal route is not yet available. Funds or other resources such as a skilled work force may not be available to carry out the whole project or a number of projects together. Where a large number of projects are running on a site or several sites, a strategy to make best use of resources may be to remove most of the radioactive material from the plant and then do the same for other plants; then return to final dismantling of each plant in sequence later.

Whatever the reasons for including periods of care and maintenance in the strategy, such periods need to be managed carefully and raise specific safety issues which need to be addressed. The operator must not be perceived as walking away from a problem and will need to explain the strategy to the local community and keep them informed.

During a period of care and maintenance the operator will need to ensure that the structure of the plant and buildings retain acceptable integrity to continue to comply with safety criteria. This means setting up a monitoring and surveillance programme and having contingency plans in place to take remedial action or, in the extreme, decommission early. This work will include: maintenance of any essential safety systems and infrastructure; monitoring structural integrity and environmental surveillance. Regular reviews of the safety case will also be needed.

The site will generally continue to be licensed and a challenge to the operator is to maintain sufficient staff and expertise through the care and maintenance period to function as a nuclear licence holder and undertake safety duties. This may be particularly difficult if the operator's or the national nuclear programme has come to an end. No doubt the operator will use contractors, but even these may be in short supply and they need to be managed. The operator may propose that the site in care and maintenance can remain unmanned, with a central team providing the nuclear expertise and remote security surveillance. Such a case could, however, only be made if the hazard and risk of an accident were extremely low. Even then the questions are whether the operator could arrange for a sufficiently fast response to an event and whether the public would be content with an unmanned site. When the site is finally decommissioned the operator will need to set up an appropriate organization to ensure it has sufficient expertise to either undertake the work or manage contractors.

In order to facilitate final decommissioning, the operator would need to ensure that there is sufficient information on the state of the plant and possible hazards. Such records need to be physically maintained so they can be read in the future. If electronic media are used then these need to be reviewed and updated regularly.

From the above discussion it can be seen that including periods of care and maintenance in a decommissioning strategy is not a trivial exercise, particularly if they are extended. It needs proper planning and adequate resources. Some operators may decide after careful consideration that it is more cost effective to decommission early than manage long term care and maintenance.

As well as safety, financial and logistical issues, there is the question of how long term periods of care and maintenance fit with policies on sustainable development and the precautionary principle. One argument is that this generation should not leave the burden of decommissioning plants that we have benefitted from to future generations. On the other hand, it can be argued that deferred decommissioning is acceptable providing this generation provides the funds, information and plans. The resolution of these arguments is essentially one for governments taking into account public opinion.

#### *4.2.4. Managing uncertainty in decommissioning*

In any project there are uncertainties and managing these is an integral part of project management. In a decommissioning project there are broad uncertainties about the future environment in which a project will take place. In addition, there may be uncertainties about the precise condition of the plant and this may cause problems in defining the decommissioning work. The uncertainties need to be taken into account in formulating strategies and plans. A strategy that involves extensive care and maintenance periods will be subject to more uncertainty, and this in itself can be a powerful driver for early decommissioning. Cost estimates will need to contain appropriate risk margins to accommodate these uncertainties and possible changes in the availability of funds from, for instance, government or investments.

The policy and regulatory framework may change in the future. Experience shows that regulatory and safety standards generally become more restrictive. Availability and standards of waste disposal options may change.

The physical environment may also change. Many nuclear sites are on rivers or on the coast and may be affected by flooding. In some parts of the world, storms are becoming more violent. These changes may mean expensive protective measures or earlier dismantling.

The features of legacy plants may not be well recorded or particularly, if there has been an accident, the plant condition may not be well understood. The operator may need to go back over records, interview retired staff and use any other sources of information. Even with this work it may still be difficult to produce a detailed plan or safety case at the start of the project; however, it is important that the overall approach is identified. The work can then proceed in a careful and controlled manner and the plan revised to take account of new knowledge. In order to achieve this it is desirable that individual activities can be undone or halted without additional hazard in case unexpected dangers come to light and the order of activities should be planned so the earlier ones provide information to assist in managing the later ones.

## 5. CONCLUSIONS

This paper has discussed some of the differences between the operational and decommissioning phases and has identified safety issues associated with various aspects of decommissioning.

A key point is the importance of developing well considered and justified strategies to act as the basis of detailed decommissioning plans.

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# DECOMMISSIONING OF THE NUCLEAR FACILITIES AT THE RISØ NATIONAL LABORATORY IN DENMARK

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**Abstract**

After 40 years of nuclear research, Denmark has decided to close down all nuclear facilities except the Waste Management Plant at the Risø National Laboratory, namely the DR 1, DR 2 and DR 3 research reactors and the Hot Cells. At a later stage it will be decided to decommission these facilities of which the Waste Management Plant will be decommissioned last. The DR 2 reactor was closed in 1975, the Hot Cells in 1993 and the DR 1 and DR 3 reactors in 2000. The selection of an optimum decommissioning strategy depends on many factors, e.g. the national policy, the characteristics of the facilities, environmental protection, radioactive waste management, future use of the site, and the cost and availability of funds for decommissioning. Two overall strategies have been considered: (1) an irreversible entombment, where the nuclear facility is entombed in concrete and thereby transformed into a final repository for low and medium level waste, and (2) decommissioning to 'green field' condition, where all buildings, equipment and materials that cannot be decontaminated below established clearance levels are removed. Entombment has been rejected and three different decommissioning scenarios with green fields as the end point are being considered. The total duration of the scenarios is 20, 35 and 50 years, respectively. The paper describes the national policy on decommissioning and the organization responsible for the decommissioning is presented. The decommissioning scenarios are described with special emphasis on safety implications and costs. Management of the decommissioning waste and its characterization in terms of activity content are presented, including the construction of standard concrete containers and temporary storage facilities at the site. A large amount of inactive or very low active waste will be created during decommissioning, and clearance of this waste from regulatory control is discussed with regard to both methodology and clearance criteria. Finally, the impact of the decommissioning on the environment is briefly addressed.

## 1. INTRODUCTION

The Risø National Laboratory (Risø) was the creation of the famous Danish physicist Niels Bohr. He took intellectual responsibility for the introduction of experimental nuclear physics in Denmark and was the driving force in convincing the relevant Danish politicians to plan for the peaceful use of nuclear power as an important part of Danish energy production.

The aim of Risø when the first Danish reactor (DR 1) went critical in 1957 was to prepare — in the long term and through experimental work — a Danish nuclear power programme. That was the motive of Niels Bohr and of Danish Governments. The DR 1 research reactor was followed by the DR 2 (1958) and DR 3 (1960) research reactors and the Hot Cell plant (1964). Around these research facilities a national laboratory was constructed and developed. In the beginning, applications of nuclear technology created a joint strategic basis for all departments at Risø. In 1985, the nuclear option was removed from Danish energy planning. Risø was at that time by far the largest research facility in the country.

After the decision to close the nuclear facilities was made in 2000, energy production and distribution remained a general research theme at Risø, with wind energy as a good example. However, the research palette of today has plenty more colours than before, and the 'new Risø' no longer depends on the old nuclear facilities. A new strategy for future research has already been implemented.

In the light of this overall development Risø wants to dissociate itself from the past. Therefore — and in accordance with this desire — the Danish Government has decided to create a new State company, independent of Risø, with the plan to transfer the task to execute the decommissioning of all the nuclear facilities from Risø to this new company.

This paper is the first international presentation of the decommissioning strategy elaborated by the new company Danish Decommissioning.

## 2. DESCRIPTION OF THE NUCLEAR FACILITIES AT THE RISØ NATIONAL LABORATORY

The Risø National Laboratory is located about 6 km north of the city of Roskilde. At the site the nuclear facilities are situated close to Roskilde Fjord. The nuclear facilities include three research reactors (DR 1, DR 2 and DR 3), the Hot Cell facility and the Waste Management Plant with storage facilities. Their locations are indicated in Fig. 1. The DR 2 and DR 3 research reactors and the interior of the Hot Cell plant during the early days of its operation are

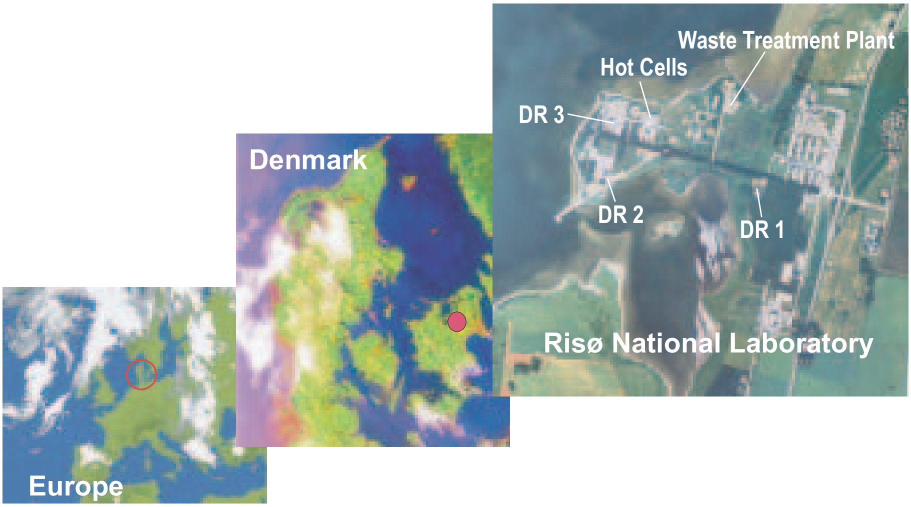


*FIG. 1. Location of the Risø National Laboratory close to the city of Roskilde, some 40 km west of Copenhagen, and the location of the nuclear facilities on the Risø peninsula.*

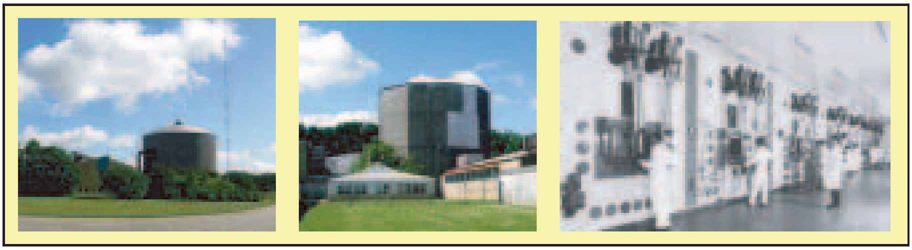

*FIG. 2. From left to right, the DR 2 and DR 3 research reactors and the interior of the Hot Cell facility.*

shown in Fig. 2. The activity content in each of the nuclear facilities has been estimated from both measurements and calculations and the results are shown in Table I with reference to the year 2000.

Tritium in the heavy water from the DR 3 reactor constitutes the largest single activity at the nuclear facilities, as can be seen in Table I, but it is, however, a very low toxicity radionuclide. The major potential radiological risks would arise during the decommissioning of the DR 3 reactor and the Hot Cell plant. Although the potentially largest doses could arise from exposure to waste in the storage facility for high radiation waste, this waste is safely contained in stainless steel containers and the probability of being exposed is therefore rather low.

TABLE I. ACTIVITY CONTENT IN THE NUCLEAR FACILITIES AT THE RISØ NATIONAL LABORATORY IN 2000 [1]

| Nuclear facility | β/γ activity (GBq) | α activity (GBq) |
|---|---|---|
| Storage facility for high-radiation waste | 700 000 | 30 000 |
| Storage hall for waste drums | 4 800 | — |
| Waste Management Plant | 8 500 | 10 |
| Research reactor DR 3 (excluding fuel) | 200 000 | — |
| Hot Cell plant | 3 000 | 100 |
| Research reactor DR 1 (including fuel) | 100 | 5 |
| Research reactor DR 2 | 60 | — |
| Cellar DR 2 (tritium in heavy water) | 3 000 000 | — |

The major characteristics of each of the nuclear facilities at Risø are briefly presented in the following paragraphs. A more detailed description of these facilities can be found in a project report initiated by the Risø National Laboratory in June 2000. This report describes the nuclear facilities to be decommissioned and gives an assessment of the work to be done and the costs incurred [1].

### 2.1. DR 1 research reactor

DR 1 was a 2 kW thermal homogeneous solution type reactor, which used 20% enriched uranium fuel and light water as a moderator. First criticality was obtained on 15 August 1957. During the first ten years of operation the reactor was used for neutron experiments and thereafter mainly for educational purposes. In the autumn of 2000, it was decided to end the operation of the reactor.

The reactor core consists of a spherical steel vessel containing 13.4 L of uranyl sulphate dissolved in light water, which will be drained before decommissioning. Around the core there is a graphite reflector contained in a steel tank and a biological shield made of heavy concrete. The reactor is provided with various irradiation facilities. The reactor was controlled by two stainless steel control rods containing boron carbide. In addition to these major reactor components, there are connecting pipes, recombiner, lead shield, cooling coil, etc.

The main part of the activity is concentrated in the fuel solution. During 43 years of operation, it has only consumed about 1 g of $^{235}U$ out of a total amount of 984 g. When the core solution is removed, the recombiner, the connecting pipes and the core tank are the most active components due mainly to $^{137}$Cs deposited on the inner surfaces (and small amounts of actinides). Small amounts of long lived activation products such as $^{14}$C, $^{60}$Co, $^{63}$Ni, $^{133}$Ba, $^{152}$Eu and $^{154}$Eu are left in the different construction parts, mainly in the core tank, the reflector tank and the concrete shield surrounding the graphite reflector.

### 2.2. DR 2 research reactor

DR 2 was a pool type, light water moderated and light water cooled reactor with a thermal power level of 5 MW. The reactor went critical for the first time on 19 December 1958. It has mainly been used for isotope production and neutron beam experiments. It was closed down on 31 October 1975 and partially decommissioned. After the final shutdown, the spent fuel elements were shipped back to the USA. The reactor block and the cooling system were sealed and the reactor hall was used for other purposes until 1997, when a pre-decommissioning study was commenced. DR 2 operated at full power from 1959. During its 5905 days of operation, the integrated thermal power was 7938 MW·d.

The reactor block is made of ordinary and heavy concrete and contains the reactor tank made of aluminium and a lead shield surrounding the core position. A shielded graphite column used for thermal neutron irradiation experiments is situated next to the core position. The reactor tank is 8 m in height and 2 m in diameter and has various beam and irradiation tubes. The primary cooling system, including the heat exchangers, is made of aluminium.

The major part of the residual activity in the reactor components is located in the stainless steel components and to some extent in the beam plugs and heavy concrete shield. The radionuclide activity is situated in the following parts of the reactor system: reactor tank ($^{60}$C), heavy concrete shield ($^{133}$Ba, $^{152+154}$Eu), beryllium reflector elements ($^{10}$Be), thermal column graphite ($^{152+154}$Eu, $^{14}$C), beam plugs ($^{60}$Co), guide tubes and S tubes ($^{60}$Co), and the primary cooling system ($^{60}$Co, $^{137}$Cs).

### 2.3. DR 3 research reactor

DR 3 was a 10 MW tank type reactor with heavy water as a moderator (and partly a reflector) and coolant. It was of the DIDO/PLUTO family constructed in the United Kingdom. DR 3 went critical for the first time on 16 January 1960 and has been operated since then on a four-week cycle, with 23 days of continuous operation and 5 days of shutdown. It was finally shut down in September 2000, its last period of operation ending in April 2000. After final shutdown, the fuel elements were removed and shipped to the USA and the heavy water (about 15 000 L) has been stored in stainless steel drums in the cellar of the DR 2 reactor.

The reactor has been used for materials testing, beam experiments, isotope production and silicon irradiation. The main reactor components are: reactor aluminium tank, primary cooling system (steel), graphite reflector, steel tank, lead shield and biological shield (heavy concrete). The coarse control arms (cadmium contained in stainless steel) are stored outside the reactor in the storage facility for high radiation waste. The auxiliary systems are still in place, but are presently undergoing modification or being removed. It is planned to use the active handling hall for decommissioning activities, including operations in the handling pond.

The major activity will be found in the following reactor components: reactor aluminium tank, graphite reflector, reactor steel tank, top shield, lead shield, biological shield, coarse control arms, irradiation rigs and thimbles, and experimental facilities. The main components have a total weight of about 1000 t and nearly all the residual activity will be found here, approximately 200 TBq of semi-long-lived and long lived radionuclides (year 2000). The tritium activity in the heavy water is about 3000 TBq. The residual activity in the reactor components has been estimated on the basis of calculations for the British DIDO reactor at Harwell, properly corrected for differences in reactor power and operating period.

### 2.4. Hot Cell facility

The Hot Cell facility was commissioned in 1964 and operated until 1989. The six concrete cells have been used for post-irradiation examination of irradiated fuel of various kinds, including plutonium enriched fuel pins. All kinds of non-destructive and destructive physical and chemical examinations have been performed. In addition, various sources for radiotherapy — mainly $^{60}Co$ — have been produced from irradiated pellets in DR 3. Following a partial decommissioning of the Hot Cell facility from 1990 to 1994, only the row of six concrete cells remains as a sarcophagus inside the building. The remaining part of the building has been released and is now used for other purposes.

The dimensions of the interior of the six cells are: 39 m in length, 4 m in width and 5 m in height. The cells are shielded by approximately 2 m of concrete walls with lead glass windows. The cells are lined inside with steel plates and a conveyor belt and parts of the ventilation systems still remain. Only long lived fission products and actinides remain in the cells, together with some small activated Co pellets. Alpha and gamma spectrometric analyses of smear samples and dose rate measurements have shown that the major part of the activity, i.e. more than 90%, is found in concrete cells 1–3. The total activity in the cells (1993) is about 3000 GBq b/g activity (mainly $^{137}Cs$ and $^{90}Sr$) and about 100 GBq actinides.

### 2.5. Fuel Fabrication facility

The Fuel Fabrication facility has produced fuel elements for the DR 3 reactor for more than 35 years. Up to 1988, the fabrication was based on high enriched (93% $^{235}U$) metallic uranium, but from then on the elements have been made from low enriched (<20% $^{235}U$) $U_3Si_2$ powder. When all fuel material in the form of unused powder, fuel plates, samples, etc., has been transferred to the DR 3 storage room, the only activity left will be in the form of uranium contaminated equipment in the connected ventilation system and in the drain pipes in the building. It is expected that most of the contaminated equipment can rather easily be completely decontaminated.

### 2.6. Waste Management Plant with storage facilities

The Waste Management Plant is responsible for the collection, conditioning and storage of radioactive waste from the laboratories and the nuclear facilities at Risø and from other Danish users of radioactive materials. No final disposal of Danish produced radioactive waste has taken place and the entire collection of waste units produced since 1960 is currently stored in three interim storage facilities at the Risø site.

The decommissioning of the Waste Management Plant will have to be postponed until the decommissioning of the other nuclear facilities has been completed and suitable substitutes have been provided. After decommissioning of the nuclear facilities, there would still be a need for a system for the treatment of radioactive waste in Denmark, as radioactive isotopes will still be used in medicine, industry and research. The active part of the Waste Management Plant consists of the treatment plant for radioactive water (evaporation using steam recompression), decontamination room (mainly for protective clothing) and laboratories for control analyses and waste characterization.

The low active waste from the wastewater treatment plant is put in drums in a bituminization cell. The storage hall for low level waste drums contains about 4700 drums. The shielded storage facility for low and medium level waste contains about 80 drums of medium level waste. Each drum is a 100 L drum inside a 220 L drum with the annular space filled with cement mortar. The storage facility for high radiation waste consists of an underground concrete block with holes and pits for high radiation waste in stainless steel containers, e.g. control rods from DR 3 and α contaminated waste from the Hot Cell facility.

## 3. THE NATIONAL POLICY ON DECOMMISSIONING

The decision taken in September 2000 by the Risø Board of Governors to permanently close down the DR 3 research reactor, and the subsequent approval by the Minister responsible for science policy mark the starting point of the new State company Danish Decommissioning. No policy existed before September 2000 and no savings were made in the past for investments in decommissioning. Within a short period very fundamental decisions had to be taken. Firstly, it was decided to create the new organization with decommissioning as its one and only task and, secondly, it was decided to indemnify Risø for the loss.

The decision to establish a governmental organization responsible for the decommissioning was taken from the very beginning as part of the dialogue between Risø and the Ministry of Research and Information Technology. Seen from Risø's point of view, it was a matter of importance to avoid an image of 'decline and fall'. Therefore, the close-down was to be seen as a starting point for a new and offensive research strategy. The Ministry of Research and Information Technology, on the other hand, wanted to exclude any possible conflict of interest between the obligation to decommission and any future tasks.

Concerns about the impact of decommissioning upon the Risø economy became a matter of lengthy negotiations between the parties. The conclusion was an agreement with the Ministry of Finance that expenditures for decommissioning should not be a part of the Risø budget, and, consequently, there would be no connection between the financing of research and the financing of decommissioning.

The planning process for decommissioning the nuclear facilities is still evolving, which means that decommissioning of the nuclear facilities does not start from a master plan including all future steps to be taken and it most certainly does not indicate that all the pitfalls ahead are disclosed. They remain to be seen! But it does mean that a firm political decision is expected to be taken to go for complete decommissioning as fast as possible to arrive at green field status within the next 20 years. In addition, it has been decided to start — as soon as possible — a parallel process of establishing a radioactive waste disposal policy to avoid a conflict between decommissioning needs and the lack of radioactive waste storage facilities.

## 4. DECOMMISSIONING STRATEGIES

Many factors must be taken into account when selecting a strategy for decommissioning nuclear facilities. These include the national policy, characteristics of the facilities, health and safety, environmental protection, radioactive waste management, availability of staff, future use of the site, improvements in decommissioning technology, cost and availability of funds for the project and various social considerations. The relative importance of these factors must be assessed case by case. Three general types of strategy are normally considered:

— **DECON** (decontamination), where all components and structures that are radioactive are cleaned or dismantled, packaged and shipped to a waste disposal site, or are stored temporarily on-site. Once this task is completed and the regulatory body has terminated the license of the site owner, the site can be reused for other purposes.
— **SAFSTOR** (safe storage), where the nuclear facility is kept intact in protected storage for tens of years. This method, which involves locking that part of the plant containing radioactive materials and monitoring it with an on-site security force, uses time as a decontaminating factor. When the activity has decayed to significantly lower levels, the unit is taken apart, similar to the DECON strategy.
— **ENTOMB** (entombment), where the radioactive structures, systems and components are entombed in a long lived substance, e.g. concrete. The entombed plant would be appropriately maintained, and be under surveillance until the activity has decayed to a level that permits termination of the plant's licence.

Three different decommissioning strategies for the nuclear facilities have been considered and some important issues that will influence the selection of the 'best' strategy have been identified:

— A prolonged cooling period (40–60 years) would not reduce the radioactive inventory in the DR 3 research reactor to a level where remotely operated tools could be avoided.
— Sufficient technology in the form of tools and knowledge is available at present for the decommissioning process.
— Concentrated planning and fast execution of the decommissioning process will give the maximum benefit from the existing staff, which possesses the relevant know-how on the existing installations and routines in handling radioactive materials and components.
— A short and continuous decommissioning process will establish the best opportunities for a rational use of the national resources, especially for Denmark with only one decommissioning project and no nuclear industry.

All estimates made so far also indicate that a continuous short decommissioning scenario is the most cost effective.

— To avoid delay in the decommissioning process awaiting planning, decision and completion of a final waste repository, a new temporary storage facility will be built at Risø to store the major part of the radioactive waste emerging from the decommissioning.

A safe storage strategy for some tens of years is considered to be inappropriate because the total costs would increase with increasing time. This is due to the fact that the costs of the actual dismantling of the facilities would remain more or less unchanged, but the surveillance costs would increase in proportion to the length of the storage period. Safe storage would also be in conflict with the well established view that problems should not be left for the coming generations to solve. The entombment strategy is considered to be quite unacceptable for several reasons, among them the very limited international experience. This strategy has been considered mostly due to a lack of facilities for the disposal of radioactive waste. It has therefore been suggested that complete decommissioning of all the nuclear facilities at Risø should be carried through to a green field status.

## 5. SCENARIOS AND METHODOLOGY FOR DECOMMISSIONING TO GREEN FIELD STATUS

Three different decommissioning scenarios to green field status have been considered for which the major difference is the cooling time for the DR 3 reactor from termination of operation to final dismantling. Cooling times of 10, 25 and 40 years have been considered. The total duration of the scenarios is estimated to be 20, 35 and 50 years, respectively, as indicated in (Fig. 3).

In all scenarios, it is assumed that the DR 1 and DR 2 reactors and the Hot Cells are decommissioned during the first ten years. The transfer of waste from the storage facilities at Risø to a final repository can more or less be carried out at any time after such a repository has been constructed.

For scenarios 2 and 3, it is foreseen that foreign staff should carry out the final stages of the decommissioning, since the necessary knowledge will no longer be available in Denmark. However, it will probably be possible to maintain sufficient knowledge to carry out the necessary inspections of the facilities during the dormancy period.

Rough estimates have been made of the radiation doses to staff members during the decommissioning operations and are summarized in Table II for scenario 1. These estimates are rather uncertain, but better estimates require more

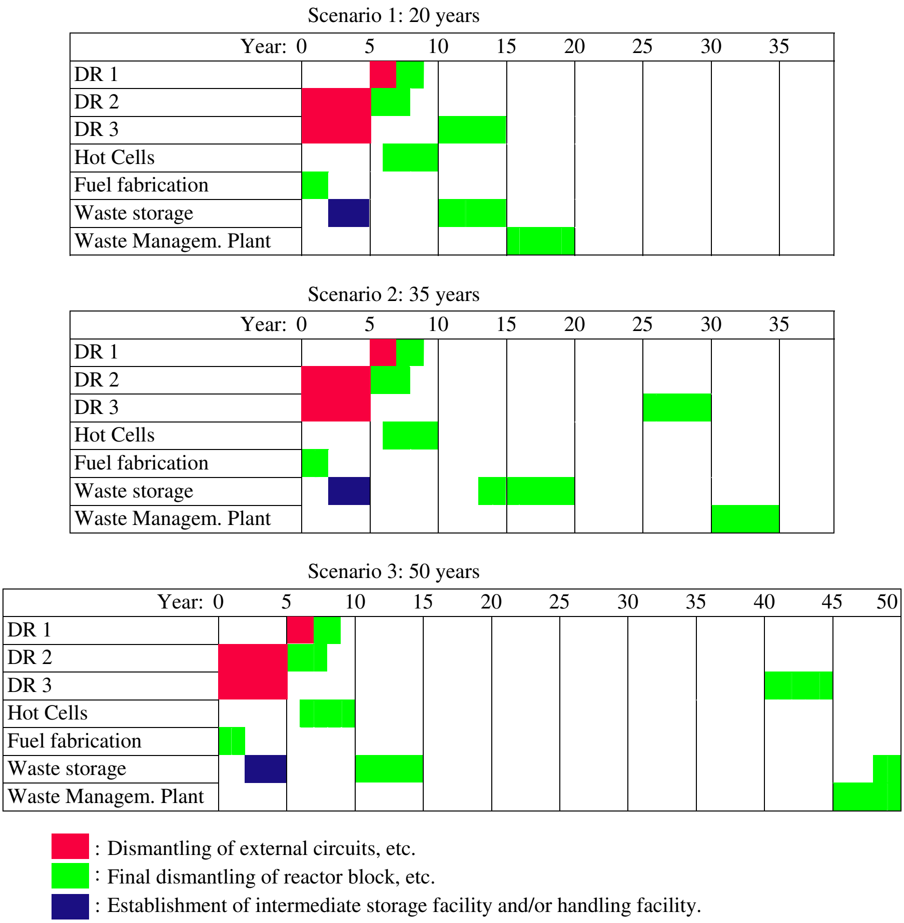


*FIG. 3. Different decommissioning scenarios for Danish nuclear facilities leading to green field status.*

precise assessment of the activity contents and the work operations to be performed.

'Hot operations' will, in all three scenarios, be performed by some kind of remote handling. The effect of radioactive decay on individual doses will be only marginal for such operations. For operations not requiring remote handling, the effect of radioactive decay would be more pronounced. On the other hand, if operations in scenarios 2 and 3, expected to be performed remotely, could be performed non-remotely due to the reduced activity content, the total collective dose might be higher for scenarios 2 and 3 compared with scenario 1.

TABLE II. RADIATION DOSES FROM DECOMMISSIONING OF RISØ'S NUCLEAR FACILITIES FOR SCENARIO 1
*(for comparison, the collective doses registered at Risø during the later years have been ~150–200 man·mSv per year)*

| Nuclear facility | Estimated collective dose (man·mSv) |
|---|---|
| Reactor DR 1 | 25 |
| Reactor DR 2 | 100 |
| Reactor DR 3 | 2000 |
| Hot Cells | 300 |
| Waste storage facilities | 70 |
| *Total* | ~2500 |

There will probably not be large differences between the three scenarios with respect to the protective measures needed for the personnel carrying out decommissioning work. The costs for the three scenarios will therefore be equal in fixed prices, apart from the differences due to expenses for keeping the organization running for different periods of time and for keeping some facilities in safe storage for the longer scenarios. Total costs for the three scenarios have been estimated to be about €150 million, i.e. on average about €7–8 million per year during the periods where substantial work is being performed.

The shortest, 20 year, scenario is thus the most attractive and has therefore been recommended. This time-frame is dictated by two opposing points of view. On the one hand, a suitable cooling period for the DR 3 reactor, which was in operation until 2000, and on the other hand the best possible use of the expertise of the existing staff. The sequence for decommissioning the different facilities is dictated mainly by: (a) the activity content within the facility and the advantage of radioactive decay; and (b) the complexity of the facility. Consequently, the following sequence for decommissioning of the different nuclear facilities has been recommended:

(1) DR 1 research reactor,
(2) DR 2 research reactor,
(3) Hot Cell plant,
(4) DR 3 research reactor,
(5) Waste Management Plant with intermediate storage facilities.

The Waste Management Plant would be decommissioned at the end because operation of this facility is necessary during the decommissioning of all the other facilities.

Much of the construction materials in the nuclear facilities, e.g. the outer part of the reactor buildings and the auxiliary systems, will not be contaminated or will be only slightly contaminated. Such materials will as far as possible be sorted from the radioactive waste and removed for recycling, reuse or disposal as inactive waste. This will diminish the volume to be placed in the final disposal facility for radioactive waste. The non-active and slightly active waste will be checked for activity before and after the components have been dismantled. This, together with the origin and the known use of the components, will be used for primary sorting. A gamma scanning laboratory will be built for the final declassification measurements. The system and procedures will be quality controlled.

After completion of decommissioning, the site may need to be restored and cleaned of the remaining contamination. The selection of restoration techniques, which can be appropriately applied, will depend upon a number of factors. The major factors include: (1) the scale of the contamination problem and the radionuclides involved; (2) the contaminated medium; (3) the location of the contaminated site with respect to the local population; and (4) the location of the contaminated site with respect to a suitable waste repository for any residues. The need for restoration will be based upon a comprehensive radiological survey of the site and a dose constraint of 50 μSv/a to the critical group.

## 6. MANAGEMENT AND CHARACTERIZATION OF RADIOACTIVE WASTE

Low level waste (LLW) and intermediate level waste (ILW) from Danish users of radioactive materials and from operation of the three research reactors has in the last forty years been stored intermediately at Risø. Together with the waste emerging from the decommissioning of Risø's nuclear facilities, it will be transferred to a final repository to be built in the future somewhere in Denmark.

It would have been preferable if a Danish repository for low and medium level waste could have been available before initiation of a significant demolition of the more active parts of the nuclear facilities. However, the time schedule for availability of a final disposal facility is uncertain, and to be able to proceed with planning for the decommissioning the intention is to use interim storage also for the waste from the decommissioning work.

The decommissioning waste consists mainly of concrete, aluminium, ordinary steel, stainless steel and graphite. Estimates are given for expected volumes of conditioned waste from the decommissioning of the DR 1, DR 2 and DR 3 research reactors with associated buildings, the concrete cells in the Hot Cell plant, small facilities such as the Fuel Fabrication facility, and the Waste Management Plant with its storage facilities. They are shown in Table III, which also shows the approximate volume of the already existing waste in drums, etc., and as separate lines the remains from Uranium Pilot Plant (UPP) experiments with uranium extraction from ores from Greenland.

A new intermediate facility will be built at Risø for storage of the waste emerging from the decommissioning of the nuclear facilities. The facility will primarily be used for a new type of waste unit in the form of concrete containers. This waste unit will be used for decommissioning waste and also for some of the existing waste drums. The concrete containers will be designed with a multiple barrier system. It comprises backfill material, stainless steel membranes and high quality concrete. For ILW, internal shielding will be used if necessary. For very low level waste, International Organization for Standardization (ISO) containers or other containers made of steel can be used.

The concrete containers will be filled with waste at the decommissioning site. Afterwards they will be moved to the new temporary storage facility. The lids of the containers will not be sealed tightly before the remaining volume in the containers is filled up with backfill material and the final disposal facility is ready to receive the waste units. Depending on the waste types, cement or gravel will be used as backfill material.

Characterization of the activity content in the containers is important and required by the authorities. Samples from the decommissioning waste will be kept as documentation in a sample library and used for non-destructive and destructive measurements. The following analyses will be used for assessing the activity content in the radioactive waste:

— Calculation of $\beta/\gamma$ activity concentrations from measurements of samples in the laboratory using a high efficiency germanium detector,
— Chemical determination of trace element concentrations in neutron activated waste for neutron activation calculations of radionuclide specific activity concentrations,
— Calculation of alpha activity concentrations from alpha spectrometric measurements of selected samples,
— Development of methodologies to determine $^{14}C$ and $^{3}H$ in reactor graphite and shielding concrete.

The requirements for the final disposal capacity have been determined to be between 3000 and 10 000 $m^3$. Probably, the facility will be a ‘near surface’

TABLE III. ESTIMATED AMOUNTS OF CONDITIONED RADIOACTIVE WASTE WITH INDICATIONS FOR CONTENTS OF SHORT AND LONG LIVED RADIONUCLIDES (EXCLUDING HIGH RADIATION WASTE AND 15 $m^3$ TRITIATED HEAVY WATER) IN 2010.

*(The two figures in the right hand column are estimates for decommissioning waste that possibly might be released as non-active waste, and for inactive waste from the dismantling of buildings, etc.)*

| Nuclear facility | Volume of conditioned waste ($m^3$) | β/γ activity short lived (GBq) | b activity long lived $T_{½}$ > 30 years (GBq) | a activity long lived actinides, etc. (GBq) | Mass of nearly inactive and inactive waste (t) |
|---|---|---|---|---|---|
| | | | Decommissioning waste | | |
| DR 1 | 2 | 5 | Low | Low | 200 + 1000 |
| DR 2 | 120 | 20 | Low | ≈ 0 | 300 + 600 |
| DR 3 complex | 1000 | 20 000[1] | 7700[1] | ≈ 0 | 1800 + 11 000 |
| | | 20 000[2] | — | | |
| Small facilities | 6 | — | Low | Low | +10 |
| Hot Cells | 50 | 3000 | Low | 100 | 2500 |
| Waste Management Plant | 50 | 1 | Low | Low | 100 + 3600 |
| | | | Existing waste | | |
| In drums, etc. | 1800 | 25 000 | 1000 | 1000 | |
| Total | 3000 | 48 000[1]/20 000[2] | 8700[1] | 1100 | 5000 + 1600 |
| UPP tailings | 1000 | Daughters | — | 30 (NORM[3]) | 500 |
| UPP ore | 2400 | Daughters | — | 100 (NORM) | 500 |

[1] The activities are based on assessments for the DIDO reactor at Harwell, UK.

[2] Tritium, mainly present in irradiated concrete shielding and generated by the $^{6}Li(n, \alpha)^{3}H$ process.

[3] NORM: naturally occurring radioactive material.

type, but the final concept has not yet been decided. The concrete containers will be constructed to withstand a certain degree of outer water pressure. Above a maximum water pressure the containers will quickly be filled with water if the facility is placed under the groundwater level. At present, construction of the final disposal facility and the process of site selection have not started.

For a final disposal facility placed outside Risø, the waste units are to be transported by road. If so, shielded transport containers will be used to comply with the guidance from the IAEA [2] and Danish regulations [3].

## 7. CLEARANCE OF NON-ACTIVE AND LOW ACTIVE WASTE

A large part of the waste from decommissioning will be a candidate for release as non-active waste, while a smaller part will require isolation in an appropriate radioactive waste facility.

Non-active waste can, without any restrictions, be deposited outside the Risø area as normal building or metal waste. It is, however, necessary to ensure that it contains sufficiently low activity levels so any form of post-release regulatory involvement is not required in order to verify that the public is being sufficiently protected. The point where there are no regulatory requirements has been defined as clearance, which is subject to *clearance levels being defined by six international organizations as values, established by the regulatory authority and expressed in terms of activity concentrations, at or below which sources of radiation may be released from regulatory control* [4].

Materials with activity content above clearance levels would be regarded as radioactive waste, whereas materials with activity levels at or below clearance levels would not be regarded as radioactive for regulatory purposes. In the European Union Council Directive on basic safety standards for radiation protection of the public, the disposal, recycling or reuse of materials containing radioactive substances may be released from the requirements of the directive provided they comply with clearance levels established by national competent authorities [5].

The European Union Article 31 Group of Experts has made recommendations on clearance levels for radionuclides in waste from the dismantling of nuclear installations [6]. These levels have been calculated from public exposure scenarios and a dose criterion of 10 μSv/a, corresponding to what has been defined as a trivial risk. Clearance levels for radionuclides that are expected during the decommissioning of the nuclear facilities at Risø are shown in Table IV.

The content of radionuclides in the candidate waste for release shall be documented to the regulatory authorities. A new low level laboratory with

TABLE IV. RECOMMENDED CLEARANCE LEVELS FROM THE EUROPEAN UNION [6]

| | Clearance level (Bq/kg) |
|---|---|
| $^{3}H$ | $10^5$ |
| $^{60}Co$ | $10^2$ |
| $^{63}Ni$ | $10^6$ |
| $^{90}Sr$ | $10^3$ |
| $^{137}Cs$ | $10^3$ |
| $^{238}U$ | $10^3$ |
| $^{239}Pu$ | $10^2$ |
| $^{241}Am$ | $10^2$ |

facilities to handle bulk quantities of waste and large items originating from the dismantling of the nuclear facilities will be built. The laboratory will be equipped with high efficiency germanium detectors, which will be calibrated using a sophisticated point source/volume source technique, enabling inhomogeneous activity distributions in bulky items to be determined by gamma spectroscopy analyses. In addition, analyses will be made for the content of $\alpha$ emitters and pure $\beta$ emitters. Procedures and methods will be quality assured in accordance with existing ISO standards.

## 8. IMPACT OF DECOMMISSIONING ON THE ENVIRONMENT

Plans for the decommissioning of the nuclear facilities at Risø will include radiation protection of the surrounding population in the same way as during the operating phase of the facilities. Procedures will therefore be established to limit potential releases of radioactive materials to the environment during dismantling of the facilities. Existing environmental surveillance programmes will be continued or even expanded to include analyses, for example $^{14}C$ releases to the environment. Emergency preparedness plans to mitigate any consequences of accidental releases of radioactive materials to the environment will be continued, although at a lower level than during the operational phase.

Assessments of potential doses to the surrounding population from atmospheric releases of radioactive materials during decommissioning, both from normal operation and from accidents, require analyses that would be extremely costly. An alternative and deterministic approach has been used relating a fractional release of the activity inventory from each nuclear plant to individual radiation doses to members of the critical group in the surrounding population. With this approach it is possible to determine the maximum doses to the critical group corresponding to an (almost impossible) 100% release of the inventory, either continuously during decommissioning or over a short time period during an accident [7].

The calculated individual doses to the critical group outside the Risø area situated at a distance of 1 km from the nuclear facilities are shown in Fig. 4, both for an annual atmospheric release rate of 1% of the inventory and for an accidental atmospheric release of 1% of the inventory over a short time period. Atmospheric releases from the DR 1 and DR 2 reactors are not included in Fig. 4, as the activity content in these facilities is very low. Individual doses from aquatic releases to Roskilde Fjord will be insignificant.

It appears from Fig. 4 that the individual doses from a 1% release rate from the DR 3 reactor would decrease with time due to radioactive decay. Doses from any future releases from the Hot Cell facility and the Waste Management Plant would remain unchanged, as they would be dominated by long lived actinides.

A fractional release of 1% of the activity inventory is extremely conservative, at least for the DR 3 reactor, as the radioactive materials are distributed as activation products within the inner parts of the construction (reactor tank, top shield, etc.). For the Hot Cell facility the activity is distributed on the inner surfaces of the concrete cells as small particles and a fractional release of 1% of the activity during dismantling would be more likely, but still rather conservative. Even if a large fraction of the activity inventories were released to the atmosphere, the maximum individual doses to the critical group would be comparable to and no more than a few times the annual doses from the natural background radiation.

## 9. SUMMARY

All the nuclear facilities at the Risø National Laboratory except the Waste Management Plant have been closed and the plan is to decommission these facilities, including the Waste Management Plant, to green field status within the next 15–20 years. The total costs are estimated to be around €150 million, corresponding to an average annual cost of about €7–8 million for the short scenario over 15–20 years. The dominant contributor to the total decommissioning costs is the DR 3 research reactor. The costs will not be evenly distributed over the period, and investment costs for building facilities, for example remote handling and decontamination, will add to the basic costs.

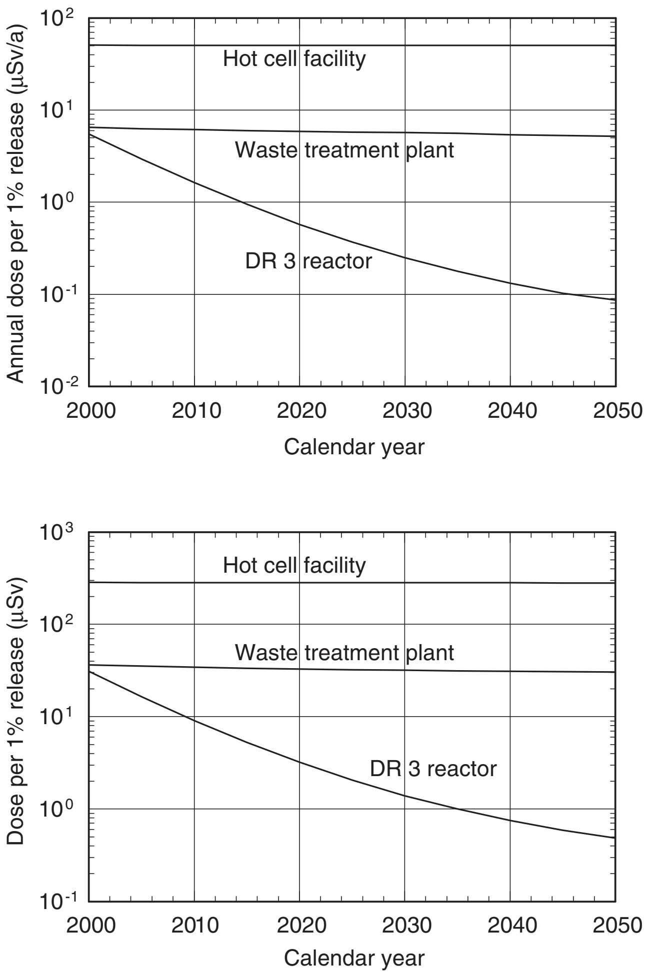


*FIG. 4. Individual doses to members of the critical group from an annual release of 1% of the activity inventory (upper figure) and from an accidental release of 1% of the activity inventory in the Hot Cell facility, the DR 3 reactor and the Waste Management Plant (excluding the storage facility for high radiation waste) over a short time period under the most probable meteorological conditions (lower figure) [7].*

A few alternative options to fast decommissioning to green field status have been considered. These include safe storage, where the nuclear plant is kept intact and placed in protective storage for several tens of years, and entombment, where the radioactive structures, systems and components are encased in a long lived substance such as concrete. The latter is equivalent to establishing an on-site shallow land burial waste disposal facility. It is very unlikely that any of these alternative options will be selected.

Storage and disposal facilities are needed for about 5000 $m^3$ of conditioned radioactive waste, including existing waste and waste produced during decommissioning. The existing storage facilities for radioactive waste are more or less filled and it is therefore planned to build a new temporary storage facility for the decommissioning waste packed into a new type of concrete waste unit. This storage facility will be used only for a relatively small number of years, with subsequent transfer of the waste units to a final repository once such a facility has been constructed.

Decommissioning of the nuclear facilities is not expected to cause any significant releases of radioactive materials to the environment but should such releases occur, only small doses comparable to doses from the naturally occurring background radiation would be the result.

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## PANEL DISCUSSION

## DECOMMISSIONING STRATEGIES AND REGULATIONS

*Chairperson:* **H. Schattke** (Germany)

*Members:* **J. Averous** (France)
**L. Noviello** (Italy)
**H. Park** (Republic of Korea)
**V. Štefula** (Czech Republic)

## Statement

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## 1. ON THE ACCEPTABILITY OF OPERATOR STRATEGIES

It is generally up to the operator to propose to the regulator some dismantling strategy. The regulator hence has to judge if these strategies are safe and sustainable. Regulators often propose strategies that involve large waiting periods before dismantling. Their arguments are based on:

- Favourable effect of radioactive decay;
- Possibility of benefiting from new dismantling technologies;
- Benefits of waiting from a financial point of view (with a constant annual interest rate, less money has to be provided at the beginning if the delay is longer).

These arguments have been shown not to be sustainable for the following reasons:

- The favourable effect of radioactive decay does not exist for fuel cycle facilities and becomes negligible after a decade of delay for power reactors (which is the minimum time needed to reach the most radioactive part of the reactor if immediate dismantling is decided);
- The benefits of new technology are not proven;
- The uncertainty of the future is problematic for the validity of the usual financial computations, and with the evolution of regulations, increases the probability of necessary financial involvement of the State;
- The loss of knowledge of the facility and of its operating history can lead to great and costly problems while dismantling, as already has been shown in some cases;
- The ability to maintain and monitor the structures of the facility over decades is difficult to prove and generally costs more than expected.

Moreover, dismantling experience has shown that current technology allows complete dismantling operations to be undertaken, and that waste elimination solutions usually exist or can exist for most waste generated by dismantling operations.

For all these reasons, the regulator should promote in most cases immediate dismantling. The main reason for deferred dismantling would be if large amounts of waste cannot be eliminated and would be kept safer within the facility. Entombment is definitely not a sustainable option as it requires, as for long term storage, permanent surveillance and maintenance.

## 2. DEALING WITH WASTE IF NO WASTE ELIMINATION PATHWAY EXISTS

If a waste elimination pathway (such as a disposal facility) does not exist for certain categories of waste, a choice has to be made by the operator between:

— Proposing deferred dismantling because the waste is considered safer if it is enclosed in the facility;
— Developing and building a specific waste storage facility.

It should be noted that if waste disposal facilities for short lived radionuclides and low level waste do exist, the waste volume remaining without an elimination pathway is often quite small and easily manageable.

The national regulation on waste usually requires the waste producer to be responsible for its waste until it is eliminated; in this case, this implies that the operator shall promote and finance (possibly with other operators dealing with the same problem) the construction of a waste elimination pathway. Often, if no pathway is shown to be available for some time, the operator chooses to build an interim storage for some special categories of waste, as it is difficult to prove the safety of the facility to be dismantled over decades.

## 3. ON THE NECESSITY TO IMPOSE SITE USE RESTRICTIONS

Recent experience involving the nuclear industry as well as the conventional industry has shown the necessity to keep track of past uses of land and to at least define the minimum use restrictions when a facility handling hazardous materials has been occupying the site. This conclusion is based on technical considerations (how far can it be proven that a piece of land has been absolutely cleaned of all hazardous contaminants), as well as on social considerations (cases when observation of a cluster of some sickness is automatically linked to past uses of the land, even if the link between this sickness and potential contamination cannot be proven).

Basic precautionary use restrictions should include minimum measurement requirements when digging or performing any civil works (in particular digging and earthworks), and a prohibition against erecting buildings involving potentially more sensitive occupants, like schools. Of course, the application of these use restrictions has to be taken into account in the urbanization plans of the vicinity in order to optimize land use.

## 4. DEALING WITH CONTAMINATION LEFT IN PLACE

Contaminated soil can be left in place, provided that optimization has been done and that it is not justified to intervene on a cost/effect basis. This topic has of course to be dealt with in an open discussion organized with stakeholders. An impact study has to be provided and land use restrictions have to be put in place and, as a precaution, possibly continuous monitoring of the funded site.

## Statement

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I want to focus on the two questions related to decommissioning and waste management posed to the panel, that I would like to restate as a question: Is it possible to decommission a nuclear facility and deal with the related wastes in case of absence of a final waste repository? My answer to this question is: the decommissioning of a nuclear facility is possible and should be pursued as far ahead of time as possible.

The reasons for this statement are many. The most important ones are safety and costs. A nuclear power plant, at the moment of final shutdown, has thousands of square metres of contaminated surfaces, thousands of tonnes of activated materials and normally also many cubic metres of radioactive liquids that must continue to be kept isolated from the environment. This means continued and extensive maintenance and surveillance. First, decommissioning actions, that is decontamination and liquid waste solidification, should be carried out to reduce risk, maintenance and surveillance, and to minimize the production of additional operational wastes.

Other decommissioning actions can minimize the volume and surface of wastes. The best, of course, would be to proceed also with waste conditioning. Is this possible without the availability of a repository? In my opinion — particularly if we are referring to a repository with engineered barriers — this is possible with minimum financial risk, on the basis of a clear definition of the areas of responsibility between waste producers and the body in charge of the repository.

Let us analyse the problem in more detail. Today the average dimensions of a waste package and the expected radioactivity content are basically standardized. The data to be collected, in order for adequate waste package characterization, are also generally known. Even better is if the data are collected according to the guidance in certain IAEA publications, such as the one being published on record keeping and one on waste inventory record keeping.[1]

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Waste Inventory Record Keeping Systems (WIRKS), for the Management and Disposal of Radioactive Waste, IAEA-TECDOC-1222, IAEA, Vienna (2001).

The body in charge of waste disposal will thus have available all the information needed to site the repository, design the engineered barriers, develop the long term waste management strategy, and eventually decide, on a case by case basis, what to do in terms of repackaging or retreatment, of those few waste packages that would not meet the final acceptance requirements of the actual repository. Of course, proceeding this way may require the need for an interim on-site storage facility. I say 'may' because in a power plant it should usually be possible to adapt existing space for interim storage. This will naturally result in extra costs as compared with those of a smooth decommissioning process with access to a final repository.

Can those costs justify a delay in the decommissioning process? I think not. In my opinion the additional costs incurred for the construction of an on-site interim storage facility are lower than the costs derived from continued operation of an unreduced controlled area, and from the related additional waste production. Most important, are costs arising from the replacement of equipment and systems at plant shutdown, which are needed for decommissioning operation and which will become obsolete because of ageing or changes in the related safety standards — not necessarily nuclear safety standards — that will take place if decommissioning is delayed. In any case, even if the costs do not balance, the risk reduction criterion, also discussed by Ms Patrice Bubar, should prevail.

I believe that from the above discussion my position on some of the other questions is clear. Safe enclosure is going to be expensive and more risky than the other two strategies, again because of ageing of support systems and degradation of the systems to be dismantled. Entombment, interpreted as leaving on-site properly reengineered wastes deriving from decommissioning in existing structures, could be a reasonable alternative to an immediate dismantling strategy if the availability of a repository is not predicted for the near future.

## Statement

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I am glad to be here for this presentation this morning. As you know, the Republic of Korea has had much experience in the construction and operation of nuclear power plants (NPPs), but we have no experience in decommissioning.

The first research reactor in the Republic of Korea, KRR-1 TRIGA Mark II, first started operation in 1962, and the second one, KRR-2 TRIGA Mark III, first started in 1972. Operation of both of these was phased out in 1995 when they reached the end of their life span and also due to the operation of a new research reactor, HANARO (High-flux Advanced Neutron Application Reactor), at the site of the Korea Atomic Energy Research Institute (KAERI) in Taejon.

The decommissioning project for both research reactors was launched in January 1997 and will be completed in December 2008. KAERI has to choose the immediate decommissioning approach because of the following reasons. First, the land and reactor buildings were sold to the Korea Electric Power Co. (KEPCO) in 1985. By the terms of the Atomic Energy Act, KAERI as the operator must decommission the reactor. Second, research and development related to decommissioning should be carried out for secure NPP decommissioning that is upcoming. Lastly, KAERI must prevent the spread of radiation hazards into the reactor building's environs, which is rapidly becoming a densely populated area because of urbanization.

Most of the radioactive wastes produced during decommissioning will be packed in 4 $m^3$ ISO type containers, which will then be stored until they are transported to the national disposal site for low and intermediate level waste. Even though it is not certain when the disposal site will be operational, decommissioning should not be deferred. Both of the reactors and related facilities are not in good condition because of minimum budgeting for the maintenance of the facilities. The most important issue is how to keep radioactive materials in a safe and well controlled condition. Therefore, KAERI decided upon immediate decommissioning of both research reactors.

Currently, the Republic of Korea has 17 NPPs in operation. They consist of 13 PWR and 4 CANDU type PHWR reactors. The first NPP in the Republic of Korea was Kori-1, which started operation in 1978. Taking into account its design life span of 30 years, it will be shut down in 2008. But the utility company for the NPP, the Korea Hydro-Nuclear Co. (KHNC), is promoting the extension of its life. However, it is expected that there will be many difficulties in obtaining public acceptance.

In considering the decommissioning of the NPP, it is recommended that heavily populated countries such as the Republic of Korea choose immediate decommissioning. According to the power supply plan of Korea, 11 more NPPs are being planned for construction and operation until the year 2015. However, it is not easy to get new sites for them. Therefore, it is desirable to locate the new reactors at current sites. Most of the sites have duplicate reactors, but their life spans are not comparable with each other. Therefore, decommissioning should wait until both reactors at the site have reached the end of their life. After decommissioning of the retired reactor, it is desirable to install the Korean Standard Nuclear Plant (KSNP), which has a capacity of 1400 MW(e). This will be one way of resolving the siting problem and reducing the cost of decommissioning and construction.

If the Republic of Korea decides to start decommissioning NPPs in 2013, it is necessary to secure the necessary and related technologies for successful decommissioning through R&D. Therefore, during the decommissioning of KRR-1 and KRR-2, basic technologies will be developed and demonstrated under middle to long term R&D programmes. The object of the first stage of the programme, from August 2001 to March 2004, is technology development related to the decommissioning of the research reactor. During the second stage of the programme, April 2004 to March 2007, the basic techniques will be developed for the decommissioning of NPPs. Thank you for your attention.

## Statement

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*Can contaminated soil be left in place and, if so, under what circumstances?*

The contaminated soil problem is typical for nuclear power plants shut down after an accident. Such is the case of the A1 nuclear power plant at the Bohunice site. The safety principles for liquid waste storage were introduced only in 1987, and thus there are hot spots of contaminated soil, predominantly because of poor liquid waste storage practices in the past.

The worst contaminated soils have already been removed and are stored in drums nowadays; however, some hot spots still remain. As a mitigation measure, water is being pumped out of the aquifer underneath and discharged into the river. This questionable decision is to prove to the public how environmentally considerate the operator is because the groundwater is seen as a potential source of drinking water and discharge into the river within the concentration limits is not in conflict with legislation.

Most recently, a project for contaminated soil landfill has been launched. It is the intention of this project to collect all the contaminated soil stored in drums, remove the hot spots from around the old leaky tanks and dispose of them in a controlled manner. The location for the landfill has been chosen within the Bohunice nuclear site.

I have been putting together the safety analysis/performance assessment of the landfill. From the assessor's point of view, I challenge the above mentioned decision on groundwater extraction and discharge into the river. The safety analysis proves that there is sufficient dispersion and retardation of the contaminants in the aquifer before it gets to the nearest well.

Quite a large amount of the contaminated soil removed during excavation of the groundworks for the new waste processing centre in Bohunice has been tentatively stored in old unused concrete basins and landscaped to a 'green field' condition. Yet, it is still part of a nuclear facility under regulatory control. A side effect of this safety analysis is that it proved that even the tentative solution to the contaminated soil problem can be re-qualified as a final solution with no further remediation activities, and the basins can be taken out of regulatory control.

So the answer to the question posed above in Slovakia is: Yes, the contaminated soil can be left 'in place' if it is done in a controlled manner with sufficient safety measures in place. That means that the soils will be accumulated in a single place — the landfill with appropriate cap, and some institutional control will be introduced to prevent human intrusion for a certain period of time. In our case the minimum institutional control period being considered is 100 years, which correlates approximately with the time required for decommissioning all of the nuclear facilities on the site (if no new ones are built in place of the existing facilities).

## Panel Discussion

## DECOMMISSIONING STRATEGIES AND REGULATIONS
### Session 2.A

R. JUNGMANN (Germany): I should like to say a few words about motivation in the field of decommissioning. The ways of helping to ensure that the nuclear facility operator does a good decommissioning job are: to make it clear that a new nuclear facility is to be built on the site after the completion of decommissioning; to make it clear that decommissioning is a challenging activity which requires excellent engineers; and to secure the support of all relevant authorities — especially their support when, as is very likely, surprises occur during the dismantling of the facility.

F.E. TAYLOR (United Kingdom): Decommissioning is certainly a challenging activity, but it is difficult to convince young graduates of that. Moreover, some nuclear facility operators faced with the task of decommissioning have already reduced their staff numbers substantially, and the remaining staff is therefore in a demotivated state. It is very difficult to remedy that situation.

As regards securing the support of all relevant authorities, we — as regulators — have recognized that we must be supportive, but we still have to regulate. It is a question of getting the balance right.

V. MASSAUT (Belgium): Radioactive decay is only a marginal consideration in decisions to delay final disposal. The main consideration is normally the absence of a disposal route. In the case of intermediate and low level waste disposal, the technical problems are said to have been resolved, so are we not making a mistake when we decide to defer the final disposal of such waste purely on the grounds that there is no disposal route?

H. SCHATTKE (Germany): The selection of a disposal route is a political rather than a technical matter.

F.E. TAYLOR (United Kingdom): It certainly is. Each country has to select disposal routes appropriate to its own needs. If you have no disposal route but are dismantling a nuclear facility, you need to store the waste in some way until a disposal route is available. Our position is that, if the waste is mobile or potentially mobile, it should be treated as soon as possible. If it is not, you can perhaps leave it untreated somewhat longer.

When dismantling a reactor, you will have large steel, graphite and other components which are difficult to dismantle and put into safe storage at the site. In my view, however, it is not a good idea to leave them undismantled for long. What to do is a political decision.

V. ŠTEFULA (Slovakia): Is there in the USA a system for receiving and disposing of sealed sources after they have been used?

C. PAPERIELLO (USA): No, there is not. After they have been used, sealed sources are often returned to the manufacturer for recycling or reuse. Plans exist for the construction of a final depository for large sealed sources, and meanwhile the US Department of Energy will accept such sources for long term storage.

E. WARNECKE (Germany): Even if decommissioning at Risø, Denmark, starts fairly soon, within say the next 20 years, is it not likely that there will not be enough qualified personnel available to do the job?

M. BAGGER HANSEN (Denmark): Although many qualified people will have retired in 20 years' time, I think there will still be some available. The decommissioning plan will include provision for the recruitment of good engineers, who will need special training in decommissioning.

E. WARNECKE (Germany): Is it likely that some of the engineers will be recruited from abroad?

M. BAGGER HANSEN (Denmark): Not all the decommissioning work will be done 'in-house'; certain tasks will be performed by outside companies, some of which may well be foreign ones.

B. JUENGER-GRAEF (Germany): Mention has been made of delays of as much as 85 years between shutdown and decommissioning. How could there possibly be qualified decommissioning personnel available after such a long delay? Would one have to rely on the availability of improved technology?

D.W. REISENWEAVER (IAEA): The IAEA feels that safe storage should not be for more than about 50 years, at the end of which at least some of the expertise necessary for decommissioning might still be available.

W.A. BIRKHOLZ (Germany): When one decommissions a facility, radioactive substances may escape if not properly controlled. How should one provide against such a risk?

F.E. TAYLOR (United Kingdom): In the United Kingdom it is required that such a risk be kept as low as reasonably practicable. We would therefore expect those engaged in decommissioning to have an appropriate risk management plan and stringent controls in place.

The risk may be higher, and the uncertainties are undoubtedly going to be greater, if there has been an accident at the facility — as in the case of one of the Windscale reactors, in which there was a fire in 1957 and regarding which, although many inspections have been carried out, some uncertainties remain. In such a situation, one cannot plan everything in detail. One has to proceed slowly, step by step, deciding on what action to take next in the light of what one discovers.

C.M. MALONEY (Canada): I should welcome views about future decommissioning activities in the light of the growing interest in radiation protection of the environment, demonstrated by the work which an ICRP task group is doing on the issue of protecting non-human species from ionizing radiation.

F.E. TAYLOR (United Kingdom): There may well in due course be changes in standards and regulations that will have to be taken into account, which is perhaps a good reason for decommissioning earlier rather than later.

J.T. GREEVES (USA): There have been references at this conference to — inter alia — unrestricted release and the 'green field' approach. I think that the various decommissioning approaches should be quantified, so as to arrive at objective cost estimates, and that it should be done on an international basis. The term 'green field' is used rather loosely, and I would be interested to hear what different people understand by it.

M. BAGGER HANSEN (Denmark): When we say that a site has green field status, we mean that it can be released for unrestricted use, even if there may still be one or more buildings on the site. We are aiming to clear the entire Risø site for unrestricted use.

F.E. TAYLOR (United Kingdom): In the United Kingdom, we refer to activity levels specified in the Radioactive Substances Act when deciding whether a substance should be considered to be radioactive. If a substance is considered not to be radioactive, it may be removed from the site.

As regards the site itself, under an act dating back to 1965 the licensee is responsible for the site until the Health and Safety Executive declares that there is no danger from ionizing radiation at the site. We are planning to hold consultations soon on what is meant by 'no danger'.

We have delicensed small sites — mainly research reactor sites— after demonstrating that there is no residual radioactivity at them, but soon we shall be faced with applications relating to larger, more complex, sites.

A. GONZÁLEZ (Spain): What should one do about maintenance during the period between shutdown and decommissioning?

M. BAGGER HANSEN (Denmark): In considering periods of 5085 years, we have envisaged major maintenance exercises every 2025 years in order to deal with corrosion, leakages, penetration of surrounding water, and so on. Also, throughout the period you need to have ventilation and humidity control systems.

D.W. REISENWEAVER (IAEA): The IAEA will soon be issuing a report entitled Safe Enclosure of Nuclear Facilities during Deferred Dismantling (Safety Reports Series No. 26), in which concerns such as corrosion during the deferral period are discussed.

G. LINSLEY (IAEA): The 'green field' image is an attractive one, particularly in public debate. For me it implies a site with no buildings or other structures left on it. If that became what was normally expected, however, might we not be committing ourselves to unrealistic goals?

J. AVEROUS (France): In France many operators are not aiming for such an end state. Particularly in the case of research facilities that use radioactive materials, some operators are aiming for an end state where one or more decontaminated buildings are left on the site. In my view, therefore, the term ‘green field’ is misleading. I believe that it began to be used, in the 1980s, by the IAEA, which should perhaps try to come up with a less misleading term. In the chemical industry, where pollution is usually much more extensive than in the nuclear industry, it is not possible to arrive at a green field and the term is not used.

D.W. REISENWEAVER (IAEA): The IAEA may have used the term ‘green field’ at some point in the past, but it does not do so now. We talk about ‘removal of regulatory controls’. In our view, decommissioning is complete when the site is no longer under regulatory control.

E. WARNECKE (Germany): Many nuclear power plants and other nuclear facilities are in regions which are economically not highly developed, and closing them down can greatly harm the local economy. Redevelopment of the site for other purposes, nuclear or non-nuclear, may therefore be highly desirable. Consequently, I would rather talk about removal of regulatory controls than about a green field, which gives the impression of precluding such redevelopment.

It has often been argued that there is an advantage in deferring decommissioning in order to reduce radiation exposures through a decrease in radionuclide inventories. This argument should be examined very carefully. In the case of reprocessing plants, there will be almost no radionuclide inventory change as they handle long lived radionuclides. In the case of nuclear power plants, after some ten years the radioactive cobalt will have decayed almost completely, but the activity of the radioactive caesium and strontium will have remained almost at the level prevailing at the time of plant shutdown. After 30 years, the overall activity level will have declined by about a factor of two, which is not a very great advantage — you will need shielding 5 cm thick instead of 10 cm, but the overall costs will not be appreciably less. Perhaps the IAEA could look into this issue.

L. NOVIELLO (Italy): On the basis of reasoning similar to that just put forward by Mr. Warnecke, we are recommending the earliest possible decommissioning of Italian nuclear fuel cycle facilities, together with the creation of interim waste storage facilities. A further argument in favour of early decommissioning is that on-site equipment suitable for decommissioning activities now may not be suitable for such activities if decommissioning is delayed for a long time.

We do not use the term ‘green field’; we speak of ‘removal from radiological control’ because some sites — with their remaining basic infrastructure (for example, connections to the high tension electricity grid) — may be ideal for other, non-nuclear purposes. If a nuclear power plant is shut down and an electricity shortage results, why not build a new power plant — not necessarily a nuclear one — on the site?

H. SCHATTKE (Germany): In my view, the term used should make it clear that the site — once it is no longer under the nuclear regulatory body's control — is available for car manufacturing or whatever. It need not be a green field.

W.A. BIRKHOLZ (Germany): Is decommissioning possible if you do not have a final waste disposal facility? In my view the answer to that question is "Yes, but...". When we started decommissioning the Greifswald nuclear power plant, we were able to transfer the radioactive waste to the final disposal facility at Morsleben. The waste had to be packaged for a predisposal period of only about a year, so that the packaging requirements were not very stringent. Then the Morsleben facility was shut down for safety reasons, so that we had to start conditioning and packaging the radioactive waste for a predisposal storage period of 3040 years. This led to an increase in costs — an increase due to the fact that we no longer had a final waste disposal facility available.

V. MASSAUT (Belgium): One can maintain institutional controls at a former nuclear site for a very long time, but ultimately knowledge about the site will cease to exist — with possibly dangerous consequences. Perhaps it would be a good idea to use former nuclear sites for facilities like chemical plants. In that way, no one would start thinking that the sites were no longer contaminated.

J. AVEROUS (France): In France, when a former nuclear site has been decontaminated and the regulatory controls removed, an entry is made in the relevant land registry file that there was a nuclear facility on that site. Land registry files, which relate essentially to land ownership, are maintained by the public authorities and have a very long lifetime; some go back for many centuries. The aim is that future owners of the site should know that a nuclear facility once stood on it.

H. PARK (Republic of Korea): We are decommissioning a research reactor located near the centre of Seoul. The land has been sold to a nuclear electricity generating company, which is, however, going to use the land for non-nuclear purposes — perhaps for a training centre or even for apartments. The fact that the land is going to be used for non-nuclear purposes is causing major problems.

L. JOVA SED (IAEA): When we talk about decommissioning, we tend to have in mind the decommissioning of nuclear power reactors, research reactors and nuclear fuel cycle facilities rather than of other facilities where radioactive materials are present — for example, hospitals. In some countries, such non-nuclear facilities are not subject to strict nuclear regulatory control and, as a result, incidents like the Goiânia accident may occur after facility shutdown. I should like to see the IAEA looking closely into the question of the decommissioning of non-nuclear facilities where radioactive materials are present.

C. PAPERIELLO (USA): Such non-nuclear facilities are fairly easy to clean up if the only radioactive materials present are short-lived medical isotopes or — say — tritium, $^{14}C$ and $^{35}S$. However, you need to worry about non-nuclear facilities where sealed radiation sources — especially ones containing long lived radionuclides — are present and to ensure that enough money is available to pay for the removal of the sources.

We are having problems with a few facilities where long lived radionuclides, particularly uranium and thorium, were once used for non-nuclear purposes. No money was put aside for their decommissioning, which will include the movement of fairly large amounts of soil. When we discover that money has not been put aside for the future decommissioning of such a facility, we require that the operator start putting money aside and draw up a decommissioning plan. We have issued written guidance on the subject.

D.W. REISENWEAVER (IAEA): Non-nuclear facilities containing radioactive materials are generally small compared with a nuclear power reactor, but there are many thousands of them. Many developing countries have neither the money to decommission such facilities nor anywhere to store the resulting waste safely. The IAEA regards this as a matter of great potential concern.

E. WARNECKE (Germany): Further to what Mr. Birkholz just said, I should like to emphasize that, if a final waste disposal facility is not available at the time of decommissioning, one must try to predict what the final disposal conditions will be — a very demanding task. In Germany, although there is now no final waste disposal facility available, the preference is still for immediate decommissioning. If discounting is not considered, the costs of immediate decommissioning of a nuclear power plant in the absence of a final waste disposal facility are not very different from the costs of decommissioning after a 30 year period of safe storage pending the entry of such a facility into operation.

In Germany, there are facilities — for example, the Wismut uranium mining facilities with tailings containing long lived radionuclides — which, under our present regulations, will have to be subject to institutional controls in perpetuity. It should be borne in mind, however, that some future generation, with better technology and greater medical knowledge, may decide to change the regulations and terminate the institutional controls.

K. SCHIFFER (Germany): The arguments for and against immediate decommissioning are very plant specific and country specific, and deciding on when to decommission means putting the arguments together like the pieces of a jigsaw puzzle. Mr. Averous spoke about indicating in a land registry file the fact that there was once a nuclear facility on the site to which the file relates. Is this also done in France in the case of sites where there have been non-nuclear facilities?

J. AVEROUS (France): Yes, it is. A good example is sites where there were coal gasification plants at the beginning of the 20th century. On one such site in Paris, a sports stadium has been built; as the contamination from a dismantled plant could not be removed completely, there was no question of building — say — homes and schools. In France, which can look back on some 200 years of industrial development, the problem of non-nuclear contamination is a big one.

K. LARSEN (Denmark): I would urge that we not drop the term ‘green field’. We need not apply it literally, and it is very useful in discussions with politicians and environmentalists.

C. PAPERIELLO (USA): The expression ‘final waste disposal’ is misleading. What we are really talking about is waste consolidation and storage for decay using geological and engineered barriers. Given sufficient time, perhaps many thousands of years, the waste will become accessible again. The question is, what will it be like after decay over such a long period?.

L. NOVIELLO (Italy): We do not aim to store radioactive waste for an indefinite period, but for a lengthy period after which it will be transferred to a final disposal facility with geological and engineered barriers. In my view, cementation — or, in some cases vitrification — of the waste is sufficient for that limited purpose. It is certainly more than what is done with most non-radioactive waste. For example, waste asbestos, which is dangerous for an indefinite period, is sent to a repository simply in polythene bags, and it can be disposed of in countries other than its country of origin.

J. AVEROUS (France): Creating a truly ‘green field’ means creating a polluted site elsewhere, so, if you are contemplating the creation of a truly green field, you should consult with all the stakeholders — those concerned about the prospective green field site and also those likely to be concerned about the prospective polluted site.

V. ŠTEFULA (Slovakia): In my country we favour immediate decommissioning, and we have started decommissioning our A1 nuclear power plant. We have a repository for low and intermediate level waste, but there will be some types of decommissioning waste which we cannot put there. Consequently, we are planning to build a buffer storage facility at Bohunice.

We have received funds from the national budget for decommissioning the A1 nuclear power plant, but it is felt that the decommissioning of other nuclear power plants should be financed largely by the operating organizations. If they cannot put aside the necessary funds in time, the question of immediate decommissioning will depend on what can be provided from the national budget.

J.T. GREEVES (USA): Different countries clearly have different positions with regard to decommissioning. For example, some countries are entombing facilities while others reject entombment and the leaving of contaminated materials in situ. Such issues will undoubtedly be discussed in November 2003, at the First Review Meeting of the Contracting Parties to the Joint Convention, and in my view the IAEA should prepare a framework for the discussions.

D.W. REISENWEAVER (IAEA): I would mention that entombment is not a decommissioning option rejected by the IAEA. We consider, however, that the requirements relating to a waste disposal site — which is essentially what the entombed facility becomes — should be met. In the case of countries with just one research reactor, we feel that entombment may even be the best option. At all events, in our view there should be a graded approach to decommissioning.

J. GINNIVER (United Kingdom): Should we, when decommissioning, be aiming for the removal of regulatory controls from sites or should there be some degree of optimization on a case by case basis at different sites?

G. LINSLEY (IAEA): I think that this question would be best dealt with in Session 2.E, Criteria for Removal of Controls.

# PLANNING AND IMPLEMENTATION

(Session 2.B)

**Chairperson**

**L. KEEN**
Canada

# CRITICAL ISSUES IN THE TRANSITION FROM OPERATION TO DECOMMISSIONING OF NUCLEAR INSTALLATIONS

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**Abstract**

The transition phase between plant operation and decommissioning is a critical one. In this period a number of modifications — both technical and organizational — are in order to adjust the plant to new objectives and requirements. It is essential that detailed planning for decommissioning begins in good time during plant operation and actions preparatory to implementation of the decommissioning strategy are initiated immediately after permanent shutdown to ensure a gradual transition and to minimize uncontrolled loss of resources. It is unfortunately common experience that this transition process is often managed inefficiently. There is therefore a great deal of room for improvement on a worldwide scale. The paper highlights the management and organizational issues in this transition period and provides guidance to minimize delays and undue extra costs, optimize personnel and other resources and initiate activities that are a precursor to decommissioning in a planned, timely and cost effective manner.

## 1. INTRODUCTION

The transition period between plant operation and implementation of the decommissioning strategy involves a number of modifications to adjust the facility to new objectives and requirements. A cultural change is also needed to reflect different management and working practices. It is essential that planning for decommissioning begins in a timely manner during operation and that activities are implemented as soon as possible after permanent shutdown to ensure controlled transition and the best use of resources. This includes, in particular, utilizing operational staff whose knowledge of the facility and its systems is invaluable in this transition period. In addition, as presented in this paper, a number of strategic and administrative issues need to be addressed before or immediately after plant permanent shutdown in support of planning for decommissioning and to reduce the burden of operational requirements. Figure 1 depicts a possible scheme for decommissioning oriented activities, projects and organizational aspects during the life cycle of a nuclear power plant. For the purposes of this paper, transition activities occur between operation and placement of the facility in a safe and stable condition in preparation for safe enclosure and/or dismantling. The focus of this paper is on strategic, organizational and management aspects rather than on technical activities per se.

## 2. PLANNING FOR DECOMMISSIONING DURING THE PLANT'S LIFETIME

Significant savings can be realized by initiating the decommissioning planning effort, in a systematic fashion, prior to permanent reactor shutdown and well before a decision to shut down is even made. The IAEA's Safety Guides [1, 2] recommend that a decommissioning plan be available from the plant's design and construction phase. The planning would continue while the reactor is still operational and information and historical resources are readily available. A comprehensive, well formulated planning programme would identify the scope of the decommissioning effort, begin preparation of required planning documents, identify and resolve waste management issues, establish a cost estimate for decommissioning, and address the safety aspects, cost and schedule of the decommissioning.

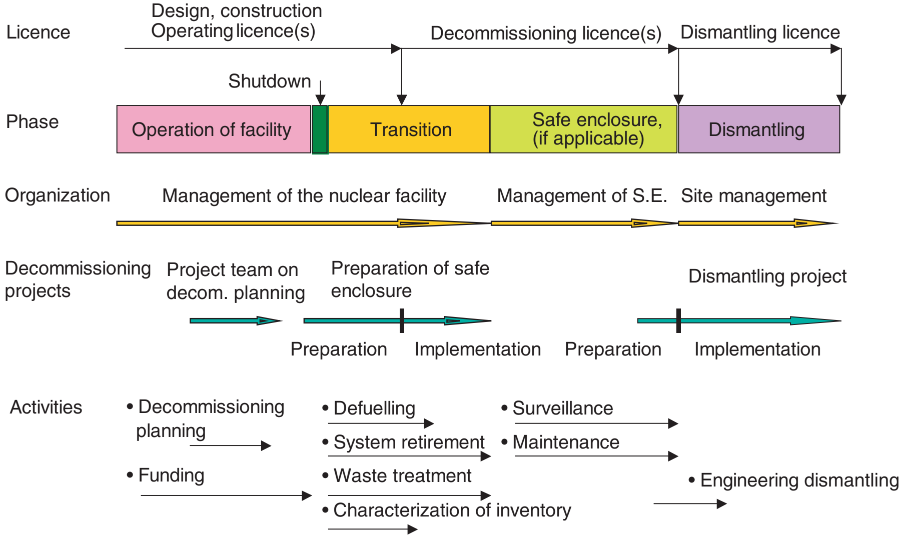


*FIG. 1. Decommissioning related activities during the life cycle of a nuclear power plant.*

The benefits listed below will typically result from early planning [3]:

- — Time and money will be saved, thus benefiting ratepayers (e.g. because the overall decommissioning schedule will be shortened considerably).
- — Planning can be done systematically, with less schedule pressure, i.e. not the decommissioning critical path.
- — The necessary information is readily available while the plant is operational and records are intact. Timely access to reliable information can speed up the decommissioning planning effort, reduce uncertainty and risks in the planned decommissioning work, and result in cost and schedule efficiencies.
- — Personnel resources (history and expertise) are still available while the plant is operating. Some of the more knowledgeable people will leave for other jobs as soon as possible after the decommissioning announcement is made and others will continue to leave as opportunities become available. Valuable experience that would aid in the decommissioning effort goes with them. Valuable experience/history will also be lost due to layoffs after shutdown.
- — After a plant enters the decommissioning phase, the employees are literally working themselves out of a job and morale could suffer along with the decommissioning effort. This letdown is not experienced when decommissioning planning is started while the plant is still in the operating phase of its life cycle.
- — Decommissioning problem areas such as waste characterization, handling and disposal will be identified and plans made for them now so that surprises and delays will be minimized after shutdown.
- — While the plant is still operational, there is time to plan for decommissioning to achieve the best results while not adversely affecting the reactor operations. A thorough planning effort is the result when sufficient time is allowed.
- — The length of time between shutdown and start of the physical decommissioning effort will be shortened considerably when pre-shutdown planning is done.

Early decommissioning planning can also ease the impact of an unplanned, permanent reactor shutdown. Unplanned, permanent shutdowns can be devastating to a utility. An unplanned shutdown further complicates the decommissioning effort since the plant may have higher priorities that deal with the reason for the shutdown. An orderly, systematic decommissioning planning effort is needed prior to permanent shutdown.

## 3. GOALS IN THE TRANSITION FROM OPERATION TO DECOMMISSIONING

The transition phase of a facility's life cycle begins during the period when it is in the final phase of operation and has been declared or forecasted to be in excess of current and future needs. Depending on national regulations, the operating licence may remain in effect during part or all of the transition phase. The goal during the transition phase is to place the facility in a stable and known condition, eliminate or mitigate hazards and transfer programmatic and financial responsibilities from the operating to the decommissioning management. Timely completion of transition activities can take advantage of facility operational capabilities before they are lost.

The decommissioning of a nuclear facility can be enhanced greatly by the completion of select activities during the transition period. There can be considerable time, even years, to carry out the transfer process from operating to decommissioning management. It is therefore important that progress is made during the transition in the direction that supports the future decommissioning strategy of the facility. Transition planning is a necessary part of overall decommissioning planning and management. Key objectives and goals during facility transition are included in Table I (elaborated from Ref. [4]).

The degree to which these goals can be achieved at a facility will vary greatly, based on its current condition, configuration and status. High priority is to be given to actions to eliminate or mitigate hazards, such as flushing process systems, removal of waste and defuelling. For other activities, a transition end point development process will ensure that the appropriate activities are identified for completion. A few examples of typical transition activities are described in Table II (elaborated from Ref. [4]).

A primary goal during transition is to focus on actions that cost effectively support a smooth process from the end of facility operations through to safe enclosure or immediate dismantling. Experience has shown that there are a number of general tasks that are appropriate for activities during the transition phase. These tasks address: non-radiological hazards; radiation fields; contamination; waste; isolation and containment; monitoring and control; refurbishment and installation, as well as documenting and labelling.

## 4. TRANSITION FROM OPERATION TO DECOMMISSIONING AS A MAJOR CULTURAL CHANGE

The period between the announcement to shut down a nuclear plant and the start of decommissioning can present significant challenges to plant

TABLE I. TRANSITION GOALS AND OBJECTIVES

- An expeditious start of activities to eliminate or mitigate hazards, beginning with those that clearly should be done regardless of the subsequent mode of decommissioning.
- Completion of activities defined as ‘transition end points’, with priority given to the specified end points for mitigation and removal of hazards and materials, respectively.
- The maximum utilization and effectiveness of current operations knowledge, personnel and operating systems/programmes to reduce the facility hazards, with emphasis placed on processes and systems for which the skills and knowledge required are unique.
- Establishing effective partnering among all involved parties, in particular among the operating and decommissioning management, contractors and authorities.
- Mitigation of the social impacts due to organizational changes.
- Reduction of costs for surveillance and maintenance and other post-operational activities.
- Identification of the treatment, storage, transport and disposal requirements for all waste.
- Review of budget and funding for specific decommissioning projects.

TABLE II. TYPICAL ACTIVITIES DURING THE TRANSITIONAL PHASE

- New nuclear fuel is sold or shipped for recycling or dismantling.
- Spent fuel is removed from the reactor and/or from the site.
- Unstable materials and/or wastes are stabilized, treated and/or removed.
- The potential for fire/explosion from violent chemical reactions or nuclear criticality is reduced or eliminated.
- The cleanout operation is completed for all systems, lines and other equipment that have the potential for significant radioactive and chemical material holdup.
- Hazardous chemicals and oil in storage are either sold or neutralized and disposed of as waste.
- Changes in the configuration and status of systems and structures as a result of transition activities are reviewed against the safety assessment. Operating requirements and controls are revised as appropriate to changed conditions.
- Barriers are installed and/or verified to be sufficient to prevent the spread of contamination.
- Appropriate levels of safeguards and security are verified.
- Facility drawings are updated reflecting changes that might have been made during the operational period.

management. They need to prepare for new technical and organizational challenges in a climate where there could be pressure to reduce staff numbers.

The move towards decommissioning can thus be regarded as a process of major organizational change, which will mostly take place during the transition phase. So far, attention has largely focused on the technical aspects of decommissioning, with relatively little attention given to organizational and other personnel issues, in particular significant reductions in personnel. These changes need to be carried out in accordance with rigorous and comprehensive management of change arrangements. Table III highlights major 'cultural' changes in moving from operation to decommissioning (elaborated from Ref. [5]).

Moreover, increased levels of uncertainty can threaten staff morale and commitment, and the decision to shut down may itself be preceded by periods of rumour and uncertainty. In an industry where security of employment has often been taken for granted, this can be unsettling for plant personnel. The plant management may also need to put in place a timely plan to deal with social impacts that can occur during plant shutdown.

During transition, plant management may also use contractors as a way of making up for any shortfalls in staffing levels that result from the loss of experienced staff. Increased use of contractors is becoming a fact of life, and it can bring benefits. However, it is vital that the licensee retain sufficient competent personnel to understand, own and use the plant's safety case, and to act as an 'intelligent customer' for work by contractors. This is especially important during the transition phase. Older plants may not have a comprehensive set of drawings and procedures, so that many historical aspects of plant design and operation which need to be accessed during the transition phase are vested in individuals rather than in documents. These people are important for the transition phase so long as their knowledge and experience can plausibly be required and, preferably also, that this experience is documented in a form which is available for use by other personnel.

## 5. ISSUES HINDERING TIMELY DECOMMISSIONING

It is common experience that the start of a number of past decommissioning projects suffered undue delays and other hindrances resulting in insufficient project progress and extra costs. The factors involved included:

— Unavailability of funds when needed;
— Sudden decision to shut down a plant permanently (e.g. on political or economic grounds);
— Lack of, or inability to decide upon, the decommissioning strategy, resulting in a 'no action' situation;
— Lack of infrastructure (such as waste storage facilities or disposal sites) or technologies;
— Lack of decommissioning oriented regulations;

TABLE III. COMPARISON BETWEEN DECOMMISSIONING AND OPERATIONS CULTURE REQUIRING A DEDICATED APPROACH

| Operations | Decommissioning |
|---|---|
| Relying on permanent structures for the operating life of the facility. | Relying on structures to assist dismantling (for temporary use). |
| Safety management systems based on the operating nuclear facility. | Safety management systems based on decommissioning tasks. |
| Management objectives are production oriented. | Management objectives are project completion oriented. |
| Routine training and refresher training. | Retraining staff for new activities and skills or use of specialized contractors. |
| Permanent employment with routine objectives. | Visible end of employment — refocus the work objective. |
| Established and developed regulations for operation. | Changing regulatory focus. |
| Predominant nuclear and radiological risk. | Reduction of nuclear and radiological risk, predominant industrial risk. |
| Focus on functioning of systems. | Focus on management of material and activity inventory (e.g. for waste minimization). |

— Loss or demotivation of key personnel and inability to adapt to cultural changes;
— Little or no planning for decommissioning during plant operation.

The following examples highlight in detail a few critical areas. One typical issue in the decommissioning of nuclear facilities is the insufficient provision — or lack — of decommissioning funds during plant operation. Except for small, low hazard facilities that can be readily dismantled using routine means, lack of funds severely impacts timeliness, cost effectiveness and, ultimately, the safety of decommissioning. If nuclear facilities are owned by the State or State bodies, ad hoc funds are to be sought in the State budget, often conflicting with urgencies in other national sectors (a very serious issue in developing countries). In addition, allocating decommissioning funds in this way may be subject to excruciating parliamentary scrutiny, heated media debate, and perception of low priority, and ultimately may result in undue delays.

Another issue can be the uncertainty in time and mode of permanent shutdown/decommissioning. An indeterminate period of several years with no firm decisions on permanent shutdown and the decommissioning strategy could be extremely frustrating for the plant staff and will result in the loss of qualified staff and historical memory. Difficulties in achieving prompt, firm decisions are often due to large scale lobbying against permanent shutdown for reasons such as expected loss of salaries, fear of staff relocation or cessation of research, radioisotope production and other programmes. Also, there is often a scarcity of funds to operate the facility or a lack of productive goals (e.g. for research reactors). It should be noted that the factors listed above are of decisive importance in countries with limited resources, where alternative market opportunities are not easily available. Lack of a decision to decommission may result in the operation of old, obsolete facilities under less than ideal conditions. In such cases, if a decision is eventually taken to restart, equipment and structure deterioration and loss or demotivation of valuable staff will hinder efficient operation.

A related issue is 'no action' after the decision to permanently shut down a nuclear facility. This is unfortunately a common practice, especially for many closed small facilities that can, by their nature, safely remain in a shutdown condition for extended periods of non-use. No action often results from the wrong perception that the risks associated with the shut down facility are trivial and can be disregarded. Eventually, no action may end with plant abandonment.

A fourth relevant issue is the lack of availability of decommissioning/waste management technologies. In several developing countries, decommissioning tends to be a first of a kind project and little or no planning exists — including availability of resources. In some countries it has proven beneficial to import technologies and other resources. However, the transfer of technologies and know-how requires the recipients to incorporate the required resources into their agendas.

A fifth issue related to lack of resources/infrastructures is decommissioning regulations. In some countries, these are either non-existent or are derived from regulations originally developed for the construction or operation of nuclear installations. For example, decommissioning oriented regulations such as clearance levels may not exist. Inadequate regulations often result in a convoluted approach, unclear responsibilities and ultimately undue delays.

A sixth — in many cases typical — issue is the often uncertain allocation of roles and responsibilities. It is well known that decommissioning requires a cultural change. For example, a staff of researchers may have difficulties in adjusting to an industrial demolition project. Transition/decommissioning inevitably requires a revised organization, new lines of reporting and communications, and the use of contractors. The operational staff familiar with the routine day to day management must now take on work with and/or management of a project that uses substantial outside resources. A related problem is the lack of qualified staff due both to loss of facility staff and a general decline of the nuclear sector.

## 6. ORGANIZATION AND PERSONNEL

The decommissioning of a large nuclear facility — and activities preparatory to it — are a major project. The best project management practices, tools and techniques, and quality assurance processes, are vital. Organizational aspects in preparation for implementing the decommissioning strategy are dealt with in the following sections.

### 6.1. Preparing for transition and decommissioning during plant operation

It is important that a project team to plan for transition and decommissioning be established well in advance of final shutdown. This team does not need to be large or be employed full time. Its technical expertise required includes knowledge of system reconfiguration or retirement, spent fuel and waste management, and other decommissioning aspects. Project expertise, such as cost estimation, scheduling, and licensing, is also important. Participation will be needed from personnel with detailed knowledge of the plant, including technical expertise and system planning. In addition, this team may need to use outside expertise in decommissioning related areas.

The team reports to the senior management not responsible for the day to day operations of the plant. The typical objectives of the project team are the following:

- updating the decommissioning plan on the basis of the decommissioning strategy,
- cost estimation,
- project risk evaluation,
- system reconfiguration and retirement,
- spent fuel options,
- waste management plans,
- licence changes,
- staff plans,
- transition end point specification.

Before operation ceases, it is essential to create a decommissioning project and to appoint a senior transition/decommissioning project manager who has the required skills, qualifications and experience and who has received the necessary authority. This manager, in consultation with the management of the operating organization, sets up a decommissioning project management team. This will include the development of details of transition and decommissioning. As the project proceeds, the team will expand and contract as needed.

### 6.2. Organization and management during facility transition

During the transition phase much of the operationally associated hazard is removed in preparation for safe enclosure and/or immediate dismantling. This may include removal of the spent fuel, draining of systems and removal of waste generated during operation. At all times the management structure will reflect the changing circumstances and continuing responsibility of the licensee for the operation, including decommissioning, of the licensed site.

The organization during the transition phase will inevitably be that which ended the operational phase of the plant's life. Even in cases where a new operator takes over for decommissioning, it is likely that most of the operating staff will be retained and will evolve to suit the circumstances of the transition phase. It is essential, prior to shutdown, that the transition of organizations be defined as well as the transition of the physical plant. This should address changes and additions in roles, responsibilities and lines of reporting. Figure 2 shows a typical facility functional organization as it might be modified by the addition of transition and decommissioning projects and tasks ('functional' means that it indicates types of activities, but not necessarily lines of reporting). In addition to the facility personnel, there will be contractors assigned to some jobs, primarily for dismantling.

### 6.3. Impact of transition/decommissioning on human resources

There are inevitable constraints on the approach to staffing as the plant transitions to implementation of the decommissioning option. In some facilities plant staff numbers are likely to be held close to operating plant levels (e.g. in reactor plants until the fuel has been removed and primary circuit decontamination has been completed). In other plants the change will depend on the need to stabilize or remove existing hazards. The number of operational staff needed will eventually fall regardless of the chosen decommissioning strategy.

There are a number of basic points to be addressed and relevant decisions to be made on the following:

— staff reduction profile,
— use of operating staff to undertake decommissioning project tasks,
— sharing key resources among plants,
— policies for choosing what work will be contracted.

The staff reduction profile will be dependent on the work to be done. Having established such a profile, commitments can be given to staff as to the length of their remaining employment and progress on staff reduction can be monitored against the planned profile.

Maintaining a large number of operational staff will necessitate that they undertake decommissioning tasks. This will require retraining in new skills and reorientation of attitudes towards a project completion outlook, e.g. system isolation, dismantling, draining and flushing, waste characterization, dismantling and size reduction techniques, etc. However, the other approach of using an outside contractor to perform a majority of the decommissioning activities may lead to resentment among the existing plant staff.

As said before, timely planning plays a major role. Being aware of the timing of final shutdown and the selected decommissioning strategy, the operator's

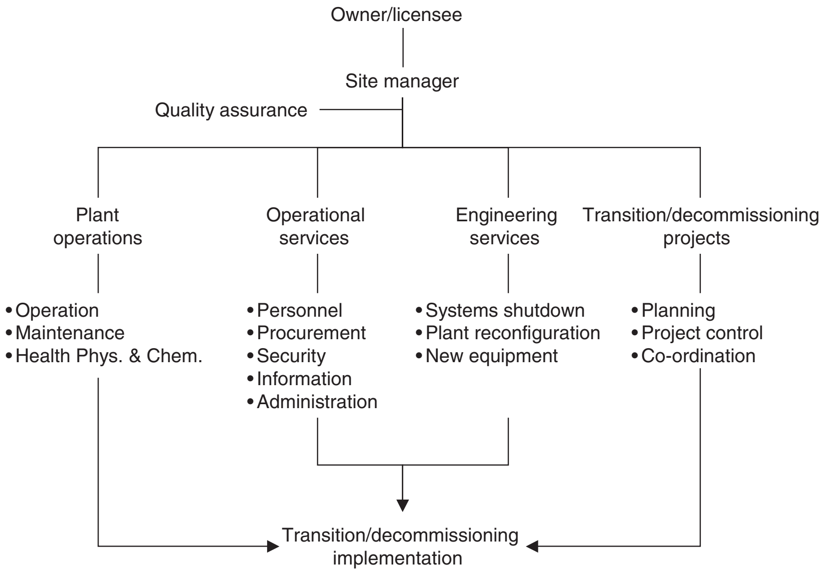


*FIG. 2. An example of a functional organization during the transition phase.*

management can facilitate personnel relocation or favour the retention of key staff.

In order to encourage a job completion attitude, it is enormously helpful if arrangements can be made to ensure the future relocation of staff to other plants, projects or similar organizations, or out placement to other job markets. One way of approaching this would be to form teams of skilled, experienced personnel who could provide services to other similar plants — effectively as contractors.

It will be important to provide appropriate incentives to the remaining staff (and contractors) to work effectively and in a manner that delivers the decommissioning programme safely within the schedule and budget. These incentives may differ from situation to situation, and while seeking to encourage a safe adherence to the decommissioning programme they should encourage staff to seek completion of the work rather than apparently perpetuating their jobs through delay.

## 7. CONCLUSIONS

Timely action to place a contaminated shut down facility in a stable and known condition as soon as possible after final shutdown is highly desirable. It is important that stabilization and other activities for facilities, systems and materials be planned and initiated prior to the end of facility operations, pending finalization of a decommissioning strategy. The conduct of activities during the final steps of a facility's operational phase and during the transition phase will take advantage of facility operational capabilities before they are lost. Actions taken at this time will pave the way to smooth decommissioning by eliminating or mitigating hazards and minimizing obstacles in a more efficient, cost effective manner. The main conclusions from this paper are therefore:

- Early planning is the key to a smooth transition from operation to decommissioning and will avoid a 'no action' scenario.
- Planning for transition requires timely allocation of dedicated resources and provisions (human, technical, financial) at established points in time.
- Timely implementation of pre-decommissioning activities will reduce expenditure and hazards, simplify waste management and help to keep the workforce motivated.
- Significant cultural and organizational changes will occur during the transition from operation to decommissioning and will need proper consideration.

— The availability of relevant data and records is essential for smooth progress into and conduct of decommissioning. Plant characterization and accurate record keeping are essential tools for this purpose. It is important to collect ‘process knowledge’ about past operations before the knowledgeable employees leave. However, it is often difficult to get an accurate ‘fix’ on the location of all accountable equipment and their radioactive inventory because of inaccurate historical data and the frequent relocation of employees. A plant wide, wall to wall inventory is necessary.
— Implementation of transition will require significant management and work efforts comparable with levels during normal operation.
— Good communication and the involvement of all stakeholders is essential for successful transition.

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# DECOMMISSIONING OF NUCLEAR POWER PLANTS: PROJECT PLANNING AND IMPLEMENTATION IN GREIFSWALD AND RHEINSBERG

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*Presented by F. Krause*

**Abstract**

Several different decommissioning projects have been performed over the past decades, on a smaller scale, to different levels of completion, i.e. safe enclosure or complete dismantling to green field conditions. After the reunification of Germany, a major decommissioning task was the situation in the former German Democratic Republic (GDR), where 30–40% of the electricity supply was intended to be from nuclear energy. Until 1990, the nuclear power plants in Greifswald and Rheinsberg covered approximately 11% of the required electricity. The decommissioning and dismantling of the Russian WWER type reactors do not pose specific problems when compared with Western PWRs. However, the size of the project and the resulting quantity of material is extraordinary. It can be concluded that dismantling of nuclear facilities is basically not a technical problem but a challenge for project management and logistics, once the legal and economic parameters have been clarified. In order to achieve a safe and cost effective project, it is necessary that all stakeholders, i.e. the Energiewerke Nord GmbH (EWN) authority, authorized experts and the public achieve a positive level of co-operation. The project has proceeded very well: agreement on the licensing strategy with the authority has been achieved; major licenses have been obtained; fuel elements have been transferred; interim storage of radioactive waste, dismantled material and spent fuel is going on; and a sophisticated database system has been developed and installed successfully.

## 1. INTRODUCTION

Over the past decades, several different decommissioning projects have been performed, on a smaller scale, to different levels of completion, i.e. safe enclosure or complete dismantling to green field conditions. After the reunification of Germany, a major decommissioning task was the situation in the former German Democratic Republic (GDR), where 30–40% of the electricity supply was planned to be from nuclear energy. Until 1990, the nuclear power plants in Greifswald and Rheinsberg provided approximately 11% of the required electricity.

At the Greifswald site, located about 200 km to the north of Berlin on the coast of the Baltic Sea, there are in total eight units of Russian PWR type WWER-440 plants (Fig. 1). Units 1–4 are model 230 and Units 5–8 are of the more recent model 213. There is also a wet storage facility for spent fuel, a ‘warm’ workshop and additional buildings for the treatment and storage of radioactive waste. At the Rheinsberg site, located about 70 km to the northwest of Berlin, there is a WWER-2 prototype reactor, which started operation in 1966 as the first nuclear power plant in the former East Germany (Fig. 2).

Immediately after the reunification of Germany in 1990, the four operating units in Greifswald were shut down, the trial running of Unit 5 was stopped and construction work at Units 6–8 was interrupted. The plant in Rheinsberg was switched off in the same year. After serious consideration about refitting and restarting some of the reactors, the decision was finally taken in 1990–1991 to decommission all of the reactors.

Due to the unexpected decommissioning decision, the initial work was focused on the removal of fuel and operational waste to provide the preconditions for decommissioning and dismantling. In parallel, Energiewerke Nord

*FIG. 1. The Greifswald site.*

*FIG. 2. The Rheinsberg site.*

GmbH (EWN) established and implemented a 'Decommissioning Project Structure', worked out the technical concept for the decommissioning and a social plan for the employees. The financing has been guaranteed by the Federal Government. The first licenses for decommissioning at both sites were granted in 1995 and since then the dismantling activities are proceeding.

The task of EWN is the decommissioning of the nuclear power plants (NPPs) of Greifswald and Rheinsberg, using existing personnel as far as is possible, at minimum cost, and as safely and as quickly as possible. Furthermore, the Greifswald site is to be remediated and prepared for reuse, with the acquired know-how to be marketed.

At the time of the shut down, there were on-site approximately 6000 employees; the roughly 8000 construction workers had already left the site. This number of employees can only be understood within the context of the previous socioeconomic system. The Greifswald site is also located in a basically agricultural region without any major industries. After the reunification, obviously, the entire legal system had to be changed, i.e. the licensing authority and the authorized expert system covering the nuclear field had to be rebuilt from zero. Obviously, the people and employees had to get adjusted to this new environment. Furthermore, it was necessary to introduce 'Western' planning and management methods.

Based on the experience from this largest decommissioning NPP project in the world, the basic steps of planning and implementation of a decommissioning project will be outlined.

## 2. STRATEGY

As can be seen from the initial conditions on-site, EWN was faced with a many-facetted issue and it was necessary to develop a strategy covering the following key areas:

— Company personnel,
— Decommissioning,
— Licensing,
— Waste management.

All these issues are interrelated and had to be solved in an integrated manner. It must be mentioned here that EWN was in one respect in a good position, namely that the German State had taken over the plant and thus a certain financial basis was ensured. First of all, measures had to be taken to reduce the number of employees, since under any circumstances it was much too high. To solve this problem, the following measures were introduced:

— Early retirement of older employees;
— Privatization of services, infrastructure and technical areas, where possible;
— Education as a result of the decommissioning and privatization;
— Dismissal, with initial economic support.

In this way, it was possible to reduce the personnel from around 6000 to only around 1400, which though still high is justifiable. This number is being continuously reviewed and slowly reduced.

The second major decision was to decide on the decommissioning strategy, i.e. direct or deferred dismantling. Taking into account the overall limiting conditions on-site, this was clearly a major issue with significant implications. In order to resolve this issue on a technical and economic basis, it was necessary to perform complete project planning and calculation for both possibilities. It could thereby be shown that direct dismantling is about 20% cheaper, produces less radioactive waste and results in less total dose commitment. In order to understand this, we must remember that the earlier Russian plants have a limited life time (especially the buildings), have no containment (i.e. are not ‘tight’) and have inadequate storage for operational waste.

Timely planning on the basis of a thorough technical and radiological registration of the plant and the organization of overall waste management are absolutely necessary preconditions for a successful project. In the pre-planning phase itself it became obvious that a large interim storage facility is needed. This was mainly due to the enormous amounts of contaminated or activated dismantled material — more than 100 000 Mg to be treated — as well as the considerable quantity of fuel elements (more than 5000) which have to be disposed off. To solve these tasks, also considering that the final storage situation in Germany is still not resolved, a major interim storage and treatment facility for radioactive waste and fuel was built on the Greifswald site, the Interim Storage North (ISN) (Fig. 3).

The ISN has a triple function in the project. It is a treatment station, a buffer storage and an interim storage. For *interim storage*, the ISN will take the spent fuel in CASTOR dry storage casks and other radioactive waste in containers, which will not be treated any further until final disposal in Germany is clarified. For the fast and economic dismantling of large components of the primary circuits, they will be transported to the *buffer storage* area of the ISN and

*FIG. 3. The Interim Storage North (ISN) facility.*

then, after decay storage, and if needed, they will be cut and packed for storage. This strategy will also be used for the activated reactor pressure vessels (RPVs) and their internals. As a *treatment station*, the ISN is designed to treat nearly every kind of radioactive waste except nuclear fuel.

Thus, the treatment and storage of all radioactive waste arisings can be completely separated from the dismantling activities. This gives a maximum of flexibility in logistics and in the waste management strategy. Various decontamination techniques are combined with decay storage possibilities in order to minimize the amounts of waste needing final disposal. The erection work on ISN was started in 1994 and was finalized in 1998, on schedule. Since March 1998, the ISN has been in operation and guarantees, with its storage capacity of approximately 200 000 $m^3$, the continuous execution of the dismantling work in Greifswald as well as in Rheinsberg.

## 3. LICENSING

The licensing procedure for a decommissioning project in Germany has to be initiated by the applicant at the earliest possible date due to the complexity of this procedure and the number of stakeholders. After the application, the licensing authority of the concerned federal state usually involves authorized experts and other concerned authorities. If it is necessary, according to German Atomic Law, the authority makes the application public.

In addition to the Atomic Law and the subordinated ordinances, the basis for the decisions of the licensing authority are the recommendations of the Radiation Protection and the Reactor Safety Commission. The Federal Ministry of Reactor Safety and Environment has to be informed and has the right to advise the licensing authority. The stakeholders in the licensing procedure and their interactions are shown in Fig. 4.

In the case of our project, the licensing strategy is intricate, since on one hand it is easier to perform the decommissioning activities with one license. On the other hand, for a large project, it is an enormous effort to obtain this one license. If an unplanned plant shutdown takes place it is necessary within a short time to prepare the licensing documents. At the same time, it is normally necessary to perform an iterative procedure with the licensing authority in order to agree on the amount and degree of detail necessary.

Since our provisional license ended on 30 June 1995 — as a result of the transition agreement on laws between both German States in 1989 — we tried to obtain as broad a license as possible and then complement this with partial dismantling license applications. In this way, the consistent use of personnel capacities, continuous planning work and continuity in the licensing

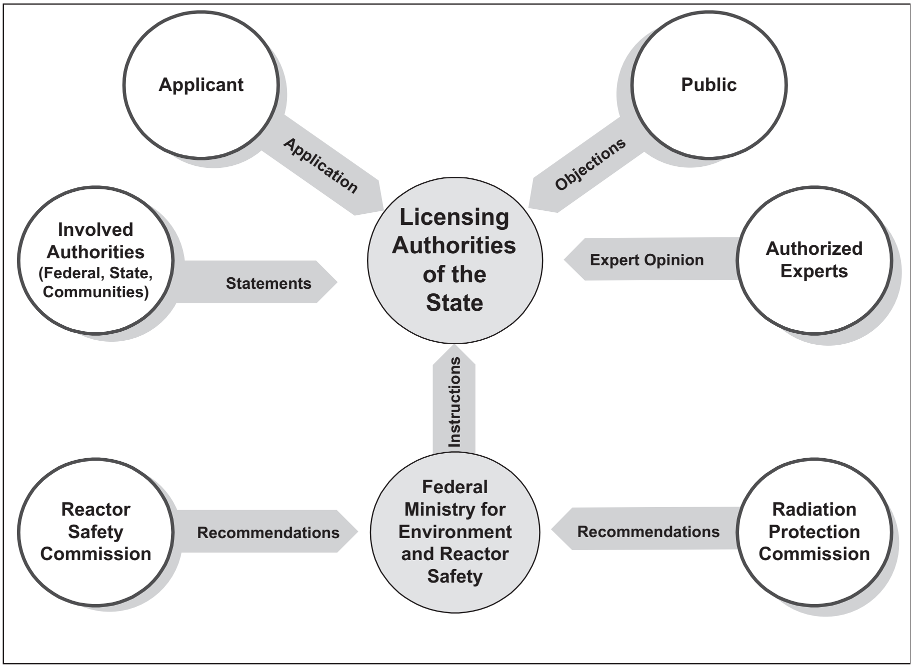


*Fig. 4. Stakeholders in the licensing procedure according to German Atomic Law.*

procedures and in-process control were guaranteed. The first license application was made in 1994 and the license was granted on a timely basis in June 1995. This first license was the basis for all decommissioning activities and further applications for the Greifswald NPP, and comprises the following main issues:

— Operation of the systems and components required for nuclear safety and radiation protection, technical safety and for the demands of decommissioning and dismantling activities;
— Adaptation of the operational manual according to the operational status of ‘reduced post-operation’ and ‘remaining operation’, with reductions in the safety requirements;
— Handling of nuclear fuel and nuclear sources for removal out of the units and disposal;
— Handling of other radioactive material, as concerned with decommissioning and dismantling of the nuclear power plant;

— Limit values for release of radioactive material into the air and water;
— Limit values for exemption of material from the Atomic Law;
— Special procedure for the release of residual material, buildings and ground, and determination of the limit values for release;
— Plant adaptations to reduce and to control the release of radioactive substances (as a precondition for the license);

and finally the dismantling of:

— Plant parts of Units 5 and 6 (controlled area);
— Generators 1–8 in Units 1–4;
— High pressure preheaters in the turbine hall of Units 1–5.

Thus, EWN was able to continue with all necessary operational activities on a legal basis and to start with the dismantling activities which secured the remaining jobs. In total, 8 main applications for decommissioning are foreseen and at present, 5 of them have been granted. EWN's licensing strategy at Rheinsberg NPP was implemented similarly and the decommissioning activities have been divided into 11 main applications; at present, 8 of them have been granted.

In this way, a pragmatic licensing procedure on the basis of the actual risk potential could be achieved. As a positive consequence of the split licenses, a more or less constant workload by the applicant, the authority and authorized experts was obtained and thus a smooth project is being realized. Close cooperation with the licensing authorities and the authorized experts is mandatory for a successful project at all levels.

## 4. WASTE MANAGEMENT

The waste management concept is mainly based on the following limiting conditions and principles:

— Provision of sufficient buffer and intermediate storage capacities to achieve a high level of flexibility in logistics and waste management. Therefore, the construction of the ISN is of great importance.
— Removal of the spent fuel from the reactors and cooling ponds to wet interim storage and later transport in dry CASTOR casks to the ISN.
— Installation of equipment for the treatment of dismantled material using modern technologies for the reduction of dose exposure and for greater efficiency.

— Further use of the existing waste facilities, and upgrading or extension as far as is economically justified.
— Use of the limited final storage capacity in Morsleben until 2000, as far as possible.

### 4.1. Fuel elements

After the shutdown of the plant in 1990, there were 5037 spent fuel elements — 3 of them are defective — and 860 fresh fuel elements on the Greifswald site. At that time, 1011 fuel elements were in the reactors, 1628 in the cooling ponds of Units 1–5, and 2398 were stored in the wet interim storage. At the Rheinsberg site, there were 220 spent fuel elements, which were loaded in CASTOR dry storage casks and transported to the ISN.

The fuel elements from the reactors and the cooling ponds have been transferred as far as possible to the wet fuel storage. A part of the low burnup fuel (235 elements) has been sold to Hungary (Paks NPP). The 860 fresh fuel elements have been sold. The fuel elements are loaded into CASTOR dry storage casks (for the loading of the CASTOR casks special equipment was installed in Unit 3), and are transported to the ISN for further storage. At present, 24 CASTOR casks are stored in hall 8 of the ISN. Since 1992, more than 4500 fuel elements have been transported safely and without technical problems.

### 4.2. Operational waste

The already produced radioactive operational waste and the waste to be generated during post- and decommissioning operations will be disposed of in the Morsleben disposal facility (ERAM). Up to the closure of this disposal facility in 1998, approximately 2584 $m^3$ of conditioned waste could be disposed of.

Included here are activated and high contaminated solid waste, low active and medium active resins as well as liquid evaporator concentrates, sludge and sludge–resin mixtures, sludge from outside the controlled area, low activated resins in the turbine hall and solid radioactive mixed waste in storage bunkers, as well as in temporary buffer storages.

The major part of this operational waste can be treated by common conditioning techniques. For this purpose, the following facilities and devices are available at the Greifswald site: a rotational thin film evaporator plant (maximum 400 L/h); drum drying facilities; equipment for drying of ion exchanger resins; compaction facility (20 Mg); sorting facilities; and high efficiency suction devices for granular material.

## 5. DISMANTLING

The basic principles for dismantling can be summarized as follows:

— It will be performed from systems/areas with lower contamination/radiation to higher and finally activated plant parts;
— It will start in Unit 5 and the turbine hall and then continue in Units 1–4 in order to use the experience from work in a low dose rate/contamination unit;
— As far as possible, commercially available equipment will be used;
— To the extent possible, large components or parts will be dismantled and transported to the ISN;
— it will take place on a room basis.

In preparation for the dismantling, measures are taken to reduce the dose rate. First of all, parts of the primary loops were decontaminated, and second, hot spots were removed with high pressure water jets or mechanically. Before dismantling activities start, asbestos containing material is removed in a controlled manner. The dismantling itself in the monitored and the controlled area takes place with conventional, and preferably mechanical, tools.

The RPVs and interior components of Units 1–4 will be remotely dismantled. The activated components of Unit 5 will be dismounted and transported to the ISN. The dismantling activities will take place in the steam generator room, which is situated around the RPV. Here, cutting caissons (dry and wet), package and transfer areas will be installed. The complete system can be disassembled and will first be installed in Unit 5 for inactive testing and afterwards in Units 1–2 and finally in Units 3–4. The inactive testing was started mid-1999 and was finalized successfully in April 2002. Thus, the dismantling of Units 1–4 can be executed in a safe manner. At present, the equipment has been transferred to Unit 2, where the first hot dismantling of a WWER reactor and its internals will be performed.

## 6. DECOMMISSIONING WASTE — TREATMENT AND STORAGE

For planning, it was necessary to record the actual plant state. In particular, this included registration of masses and materials, dose exposure rates in the plant rooms and of the components as well as the preparation of a contamination catalogue.

In total, 715 000 Mg of material have to be treated during the decommissioning of the Greifswald and Rheinsberg sites. Of that, about 140 000 Mg are dismantled plant parts and concrete while the rest, about 575 000 Mg, are remaining buildings. All these materials have to be classified as radioactive residuals or possibly contaminated material and must be treated accordingly. The resulting material flow in this dimension is extraordinary and it is a major task to manage it logistically. Here, the ISN at the Greifswald site with its space and treatment capacity, is crucial for continuous waste flow.

The ISN started operation in March 1998 and serves as a treatment station, a buffer storage and an interim storage. In this way, the logistical security needed for continuous dismantling is guaranteed. The building comprises eight storage halls, a loading corridor and a conditioning area. The storage has a theoretically usable storage volume of 200 000 $m^3$. Storage hall 8 will house spent fuel elements in CASTOR casks. Storage halls 6 and 7 will be used for big components from the primary circuits, awaiting further treatment. In halls 1–5, all kinds of packages will be kept for both interim and buffer storage.

The conditioning area consists of five caissons: one is intended to be used for maintaining the fuel element casks. The other caissons will be used for treating and conditioning activities, e.g. cutting, volume reduction, high pressure compaction, concentration of liquid waste, drying and packaging.

Additionally, the ‘warm’ workshop on the Greifswald site is used for dismantling and decontamination work. For the easy classification of material, in total three classification facilities (chambers with several gamma detectors) are in operation.

The timely definition of the disposal routes for the collection and sorting of the material produced and their classification makes it possible to proceed systematically and to reduce the amount of radioactive waste. It is distinguished by the following classes:

— Class A: Free release,
— Class B: Reuse,
— Class C: Disposal as conventional waste,
— Class D: Decay storage,
— Class E: Reuse in nuclear facilities,
— Class F: Disposal as radioactive waste.

The limiting values for classes A, B and C are an integral part of the license for decommissioning from 30 June 1995.

## 7. PROJECT MANAGEMENT

The project is time limited, with a clearly defined content and objective and cannot be repeated. Accordingly, there is a range of individual measures, which are unique themselves and time limited as well. To organize all these measures, they have to be integrated into hierarchical structures. These structures originate from the different approaches, which can be part of the project.

For example, if it is necessary to look at the timely, logical step-by-step execution of the measures, the individual measures have to be subordinated to the 'phase structure', involving planning, procurement and execution. The use of a relational database system permits subordination of every single measure under different and independent structures. In this way, it is possible to approach the issue from different points of view at any time. The project structure plan for the mega project "Decommissioning of the NPPs of Greifswald and Rheinsberg" contains the following elements:

— Basic handling structure,
— Responsibility structure,
— Object structure,
— Work category structure,
— Phase structure.

Priority was given to the basic handling structure, which is derived from the sequences of the decommissioning work. In this connection, the mega project is divided into six 'projects' (Fig. 5).

On the basis of an analysis of the company development and personnel strategy, a technical concept was worked out and the project was broken down to 'working package' level. The basic handling structure is the primary structure, which is directly related to the step-by-step execution of the decommissioning activities. Beneath the project level are the following sublevels:

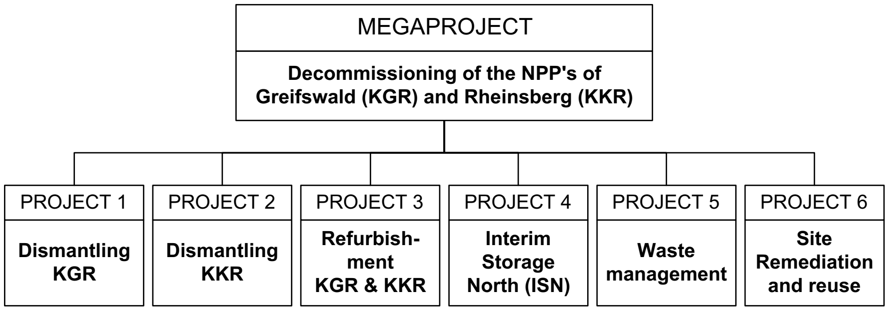


*FIG. 5. Project structure.*

— Part projects,
— Programmes,
— Working packages,
— Activities,
— Actions,
— Tasks.

The working packages are at the centre of all planning and control work in the framework of the basic handling structure of the project. At this level, top and bottom control as well as estimation and calculation are brought together, as depicted in Fig. 6.

The project was optimized from the cost and personnel points of view in order to obtain a constant number of personnel. For the project management, software has been developed allowing, in addition to the normal project control tasks, performance of technical planning, work preparation planning, tracking and control of dismantled material and radioactive waste, etc. The

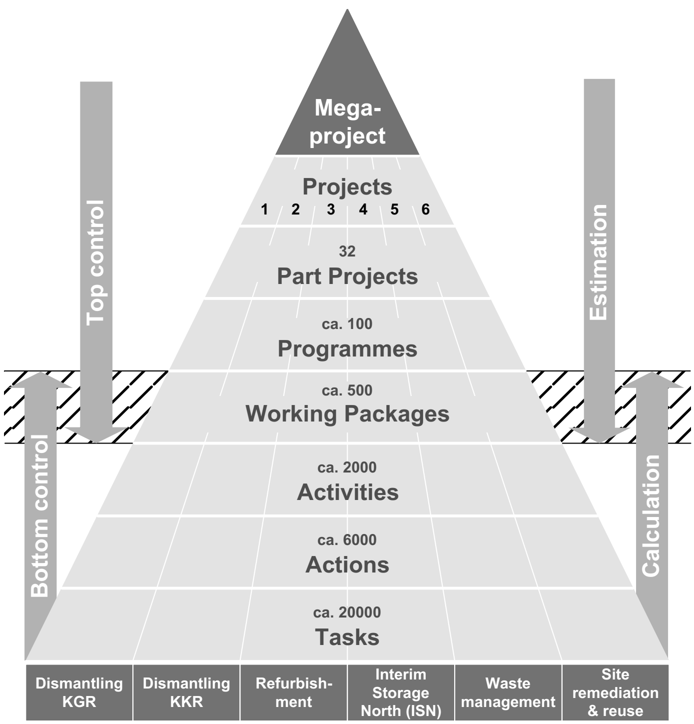


*FIG. 6. Basic handling structure.*

Management Information System (MIS) is a software package consisting of the following parts:

— Decommissioning information system,
— Documentation management and service event tracking system,
— Environmental information system.

The most important part of the MIS is the decommissioning information system, covering the complete process from project planning to project progress supervision. The other parts have been developed to increase the functionality of the system. The objectives of the MIS are to:

— Make the decommissioning progress transparent,
— Get authoritative and reliable information about all important subjects concerning the decommissioning process at any time.
— Support decision making processes in the course of decommissioning to increase safety and efficiency,
— Collect, systemize and evaluate experience in the course of decommissioning.

A software system for a nuclear decommissioning project which fulfils these general considerations and basic requirements was not available on the market. So, it was necessary to develop this software in-house, with some assistance from contractors. EWN succeeded in implementing the MIS in a timely manner, so that it was possible, in addition to the normal project tasks, to decisively support the project management. Actual data from the dismantling operations are registered, evaluated and fed back into the system (Fig. 7).

## 8. CONCLUDING REMARKS/RECOMMENDATIONS

After initial difficulties caused by massive personnel reductions combined with the introduction of a market economy and West German laws and procedures, EWN has succeeded in restructuring the company to arrive at a size suited to the task of decommissioning. A positive atmosphere has now been created to enable work to proceed effectively and to prepare part of the personnel and the site for the new tasks.

The decommissioning and dismantling of the Russian WWER type reactors do not pose specific problems when compared with Western PWRs. However, the size of the project and the resulting volume of material is extraordinary. It can be concluded that dismantling of nuclear facilities is basically

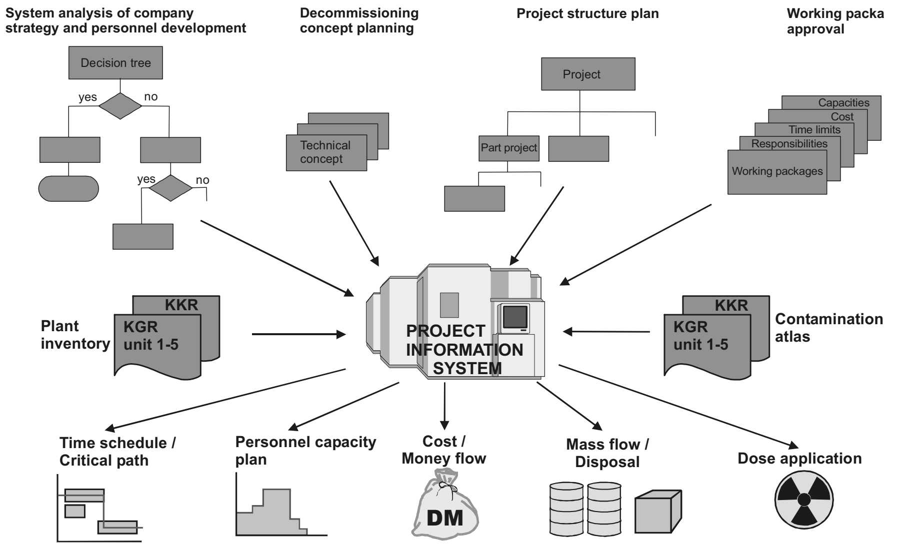


*FIG. 7. Project Management System (PMS).*

not a technical problem but a challenge for project management and logistics, once the legal and economic conditions have been clarified. In order to achieve a safe and cost effective project, it is necessary that all stakeholders, i.e. EWN, the authority and authorized experts, and the public achieve co-operation.

The project has proceeded very well: agreement on the licensing strategy with the authority has been achieved, major licenses have been obtained, fuel elements have been transferred, interim storage of radioactive waste, dismantled material and spent fuel is taking place, and a sophisticated database system has been developed and installed successfully.

To sum up, the lessons learned by the planning and implementation of this decommissioning project are:

— A thorough inventory (material, radiological data) of the plant is a necessary prerequisite for all planning, especially for the timely erection and implementation of the equipment and the logistics for waste management.
— Social aspects and psychological effects must be taken into account.
— If the project is not too large, one license for all activities is recommended.
— Clear and realistic requirements from the licensing authority related to the real and decreased safety risks are mandatory — the 'self-service shop' mentality should be avoided.

— The overall project must be planned to be timely and cover all activities, from shutdown to disposal.
— A project management structure must be established, all site activities have to be integrated.
— The public should be informed on a timely basis and openly.
— Decommissioning of nuclear power plants is basically not a technical problem, but rather a management and waste management logistical issue.
— For normal dismantling activities, simple and sturdy tools and equipment should be used; mock-up tests should be performed if new or complicated technology is required.
— The as low as reasonably achievable (ALARA) principle must be strictly applied even in the planning phase.

Finally it must be stated that, in any case, the strategy and the technical solution for each decommissioning project is different from others due to the various types of plants, the specific conditions in each country and the different objectives of the stakeholders. But, with every additional project and the resulting experience, the existing technologies and management tools can be further optimized, technically and economically. Thus, the ongoing exchange of know-how and experience — national and international — is of major interest, especially for countries with less experience in the field of decommissioning of nuclear facilities.

# PANEL DISCUSSION

# PLANNING AND IMPLEMENTATION

*Chairperson:* **L. Keen** (Canada)

*Members:* **L. Goodman** (United States of America)
**V. Ivanov** (Russian Federation)
**J.L. Santiago** (Spain)

**Statement**

# DECOMMISSIONING: THINK ABOUT THE BACK END FIRST

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Decommissioning is different from operating a nuclear plant. While both involve a reactor, the priorities and activities differ. This summary will address the keys to successful decommissioning as learned from decommissioning Fermi 1. This project shows that plants can be decommissioned after a safe storage period. Fermi 1 was a sodium cooled fast breeder reactor that was permanently shut down in 1972. Decommissioning is under way now following a safe storage period.

The four keys to successful decommissioning are:

— Thinking about the back end first,
— Planning where you are going,
— Evaluating how you will get there,
— Assessing the journey.

The most important key is to think about the back end first: think about the waste that will be generated before work is started. This waste needs to be assessed from more than just the radiological standpoint.

For example, some paints at Fermi 1 contain lead and/or PCBs. Work was stopped earlier this year when more paint was found to have PCBs than expected from earlier sampling. A hazards assessment programme was prepared and arrangements made for waste disposal of painted equipment, piping and structural members before dismantling resumed of any materials where the paint could contain PCBs.

In planning the removal of sodium residues, the by-products from the reaction of the residues in situ needed to be addressed. Plans were made for contaminated hydrogen gas and caustic before starting the processing.

Waste needs to be characterized before it is produced for both radiological and hazardous constituents. Good planning that integrates waste management with activity planning is essential for success.

To plan where the project is going, first the end state needs to be determined. Then steps to get the facility in the desired condition can be evaluated. The steps need to be communicated, then scheduled. The schedule needs to be communicated for success.

Safety is the key to evaluating how the end state will be reached. Safety is more important during decommissioning than plant operationthere are more challenges and people are performing hazardous activities daily. The hazards need to be evaluated for each activity and work planned to minimize hazards.

As decommissioning proceeds, what has been learned at the facility and by others needs to be assessed. Then, what should continue to be done and what should be changed to be safer or more efficient can be identified.

The biggest lesson from the Fermi 1 decommissioning project is that hazardous materials and conditions need to be considered first before starting work activities to ensure that waste can be disposed of and people will go home safely at the end of every day.

## Statement

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*(1) What are the specific safety issues associated with immediate dismantling, safe enclosure and entombment?*

In principle all specific safety issues must be resolved in the design that must be developed for the facility's decommissioning during the period of its operation. So this question has meaning only if there was some accident and it is necessary to dismantle equipment and transport it to the place of entombment. In any case first of all there must be a special database with complete and relevant information about that equipment, including its history of operation. It is absolutely necessary to have radioactive dose estimation in order to develop safe remote instruments, casks, etc.

The second issue is the necessity to have a complete set of radioactivity measurement and dismantling instruments, in some cases on a robot basis. Such instruments must therefore be developed and fabricated beforehand; their storage location should be noted and procedures for their transport should be easy to carry out

The third problem, in my opinion, is the necessity to have special sites for safe, temporary storage of casks, containers with fragments of dismantled equipment and even parts of such equipment (if they have a low level of radioactive contamination). These special sites for temporary storage will be very useful in carrying out all of the required measures.

*(2) What are the significant issues associated with the transition from operations to the implementation of the decommissioning strategy?*

Before facility shutdown, the decommissioning design must be developed. This design involves operational personnel, the regulatory body and the operating company. In addition, facility shutdown leads inevitably to a reduction in the number of operating personnel and some safety systems; for example, fire prevention or radioactive dose control may be weakened. In any case, all safety systems must be under control.

There is also the issue of the loss of skilled specialists because there are no career prospects. In many cases, especially unique facilities such as research reactors, fast reactors, special stands, reprocessing equipment, etc., there is a need before design development and sometimes during decommissioning to carry out R&D to solve difficult technical and technological problems.

As was mentioned above, there must be a special database with complete information on the parameters and operational history of every system and piece of equipment.

Perhaps it is not typical for Western companies, but in the Russian Federation it is very important to have sufficient funds accumulated for decommissioning.

*(3) When should planning for decommissioning be initiated?*

Theoretically, planning must be initiated during design development for construction. In practice, at least in the Russian Federation nowadays, planning for decommissioning begins only several years before facility shutdown. This is wrong and was the result of economic difficulties after 1992. For example, planning for decommissioning of the Leningrad Nuclear Power Plant (NPP) started in 2002. At this moment I am working on a feasibility study for creation of a special database. This database will accumulate information on all NPP equipment that will be used by the designer during development of the decommissioning project. Such a database must be created in accordance with GAN requirement. It is clear that this work began too late and there will be additional difficulties to find and to correct information linked with the history of this NPP.

*(4) When, how and to what extent should characterization be performed to support decommissioning implementation?*

As I mentioned earlier, start of work on decommissioning must be simultaneous with facility design development. The overall design should have dedicated features dealing with facility decommissioning. All information used for decommissioning design development should be collected in a special database, along with a history of the facility's operation. This database must not only contain information on radioactive and nuclear hazards during construction, but also on fire hazards. The latter is especially important because during the decommissioning process there will be fire hazards for which procedures are needed. Such a system, containing all fire hazard parameters during construction and for installation monitoring, was developed by a company in the Russian Federation, and its implementation has begun.

*(5) Are the types of waste generated during decommissioning different from those generated during operation of a facility and, if so, how should they be managed?*

There will be radioactive and non-radioactive wastes that are different from the type of wastes produced during operation, but of course they are produced only when the actual process of decommissioning begins, i.e. cutting of primary equipment, dismantling, etc. First of all there will be small particles and powders of activated corrosion products and major material impurities. Such types of waste will be in the air, in liquid form or different chemical form. In addition, there will be typical wastes such as fission products and activated materials from coolants. These wastes may be managed by careful collection, filtration and then transportation to a specific facility that converts it to a form suitable for storage.

*(6) What type of record keeping system should be established to support decommissioning?*

Relatively new facilities (10–15 years old) all have computer control systems that can record and keep all relevant parameters of equipments and construction. There is a necessity only to create and constantly refresh the special database for the decommissioning design. Old facilities, such as research reactors, semi-industrial or laboratory scale installations, unfortunately do not have similar systems so it is necessary to create a database on the basis of operational drawings, scientific reports and other documents.

Statement

# THE TRANSITION FROM OPERATION TO DECOMMISSIONING IN SPAIN

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## 1. INTRODUCTION

The transition phase between plant operation and decommissioning is a critical one. In this period, a number of technical and organizational changes are needed in order to adjust the plant to the new objectives and requirements. Significant savings can be realized by initiating decommissioning planning, in a systematic fashion, prior to permanent shutdown.

In Spain, the nuclear operators and the national agency responsible for radioactive waste management and decommissioning, ENRESA, have reached an agreement to co-ordinate efforts to ensure a gradual transition process and to minimize the loss of resources. I would like to refer in this very short presentation to the arrangements that have been established to manage this transition phase in an efficient way.

## 2. RESPONSIBILITIES

The operator is generally responsible for maintaining the necessary records of the plant and its operation, for removing the spent fuel from the pools to a safe storage and for conditioning all operational waste. ENRESA is responsible for preparing all necessary plans for decommissioning and spent fuel/waste management, and for implementing the decommissioning activities.

## 3. PLANNING FOR DECOMMISSIONING

The planning of decommissioning activities should start five years before the expected shutdown date. An early strategic plan should be developed, identifying different viable decommissioning options. This plan should describe the selected decommissioning strategy and should provide the rationale for this choice and a time-schedule of decommissioning activities. The plan should also include the options for the transfer of the spent fuel to a safe interim storage location, prior to the start of the decommissioning works, and a cost estimate to complete decommissioning according to the strategy and schedule chosen. ENRESA is responsible for developing this plan, in co-operation with the operator, which should provide the plant radiological data and the inventories of spent fuel and operational waste. The strategic plan will be presented to the regulator for review and the regulator should agree that the strategy proposed will result in safe activities and an acceptable end state.

Once the strategic plan is approved, detailed decommissioning plans should be prepared, including an environmental impact assessment. These detailed licensing documents will contain information on the systems and parts of the plant to be decommissioned, the methods to be used and the safety analyses for the tasks to be performed, the amounts of residual materials and radionuclide content, the management of waste and materials, and other issues such as the competence and organization of the staff, emergency planning, control of discharges and effluents and quality assurance. These documents should be completed in a period of three years and should be ready by the expected shutdown date of the plant.

The final shutdown of a nuclear facility requires formal notification to the regulatory body, which will establish the conditions to be met prior to decommissioning. Decommissioning plans will be revised, if necessary, following the above conditions, and will be submitted for regulatory consent to begin the decommissioning activities.

## 4. OPERATIONAL WASTES

Regarding operational wastes, the objective is to have them conditioned by the operator by the permanent shutdown date. In order to achieve this goal, studies on the approval of the conditioning methods to be performed by ENRESA will be initiated five years before the expected shutdown date.

## 5. SPENT FUEL

A key safety question concerns the plans for the spent fuel. The preferred option is the transportation off-site after a cooling period to a centralized storage site. Yet another possibility is for the fuel to be stored at a separate facility on the site.

The spent fuel management plan will be prepared by ENRESA and will be submitted to the regulator jointly with the decommissioning plans, i.e. a year before the expected shutdown of the plant.

## 6. TRANSFER OF THE SITE TO ENRESA

Decommissioning works are planned to start about three years after permanent shutdown. During this period, the operator is still responsible for the plant and should remove the spent fuel from the pools to a safe storage location and should condition all operational waste. Once regulatory approval for decommissioning is granted, the site and the title will be temporarily transferred from the operator to ENRESA for the decommissioning works. When the decommissioning operations are completed, the site will be returned to the operator.

## 7. ORGANIZATION AND PERSONNEL

The decision to permanently cease operation will have a profound impact on the operating organization. New organizational and human factor issues will arise, such as the realization that long term employment at the facility is not realistic and the need to maintain key staff and expertise.

Decommissioning requires an appropriate mixture of experienced workers with operational memory and new workers with decommissioning experience. ENRESA and the operator will together study possible areas for co-operation in order to identify the services that can be provided by the operating organization.

## 8. CONCLUSION

Finally, we believe that co-ordination of efforts between the operators and ENRESA is essential to: reduce expenditure and hazards; simplify waste and waste management; help to minimize the impact on the work force; and prepare the way for decommissioning and decontamination questions.

**Panel Discussion**

## PLANNING AND IMPLEMENTATION
### Session 2.B

L.W. CAMPER (USA): When did preparations start for the decommissioning of the Greifswald and Rheinsberg nuclear power plants?

F. KRAUSE (Germany): We started the preparations at the beginning of 1990.

L.W. CAMPER (USA): When did you receive the approvals for decommissioning?

F. KRAUSE (Germany): In the middle of 1995.

L.W. CAMPER (USA): Did it take the regulators as long as five years to deal with your applications?

F. KRAUSE (Germany): No, it took the regulators about two and a half years. The approval procedures did not start in 1990, but over two years later, after we had worked out technical strategies, submitted safety reports, and so on.

W.A. BIRKHOLZ (Germany): As one of the regulators, I recall that there were very special circumstances in Germany during the early 1990s. For example, after German reunification all licences relating to nuclear power plants in the former German Democratic Republic were due to expire on 30 June 1995. Matters were complicated by the fact that the authorities responsible for issuing new licences had first to be established in federal states (called 'Länder' in German), which had not existed during the lifetime of the German Democratic Republic. The issuing authorities first issued licences designed to resolve the question of ownership of the nuclear power plants and to set out the general strategies for decommissioning the plants. It subsequently issued licences for specific decommissioning steps. Some licences have still to be issued.

M. LARAIA (IAEA): A period of a few years for the processing of an application to decommission a nuclear facility is not unusual, especially in the case of large nuclear facilities. The licensing procedure can take even longer if, as in Germany, licences relating to a particular facility are issued in stages — first an umbrella licence covering the overall decommissioning strategy and then licences for specific activities.

In that connection, I should like to emphasize that while the licensing procedure is under way it is important, for the sake of efficiency, that various activities which are necessary preparations for decommissioning be permitted — for example, the radiological characterization of operational waste. Fortunately, during the transition phase such activities can as a rule be conducted under the operating licence.

R. JUNGMANN (Germany): In my view, former operators are the best dismantlers, once they have gone through the transition phase, since they did a great deal of dismantling in the course of repair, maintenance and backfitting activities.

M. LARAIA (IAEA): There are pros and cons as regards using former operators — rather than outside contractors — as dismantlers, and different countries have different preferences. In the USA and some other countries, there is a general preference for using outside contractors specialized in dismantling, as it is felt that they can do a better job than former operators. Social considerations may play a role, however, as in the case of the Greifswald nuclear power plant, which was dismantled largely by former operating personnel, who thereby avoided becoming unemployed immediately after plant shutdown.

D.W. REISENWEAVER (IAEA): Former operators will obviously be very knowledgeable about the facilities which are to be dismantled, but they will have to change their thinking if they become involved in dismantling, which is a very messy business compared with the operation of a facility. Moreover, there is always the risk that the former operators will drag their feet when dismantling in order to keep their jobs for as long as possible. The important thing is motivation, to induce the former operators to work expeditiously and also safely — sometimes a difficult balancing act.

G.F. BISSMARCK (Sweden): Mr. Krause referred to a big reduction in personnel as a result of the shutdown of the Greifswald nuclear power plant. What happened to those who lost their jobs?

F. KRAUSE (Germany): Some experienced people found jobs at nuclear power plants in western Germany and some set up engineering consultancies, service companies and the like. Many people simply went into retirement.

R.D. WENDLING (Germany): The decommissioning of the Greifswald nuclear power plant had not been foreseen before the reunification of Germany, so that the licensing procedure was not typical from the timing point of view. The licensing procedure for the decommissioning of a large nuclear power plant, which involves close interaction between the applicant and the authorities, should take about two years, at the end of which a first — umbrella — licence is issued.

I should like to ask Mr. Laraia whether the general statements he made regarding nuclear power plants in the transition phase are applicable also to smaller nuclear facilities and to nonnuclear facilities housing radiation sources.

M. LARAIA (IAEA): I think most of them are, especially to such facilities when they are ‘in limbo’ — a state of undeclared shutdown. A number of incidents involving casualties have occurred at facilities in limbo, which are examples of poorly managed transition with insufficient qualified personnel and unclear lines of responsibility.

L. GOODMAN (USA): In his oral presentation, Mr. Krause said that there is more radioactive waste associated with safe storage and delayed decommissioning than with immediate decommissioning. Why is that so?

F. KRAUSE (Germany): It is likely that, after safe storage for 30–40 years, many plant systems necessary during decommissioning (for example, the air conditioning system) will be faulty and will have to be replaced before dismantling can start.

C.M. MALONEY (Canada): After decommissioning the Greifswald and Rheinsberg nuclear power plants, were you able to conclude that you had been right to opt for immediate rather than delayed decommissioning?

F. KRAUSE (Germany): Yes, we were. In that connection, I would mention that the two plants used to undergo chemical decontamination every year while they were still in operation, so that the radiation levels at points such as the primary coolant circuit, the pumps and the steam generator were very low, which facilitated decommissioning.

J.T. GREEVES (USA): A figure of €300 million has been mentioned as the cost of decommissioning a nuclear power reactor. Would Mr. Krause care to comment on that figure in the light of the experience of decommissioning the power reactors at Greifswald?

F. KRAUSE (Germany): It is estimated that the total costs for the company responsible for decommissioning the Greifswald nuclear power plant, Energiewerke Nord GmbH (EWN), over a period of 30 years will be somewhat in excess of €3000 million. Those costs include — inter alia — the costs of constructing and operating the Interim Storage North and the costs of final storage of the fuel elements and the operational and decommissioning waste over and above the reactor dismantling costs. The cost of dismantling each reactor was about €150 million.

M. LARAIA (IAEA): My experience suggests that one should be very cautious when comparing the decommissioning costs for different plants. We recently compared the decommissioning costs for different WWERs, expecting them to be fairly similar from one plant to another, especially in the case of countries in a similar socioeconomic situation. We found that there were major discrepancies. So the figure of €300 million referred to by Mr. Greeves is only a very rough estimate.

V.L. KHOLOSHA (Ukraine): I should like to comment on two contrasting approaches to the decommissioning of nuclear power plants, the 'green field' approach and safe storage for 300 years, and to do so from various points of view. From the political point of view, there is, in my opinion, little to choose between them; it is possible to arrive at a local consensus in favour of each approach where it has been adopted.

From the economic point of view, safe storage is more advantageous. For example, assuming that with both approaches the reactor fuel is removed soon after shutdown, the costs associated with decommissioning are about $300 million per reactor in the case of the green field approach and $50 million per reactor in the case of safe storage. In both cases, there is compliance with nuclear safety principles and standards — and also with radioactive waste management principles and standards.

As regards the ALARA principle, there is compliance with it in the case of the green field approach, but the radiation doses associated with decommissioning are received now and — if the linear dose model is valid — there may be an increase in cancer incidence. In the case of safe storage, there is only partial compliance with the ALARA principle, but the radiation doses associated with decommissioning are deferred — perhaps until a time when there are improved technologies for dealing with ionizing radiation.

The green field approach is being implemented in Germany and safe storage in the Russian Federation, and in any comparative assessment one should bear in mind that Europe has a high population density, whereas the Siberian part of the Russian Federation has a low population density.

My general conclusion is that there is no single approach suitable for all countries.

J. GINNIVER (United Kingdom): In most countries, responsibility for decommissioning nuclear facilities rests with the facility operators. In Spain, however, it is transferred to ENRESA (Spain's national enterprise for radioactive waste management). What are the advantages of this transfer of responsibility?

J.L. SANTIAGO (Spain): ENRESA — a Government owned enterprise — is independent of the nuclear facility operators, which is considered to be an advantage from the public opinion point of view. Also, ENRESA was established for — and has great experience in — radioactive waste management, which will be an advantage when large amounts of decommissioning waste have to be dealt with.

J. GINNIVER (United Kingdom): Once the responsibility for decommissioning has been transferred, are operators likely to be involved in the decommissioning activities? If they are not involved, ENRESA will not benefit from their knowledge of the facilities being decommissioned.

J.L. SANTIAGO (Spain): The agreements concluded by ENRESA with operators envisage the provision of expertise and services by the operators to ENRESA. The operators are generally pleased to provide expertise and services as it means that they will not have to reduce their work forces so drastically.

There will be continuous interaction during decommissioning between ENRESA and the operators, who are the ones who will decide what the end state is to be — for example, a site with or without buildings. ENRESA will go along with their decision.

R.D. WENDLING (Germany): One can dismantle a nuclear power plant after it has been in safe storage for 30 years. I should like to ask Ms Goodman, however, which she would prefer — dismantling after safe storage for 30 years or dismantling immediately after shutdown?

L. GOODMAN (USA): I would prefer dismantling immediately after shutdown, because one is still knowledgeable about the plant. An advantage of waiting for 30 years, however, is that one does not have the emotional problems associated with dismantling a plant which one has been operating until recently.

L. KEEN (Canada): What kind of information about a plant is important when one starts decommissioning it 30 years after shutdown?

L. GOODMAN (USA): Up to date drawings and accurate reports on what was done during shutdown and throughout the transition phase. We have brought together retirees in order to tap their memories of waste handling, spills that may have occurred, and so on.

D.W. REISENWEAVER (IAEA): On what medium should we store information now in order to ensure that it will still be comprehensible in, say, 50 years' time — or should we transfer the information from one medium to another as time passes and information storage technology evolves?

V. IVANOV (Russian Federation): In my view, there are no technical problems — one simply transfers the information from one medium to another over time. The only problems are organizational ones, because people are involved.

M. LARAIA (IAEA): Further to Mr. Ivanov's reply, I would point out that the evolution of information technology over the past 20 years was unpredictable and took people by surprise. We are aware now, however, of its likely impact on long term record keeping, so we should be prepared. Electronic record keeping offers advantages where decommissioning records are concerned, but I expect that most regulators will wish to have, if only for backup purposes, paper based records available at all times.

L. GOODMAN (USA): Operators who have put a plant into safe storage are unlikely to be interested in upgrading their record keeping systems periodically for the next several decades. What they should do at a minimum, however, is — perhaps every two years — place the information about where radioactive material was used on a current information storage medium in order to ensure the survival of that information at the very least. We have found that although information technology is changing, anything that is readable if you hold it up to the light from an electric light bulb is good enough as an information storage medium.

J.L. SANTIAGO (Spain): If you are going to put a plant designed some 40 years ago into safe storage for 300 years, you will have to substantially reinforce it, which will be a major operation, and you will be creating a nuclear facility which will have to be maintained. We have decided to postpone the decommissioning of the Vandellos nuclear power plant, but that is because we do not have a disposal route for the decommissioning waste. Once we have that, we shall start decommissioning, as we believe that one should decommission such facilities as soon as possible after shutdown.

# FUNDING APPROACHES AND STRATEGIES

(Session 2.C)

**Chairperson**

**J. BARCELÓ VERNET**

Spain

# EUROPEAN REGULATIONS ON FINANCIAL PROVISIONS FOR DECOMMISSIONING AND DISPOSAL COSTS

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**Abstract**

The subject of the paper is the regulations currently in force in the member States of the European Community for financial provisions for the decommissioning of nuclear power stations and for nuclear disposal, as well as the assessment of these regulations. This complex subject is discussed as follows: first the requirements which must be met in order to be able to accumulate, manage, and in case of need, make use of financial resources according to the polluter and the relevant operating period are stated. After that the regulations the individual European countries have created to establish a well structured system which meets these requirements are explained. In the third part of the paper the experience gained so far is presented, and whether there is a need for action based on the experience available. Following this will be a discussion of the regulatory possibilities and what regulatory difficulties are involved in the individual systems and, in particular, a change-over between the systems. A brief summary of the main results is the final topic in the paper.

## 1. DEMANDS MADE ON REGULATIONS FOR FINANCIAL PROVISIONS

Nuclear power stations can be neither operated nor dismantled without producing radioactive substances that require disposal. The operators of nuclear power plants are obliged, on the basis of statutory regulations under public law in terms of the ‘polluter pays’ principle, to regularly dispose of the radioactive substances produced. From a financial point of view, this presupposes the following:

— Determination of the amount of financial resources required,
— Accumulation of financial resources according to the polluter and the relevant operating period,
— Professional, target oriented management of the financial resources.

### 1.1. Determination of the amount of financial resources required

The amount of financial resources that must be accumulated in order to dispose of radioactive waste assumes knowledge of what radioactive substances need to be disposed of, how they are produced and their quantity. This knowledge is available to the operators of the nuclear power plants, who are have to carry out disposal.

In addition, information is necessary on the manner in which these radioactive substances can be disposed of and on the costs involved. For example, in Germany important disposal steps, such as the setting-up and operation of final storage sites, are assigned by law to be the responsibility of the government. As long as the cost of individual items of disposal activity cannot be exactly determined, due to governmental inactivity or activity delays in such areas, uncertainty is the result. The responsibility for such uncertainty rests solely with the government and is independent of the way in which financial provisions are made by the operators for the disposal of radioactive substances. If the disposal strategies chosen by the member States deviate from one another (e.g. final storage in deep geological strata in Germany, final storage close to the surface in France), the financial resources that need to be raised by the operators also differ markedly with regard to the amounts. This is, from the point of view of a European competition situation, not acceptable.

### 1.2. Accumulation of financial resources according to the polluter and relevant operating period

If the type and quantity of the accumulated radioactive substances to be disposed of are as well known as the respective disposal routes and their cost, the financial resources required can be accumulated. Accumulation of the necessary financial resources should take place according to the polluter and the relevant operating period.

A suitable accumulation in line with the relevant period of operating time can be said to be achieved if, at the point in time at which the disposal obligations are established, i.e. during the period of electricity generation, resources for disposal of the radioactive material are also accumulated, since after the end of power station operation earnings from electricity generation cease. Moreover, this is in line with the polluter pays principle if the party in whose plant the radioactive material to be disposed of has been produced is obliged to dispose of it so that neither it nor any third party is held liable for the maintenance of adequate financial resources. The costs involved are regularly passed on to customers, a situation which takes into account the polluter pays principle because those who benefit from the advantages of this type of electricity generation also have to pay the full cost of the respective electricity supply costs, including disposal.

In this connection it must be noted that, with an accumulation of financial resources according to the polluter and the relevant operating period, there can be a considerable span of time between the production of radioactive substances to be disposed of and their disposal, and the use of the financial resources necessary for this activity. This gives rise to the question of whether, with regard to the disposal costs, inflationary tendencies have to be anticipated because of any possible price increases, and whether due to possible interest rate effects a discounting of the entire financial volume necessary should be effected.

The principle of 'caution', which is anchored by statute in German commercial law, could be negatively affected by discounting, since it is assumed that certain returns on investment are earned over a considerably long period of time. Any incorrect forecast would therefore result in a corresponding shortage of cover.

### 1.3. Professional, target oriented management of financial resources

Depending on whether the amounts necessary for future fulfilment have been accumulated or whether the sum necessary was discounted, either maintenance of the value and/or a return on investment in the amount of the discounting is necessary. This requires appropriate, competent management of the resources.

## 2. EXISTING SYSTEMS OF FINANCIAL PROVISIONS

In the member States of the European Community, different approaches are currently being taken to ensure that the necessary financial provisions are being made. In terms of the requirements stated in Sections 1.1–1.3, structural differences in individual countries can be discerned which are also attributable to whether a model of an external fund or of internal management of the financial resources within the company, be it in an internal special fund or otherwise, has been chosen.

The model of an external fund is the basis for regulations in Finland, Sweden and Spain, while internal management of resources forms the basis of the regulations in Germany, France and Netherlands. A special situation exists in Belgium and the United Kingdom: there, in each case, for certain areas both models have been implemented. In relation to installed capacity, it should be stated that for approximately 75% of the nuclear energy capacity in the States of the European Community the model of internal management of resources has been selected and for approximately 25% the model of an external fund is being used.

### 2.1. Determination of the amount of financial resources required

Those European countries with companies operating nuclear power plants at which external funding models have been used have persons from outside the company to manage the fund. These persons are selected by the respective government. Hence, in these countries a group of people who are not responsible under the law applying to atomic energy for the disposal of radioactive material participate in decision making regarding the amount of the financial resources necessary.

The structural characteristics are different in those countries where the resources are managed within the company. In such a case, initially only those obliged to dispose of material are required to determine the necessary amount of financial provisions. Only in a second stage are persons from outside the company involved in the question of whether this amount is in fact correct: auditing companies check whether these resources are adequate for meeting the appropriate disposal commitments, and fiscal authorities check whether the financial resources are accrued in an amount which exceeds the level necessary. As a result, in these countries persons external to the company check whether the resources are adequate and whether the resources set aside are excessive.

### 2.2. Accumulation of financial resources according to the polluter and relevant operating period

Irrespective of whether a model of an external fund or a model of internal management of resources has been chosen in those countries, in the member States of the European Community the necessary resources are already being accumulated during operation and thus during the production of the radioactive material that needs to be disposed.

Likewise, independent of the choice of model of financial provision in some countries (e.g. Belgium, United Kingdom), discounting is carried out, while in other countries (e.g. Germany, France) the amount for fulfilment is being accumulated in line with the relevant operating period.

### 2.3. Professional, target oriented management of the financial resources

The situation here is the same as for the issue of the correct determination of the necessary amount of financial resources to be accumulated. In those countries in which the model of external funding has been firmly established, persons external to the company who are under no obligation to dispose of the radioactive material can co-determine the appropriation and management of the financial resources. There are also additional statutory restrictions with regard to the management of the financial resources which only permit certain forms of investment.

In countries with a model of internal management of funds, auditing companies carry out checks on set dates to determine whether, according to the management of the financial resources, funds are available in the order of magnitude necessary, while the tax authorities, checking from the opposite point of view, see whether more than the necessary amount of financial resources is available.

## 3. EXPERIENCE AND THE NEED FOR ACTION

As questions of disposal have accompanied the peaceful use of nuclear energy from the outset, experience of the efficiency of the financing models already chosen has been gained irrespective of the fact that decommissioning projects have so far already been completely implemented only in small numbers. Generally speaking, it can be stated that — no matter which financing model was chosen in the past — no case has occurred which could give rise to the fear that no financial resources or insufficient financial resources were available for the disposal of radioactive substances. However, experience has been gained in individual cases, which permits conclusions to be drawn with regard to possible improvement of the particular models.

### 3.1. Determination of the amount of the financial resources required

Considerable differences are found between individual countries as regards what financial resources are considered necessary for disposal. In view of the fact that both in the case of the fund model and in the case of the accrual model, third parties external to the company are involved either in the fixing or the checking of the correct amount of these financial resources, it cannot be concluded that these differences are based on the different systems of financial provisions. It is more likely that the differences are based on what disposal strategies with regard to final storage and the decommissioning of nuclear power plants (immediate dismantling and safe enclosure) are pursued. The differences increase exponentially if in individual countries discounting is permitted and not in others.

Governmental attention to financial resources should therefore bring about substantive clarification and harmonization in the disposal field in the form of modifications to the safeguarding of financial resources.

### 3.2. Accumulation of financial resources according to the polluter and relevant operating period

Differences between the various financing models are not apparent, and no negative experience has been gained. The problem of discounting has already been highlighted..

### 3.3. Professional, target oriented management of the financial resources

That so far there have been no cases of financing bottlenecks in the countries of Western Europe as regards the disposal of radioactive waste is merely an indication of the efficiency of the existing financing systems. Indeed, it is doubtful whether the management of financial resources from external funds is superior to the management by the parties obliged to arrange for disposal themselves as far as reliability is concerned. For example, the management of the Swiss Decommissioning Fund achieved a negative return on investment of –0.7% in 1994; in that case neither a value increase nor even the maintenance of the value of the financial resources took place in the year concerned.

Despite that, the model of internal management of funds is regarded as critical because it is claimed that the financial resources are less secure than in an investment by an external fund. This argument is based on the idea that insolvency is to be feared. Either companies operating nuclear power plants could become insolvent or companies operating such plants could invest financial resources in business companies, which could, on their part, become insolvent.

In view of the cost situation in the electricity market and the favourable electricity generation costs from the operation of existing nuclear power plants, the insolvency of companies operating nuclear power plants appears to be totally remote. For this reason, this will not be pursued any further. Irrespective of this, if such an insolvency were conceivable, it would have a detrimental effect, within the scope of the models of external funding, as all further contributions from the insolvent operator would cease. But, as I have just said: we are in the area of the unreal.

In view of spectacular cases of insolvency the issue of whether money is invested in companies, which at a later point in time themselves become insolvent, could be examined. However the following points militate against this being a structural disadvantage for models of internal management of financial resources.

In the cases of the spectacular insolvencies of companies (e.g. Enron, WorldCom), deficiencies in the system have been revealed. The possible effects of such systemic deficiencies, namely deliberate and criminal falsification of balance sheets, and presumably also criminal omissions on the part of auditing companies, cannot be restricted to an individual group of investors such as utility companies. These are things that can obviously affect the international capital market and, unfortunately, are actually affecting it at the present time. For this reason it does not appear appropriate to link regulations to individual consequences, which are generally possible only with a good deal of imagination. If serious economic disadvantages are conceivable as a result of the falsification of balance sheets and the negligent audits mentioned, the only recommendation that can be made is that this deplorable state of affair must be eliminated.

## 4. ROOM FOR MANEUVER

It remains questionable whether a change in financing systems is possible at all and what obstacles, if any, are present. The change from a fund model to an internal model, as a matter of principle, does not face any legal reservations. Such a change has so far been made once: after a fund model was introduced in 1994 for the nuclear power plants of BNFL, it was abolished in 1997.

The change from a model of internal management of resources to a model of an external fund should be viewed more critically, because this of necessity involves withdrawing from the operator funds they have to meet future commitments. This problem is then increased exponentially if only the financial resources are withdrawn, without at the same time the corresponding obligation to carry out disposal being removed. However, regardless of this there are serious legal objections to such a transfer of financial resources to an external fund

Normally, a one sided special obligation would be created for companies which operate nuclear power plants, while other companies with obligations on a comparable scale (e.g. mining, chemicals, insurance companies) would be spared by such a system. Thus there would be discrimination within the same state. Such intervention would additionally go further than is necessary in order to offset the alleged disadvantages. It would thus violate the principle of proportionality now expressly established in European law (Article 5, para. 3, EC). The withdrawal of financial resources, together with the disposal obligation simultaneously remaining with the operators, would represent a violation of property rights with regard to the financial resources. A justification for this cannot be seen on the basis of what has been stated above.

Finally, for the legal area of the European Union, the subsidiarity principle — Article 5, para. 2 EC — would still have to be observed. Harmonization for harmonization's sake is legally inadmissible.

## 5. SUMMARY

In summary,

(1) In the countries considered here the respective financing systems chosen have been tried and proven.

(2) There is a need for action by governmental organizations in two respects:

- A clarification of the costs of disposal necessitates a clarification of the disposal routes. This necessarily includes the clarification and implementation of final storage concepts.
- The need for governmental action exists to the extent that in the financial markets, in the current situation, structural deficiencies in the system have been revealed. These real systemic deficiencies should be tackled first, and not any anticipatory, consequential problems

(3) There are, as a result of the subsidiarity principle under European law of the principle of proportionality and of the protection of property, serious objections to intervention going beyond that which also includes fundamental restructuring of the financing system.

# FUNDING OF FUTURE DISMANTLING AND DECOMMISSIONING COSTS IN THE FINNISH STATE NUCLEAR WASTE MANAGEMENT FUND

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**Abstract**

The financial provisions for all nuclear waste management, including dismantling and decommissioning (D&D), in Finland have been arranged through the State Nuclear Waste Management Fund, which was founded in 1988. A producer of nuclear waste is fully responsible for its nuclear waste management, including D&D. The main objectives of the system, created through the legislation, are: (a) at any time there shall be sufficient funds available to take care of the nuclear waste management measures caused by the waste produced up to that time; and (b) the financial burden caused by the production of wastes shall, in a timely manner, be reflected in the cost of electricity produced through the activity giving rise to those wastes. The part of liability that is not covered by money in the Fund must always be fully guaranteed. The State Nuclear Waste Management Fund is a special purpose fund, segregated from the State budget. The licence holders are entitled to borrow back 75% of the capital of the Fund against the provision of full guarantees and at current interest rates. In addition, the State has the right to borrow the rest of the capital. Plans and cost estimates for the remaining nuclear waste management measures are updated yearly by the nuclear power companies and approved by the authorities. The assessed liability and fees to be paid into the Fund by the companies are then confirmed. No discounting is used. The funding system in Finland seems to work well and so far no serious problems have arisen as regards the future availability of sufficient capital for nuclear power plant D&D.

## 1. GENERAL FRAMEWORK

In Finland presently some 27% of all electricity is produced by nuclear power. The total capacity of the four nuclear power units, situated at two different sites, is 2656 MW. Teollisuuden Voima Oy (TVO) operates the Olkiluoto power plant with two 840 MW(e) BWR units supplied by Asea-Atom and commissioned in 1979 and 1982. Fortum Power and Heat Oy (the former IVO) operates two 488 MW(e) Russian type PWR units commissioned in 1977 and 1981 at the Loviisa site. In addition, there is one small research reactor.

This statistical information already reveals two factors that have had a decisive influence on the system through which funds are collected for dismantling and decommissioning (D&D) of nuclear facilities in Finland. The first of these factors is that the Atomic Energy Act promulgated in 1957, i.e. ten years before the order for the first nuclear power plant unit was placed, declared that any company or organization that met the requirements set out in the legislation was eligible to produce nuclear energy. In other words, production of nuclear energy was not to be a State monopoly. Electricity production in general has never been a State monopoly in Finland. This starting point, considering nuclear energy production as a commercial activity, has also been maintained in the Nuclear Energy Act, replacing the old Atomic Energy Act in 1988.

The other factor is the relatively small size of the Finnish 'nuclear plant fleet'. This has indirectly influenced the strategies for nuclear waste management and decommissioning. At an early stage it became obvious that the reprocessing of spent fuel in Finland was not, in practice, an option. Furthermore, in spite of the small scale of the Finnish nuclear programme, there seemed to be no guarantee of finding suitable foreign reprocessing or disposal services for all the spent fuel generated in Finland. Both the high prices of these services and the non-proliferation aspects were seen as potential obstacles. Thus, decommissioning was not seen as the only financial liability of the nuclear facilities. It was found to be quite possible that in the future, after the nuclear power plants were closed down, a significant task of disposal of spent nuclear fuel would still have to be carried out. Consequently, decommissioning was seen to be only a part of the major question of nuclear waste management and not a separate undertaking.

Finland is one of the countries that consider nuclear power to be a viable option for electricity production. This was recently demonstrated by the Finnish Parliament when it gave, by ratifying a so-called 'decision-in-principle', political acceptance for the construction of a new nuclear power plant unit in Finland. The operator of this new unit will be TVO. As for the existing nuclear power plant units, their planned lifetimes are at least 40 years. The current operating licences are in force until the end of 2007 (for Loviisa) and 2018 (for Olkiluoto). This means that there will probably be nuclear power plants in operation in Finland for a long time. On the other hand, there is still no decommissioned nuclear facility in Finland. And the experimental uranium mining effort did not really take off.

## 2. BASIC PRINCIPLES OF FINANCIAL PROVISIONS FOR THE COSTS OF NUCLEAR WASTE MANAGEMENT

The old Atomic Energy Act included only very general provisions on nuclear waste management, since waste management was not considered a significant issue in the 1950s. Fortunately, the Act gave extensive powers to the authorities to draw up licence conditions on arrangements for nuclear waste management and decommissioning, and on collecting reserves to cover the respective costs and include these conditions in the operating licences of the nuclear facilities. In that connection, it was, however, seen that a stronger legal basis for provisions for the costs of nuclear waste management was needed. This was one of the important reasons to start, at the end of the 1970s, the drafting of new nuclear legislation. However, due to both substantial disagreements and legislative problems, the new act, the Nuclear Energy Act, did not enter into force until 1988.

When drafting the legislation for financial provisions for the costs of nuclear waste management in Finland the following two, now almost globally accepted, principles were chosen as starting points:

— The costs of management of any quantity of nuclear waste should be reflected in the cost of the nuclear electricity production giving rise to those wastes (timeliness);
— The funds collected should be available when waste management operations are carried out and they should be sufficient for that purpose.

In the Finnish solution, the manner of implementing the principle of availability and sufficiency strongly influenced the manner of implementing the timeliness principle.

From the political point of view, the administration of the funds to be collected was an important question. Two views were competing: on one side those who, at least partly for ideological reasons, saw that the funds should be administered by the State, and on the other side those who considered that the State was the most unreliable trustee of the capital. Several alternative funding methods were studied. For example:

— Internal funding of nuclear companies;
— Internal funding of nuclear companies plus full guarantees to be furnished to the State;
— Internal funding of nuclear companies, plus a bank deposit on a blocked account in the Bank of Finland;
— External funding without the right of borrowing back;

— External funding with the right of borrowing back with or without the obligation to provide guarantees;
— Annual transfer of the funds to the State budget.

The outcome was a compromise, according to which an external segregated fund, the "State Nuclear Waste Management Fund", was established and detailed legislation was created for it. The nuclear companies were entitled to borrow back, at the market interest rate, 75% of the capital of the fund against the provision of full guarantees. The State was to have the right to borrow the remaining capital, i.e. at least 25%, at the same market interest rate. One factor contributing to this compromise was that the companies had already collected, pursuant to the then existing obligations, a relatively significant amount of money and a sudden transfer of that money into the Fund would have been complicated.

As mentioned above, the primary responsibility for nuclear waste management is assigned to the licence holders while the State has a supportive backup role only. Consequently, it was considered that it would not be appropriate to collect funds from the licence holders through a system based on a levy. Instead, the system selected was based on the requirement that at any moment there shall be, in the Fund, sufficient funds available to cover the remaining waste management measures necessary for the waste produced up to that time. Accordingly, the capital of the Fund is annually adjusted, normally with additional contributions from the licence holders. However, repayments from the Fund to the operators are also possible.

It is worth stressing that the Fund does not pay for the waste management measures, but continues to keep the money corresponding to the costs of the remaining measures. Theoretically, all the funds have been returned to the operators when they carried out all the necessary waste management operations. For these reasons, the Fund could be described as a "guarantee fund".

No obligation of balance sheet specifications to control the source of the money paid into the Fund has been set for the licence holders. Consequently, on the basis of the funding system it is not possible to consider precisely the effect of waste management costs on the cost of nuclear electricity. (It is worth noting that today the price of electricity is determined by market conditions.)

The cost of D&D immediately turns attention to the 'remaining waste management costs' when a facility is taken into operation. If such a large sum, forming a considerable portion of the total cost of waste management, were immediately transferred to the Fund, the effect of the costs would not be included on a timely basis and correctly in the production costs of electricity. Also, the construction costs of final disposal facilities for spent fuel constitute a type of significant investment cost which is completely discharged only in the distant future. When creating the funding system, this problem was solved by a provision that allows, during the first 25 years of operation of a nuclear facility, the collection of funds as a gradually increasing fraction of the calculated costs. However, in order to cover the total liability, the licence holder must give full guarantees to the State to cover the difference of the liability and the amount of the funded capital. For the existing four nuclear power plant units in Finland, the 25 year distribution period is now over.

In a way, one can say that each licence holder has its own 'account' in the Fund and the State authorities regularly establish the required balance of that account. According to the Nuclear Energy Act, the transfer of a nuclear facility to another legal person does not automatically transfer the obligation of waste management or the 'account' to the new owner; rather, the transferee has to open an account of its own. However, with the consent of the authorities the obligation of waste management and the 'account' can be transferred. In the case where the licence holder with an obligation of waste management is no longer capable of taking care of its obligation for financial reasons and/or measures of waste management, the State can take over both the waste and the 'account'. The guarantees furnished by the licence holder to the Fund ensure that the Fund can return money to the State in time with the actual waste management measures.

According to the Nuclear Energy Act, the legal 'person' whose activities produce nuclear waste is fully responsible for nuclear waste management, including D&D. It can be released from that obligation only by the consent of the Government. If a nuclear power company ceases to exist or becomes unable to fulfil its obligation, the task is transferred to the State.

In theory at least, if a nuclear facility should for any reason stop its operation and also stop the production of more waste, the money accumulated in the Fund and the securities given to the State would together suffice to handle the situation and take care of the management of all the existing waste and the D&D of the plant. As the actual waste management measures would not be taken immediately, the interest accrued in the meantime by this existing capital is used to compensate for inflation and cost escalation.

## 3. OPERATION OF THE FINNISH NUCLEAR WASTE MANAGEMENT FUNDING SYSTEM

### 3.1. Organizations involved and their roles

The Ministry of Trade and Industry is responsible for nuclear energy in Finland. One of its duties is to ensure that the plans for waste management by the nuclear power companies and the implementation of these plans comply with the national policy. Each year the Ministry also determines, through various decisions, the amount of money each licence holder must have in the State Nuclear Waste Management Fund. The Ministry also makes sure that the operation of the Fund complies with legislation.

The State Nuclear Waste Management Fund is responsible for the management of the capital collected for nuclear waste management. The Fund has a Board of four members nominated by the Government. The Board has to include representatives from the Ministry of Trade and Industry, Ministry of Finance and the State Treasury. The current Chairman comes from outside the public administration. The Fund has two auditors, one of whom is selected by the nuclear power utilities. It also has a Managing Director, secretary and accountant, all part-time. Currently, the Fund's capital amounts to about €1200 million. In 2001, the profit of the Fund was €47 million. The annual administrative costs of the Fund have been about €50 000.

The Radiation and Nuclear Safety Authority (STUK) reviews, especially from the safety point of view, proposals on the basis of which the assessed remaining liabilities are established, and gives its opinion to the Ministry of Trade and Industry. In addition, the VTT Technical Research Centre of Finland reviews the proposals and cost estimates and gives the Ministry its opinion.

### 3.2. Assessment of liabilities

As mentioned above, the financial provisions for the future management of nuclear waste are based on the principle that the funds, covering the cost of the remaining operations needed to manage the waste that has already been produced, are available at any moment. Accordingly, the payments to the State Nuclear Waste Management Fund are based on the estimated costs for the future management of the currently existing nuclear wastes.

In practice, these estimates are based on proposals provided annually by each licence holder and confirmed, after scrutiny, and sometimes negotiations, by the Ministry of Trade and Industry. The cost estimates are always calculated in current prices, on the basis of current plans and technology. No discounting is used. These confirmed estimates or assessed liabilities form the basis for establishing the amount of money that each licence holder should have in the Fund. This amount that the Ministry also confirms each year is called the 'fund target'. It is then up to the Fund to see that the licence holder's share of the money in the Fund is balanced with the fund target.

To take into account the 'fixed costs', i.e. costs the total amount of which is not at all or rather weakly linked to the life cycle of the facility, the fund target is gradually increased during the first 25 years in proportion to the years of operation completed, so that the capital reaches the assessed liability sufficiently early before the estimated cessation of operation of the nuclear facility. From a licence holder's point of view, the gradual collection method supports the evenly distributed transfer of waste management costs to the cost of electricity.

The detailed instructions for determining the fund target as a fraction of the liability are given in a Decision by the Council of State (Cabinet). The fund target depends on the energy produced, but there is a minimum target that must be reached even with no energy output.

It is worth noting that the assessed liability is not equal to the total cost of waste management, but is based on the estimated costs of the remaining measures. These estimates may change considerably during a year. Firstly, they are made according to current plans and technology. Thus, changes or corrections in plans, possible innovations and changes in the cost level as well as changes in national policy may influence the assessed liability. An example of the policy changes is the requirement, introduced at the beginning of 1995, of final disposal of all spent fuel in Finland. Secondly, the waste management operations carried out by a licence holder decrease the liability and sometimes these operations can be very costly. Actual examples of these kinds of changes are the completion of disposal facilities for low and intermediate level wastes. There are also other reasons that may give rise to sudden changes.

Due to the fact that the Fund targets are confirmed on the basis of assessed liabilities, these sudden changes can conflict with the aim that the cost of nuclear waste management should be smoothly transferred into the cost of electricity. To take this into account, the Nuclear Energy Act allows handling of an exceptionally large, sudden increase or decrease in the assessed liability, under certain precautions, by confirming temporarily (for a maximum of five years) the final liability that is lower/higher than the assessed liability.

Because of the method assumed to handle the high fixed costs and also major changes, the fund target can be less than the assessed liability. As a precaution against insolvency, the part of the assessed liability that is not covered by the money in the Fund must be covered with guarantees furnished by the licence holder. These guarantees are given to the Ministry of Trade and Industry, not to the Fund. They can, according to the Nuclear Energy Act, be a credit insurance provided by an insurance company, direct liability guarantees provided by a Finnish commercial bank, real estate mortgages or direct liability guarantees provided by a Finnish association. Mortgages on a nuclear power plant itself cannot be accepted. Each security has to be separately accepted by the Ministry of Trade and Industry. In practice, TVO has used direct liability guarantees of its shareholders and Fortum real estate mortgages related to its conventional power plants. As an additional precaution against unforeseen events, supplementary guarantees covering 10% of the assessed liability must be given to the Ministry.

### 3.3. Administration of the Fund capital

The State Nuclear Waste Management Fund manages the funds collected to guarantee future nuclear waste management. The Fund is to maintain and increase the value of this capital through a cautious lending policy and under the limitations set by the nuclear energy legislation. Any interest earned is added to the capital and in this way benefits the licence holders by decreasing the payments. On the other hand, all financial losses suffered by the Fund will be deducted from the capital of the Fund, a fact that introduces an element of collective liability into the system.

The share of each licence holder of the capital of the Fund or the amount of money each licence holder actually has in the Fund is called 'fund holding'. The fund holding is made up of the payments by the licence holder, its relative share of the accumulated interests of the capital and also potentially of its share of the losses. The fund holding varies during the year and can be regarded as the daily balance of a licence holder's 'account' in the Fund.

The fund holding related to the last day of the previous calendar year is compared by the Fund with the fund target determined by the Ministry of Trade and Industry; the difference is defined either as a fee to be paid to the Fund or as a refund to be paid to the licence holder. Refunds to the licence holders will be more probable now, when the accumulation period of 25 years is over and waste management plans and measures are being actively implemented. However, some returns have been occasionally paid due to changes in waste management plans and high real interest rates.

The accumulated capital is lent out by the Fund. A licence holder, or its shareholders, can borrow back up to 75% of its fund holding against full guarantees given to the Fund. The Board of the Fund must in each case approve these securities, which should not be mixed with the guarantees given to the Ministry. TVO normally provides direct liability guarantees of its shareholders and Fortum uses shares it owns in a hydropower company.

In normal cases, the fixed period of a loan is five years. The interest rate is presently fixed by legislation to be Euribor +0.15%.

The remaining Fund capital, consequently at least 25%, is offered to the State as a loan with the same interest rate. The part of the capital that the licence holders, their shareholders or the State do not want to borrow is to be invested against full guarantees in some other way yielding the best possible return. The utilities and the State have normally borrowed the amounts they have been entitled to. Only earlier, during a certain period when the fixed interest rate at that time was rather high, did the State not fully use its right to a loan. The total amount of money borrowed by the State is today some €250 million.

The Ministry of Trade and Industry confirms, at the end of January, the assessed liabilities as of 31 December and determines the corresponding Fund targets. The State Nuclear Waste Management Fund then determines, in February, the fund holding of each licence holder at the end of the previous year and the balance between this fund holding and the fund target. On 1 April, all payments to and from the Fund, including those connected with the issuing and repaying of the loans, are made simultaneously, in practice largely compensating each other. Thus, the actual money flows are often much smaller than the determined fees.

In the licence holder's (company's) balance sheet, a payment to the Fund is an expense, and a received payment from the Fund is an income. This expenditure or income is included into the balance sheet of the calendar year ending before the payment is actually made since it reflects the situation at the end of that year. The annual waste management fee is treated as a deductible expense and the possible return from the Fund is taxable income. However, the costs of waste management measures carried out by the company during the previous calendar year and which reduce the remaining waste management costs, in that way either having a decreasing effect on the fee or causing a payment from the Fund, are treated as deductible expenses. Thus, at least in theory, the actual expenses are balanced by the return from the Fund.

## 4. SPECIFIC ISSUES CONNECTED WITH THE COSTS OF D&D

### 4.1. Dismantling and decommissioning plans for the power plants

The four nuclear power reactors in Finland were put into operation between 1977 and 1982, while the current operation licences will be in force until the end of 2007 (Loviisa) and 2018 (Olkiluoto), as mentioned earlier. The decommissioning plan for the Loviisa power plant is based on immediate dismantling in less than ten years from the shutdown of the reactors, excluding facilities needed for spent fuel storage. The current basic plan for the Olkiluoto power plant envisages a 30 year safe storage period prior to dismantling of the reactors. When the planned life cycle for all the units is at a minimum of some 40 years, and if D&D plans are carried out following the current plans, the D&D period of the existing plants would start approximately in 2030 and be completed in 2060 or later, depending on the final life cycle.

According to a policy implemented by decisions of the authorities, the licence holders have, since 1983, been obligated to update their decommissioning plans every five years. These plans aim at ensuring that decommissioning can be appropriately performed when needed and that the estimates for the decommissioning costs are realistic. The latest updates of these decommissioning plans were published at the end of 1998. So the next updating will take place by the end of 2003.

The Finnish decommissioning plans cover dismantling of only structures and components that exceed the clearance constraints. Similarly, the funding system covers only radioactive waste from the dismantling. The 'green field' option is not required. The estimated amount of waste to be disposed of is 15 000 $m^3$ for the Loviisa plant and 28 000 $m^3$ for the Olkiluoto plant.

Some essential technical details of the decommissioning plans have not been fixed so far. For instance TVO, in spite of its primary option of delayed dismantling, is also studying the immediate dismantling option. Furthermore, the company has not decided finally whether the pressure vessels will be disposed of in pieces or as a whole.

Both nuclear companies plan on-site disposal of dismantling waste. The existing underground repositories for operating low and intermediate level waste would be expanded for the disposal of dismantling waste. In addition to technical benefits, on-site disposal is estimated to be much more cost effective compared with other alternatives. The decommissioning waste disposal plans include fairly comprehensive safety assessments.

### 4.2. Cost estimates

The cost estimate of D&D using the current price level is €192 million for Loviisa and €156 million for Olkiluoto. Accordingly, the total sum of provisions for D&D is now about €350 million, or about one third of the total sum of provisions for nuclear waste management in Finland.

In international comparisons, the estimated costs of D&D in Finland seem to be relatively low. Many reasons for this can be identified. First of all, the basis of calculations varies significantly from one country to another. The fact that dismantling according to Finnish legislation involves the contaminated parts of the facility only naturally limits the cost of dismantling compared with that of the green field option. Secondly, considerable cost reductions are assumed to be achieved through effective arrangements at the site, and especially from the on-site final disposal of decommissioning waste.

The critical question, however, is not the exactness of the cost estimate today, but how the system takes into account the difficulty of arriving at reliable estimates. As a nuclear company may at any time, at least in theory, lose its capability for, or interest in, the orderly management of D&D, the Finnish funding system contains some built-in features to minimize the risk of the State having to contribute additional funds to carry out these operations.

It is obvious that the estimates of D&D costs have, especially in the past, been mostly based on theoretical considerations. However, the system continuously requires new, updated estimates that must take into account the practical experience accumulating worldwide. The estimates must not rely on improvements in waste management methods, but must, according to the law, always be based on the technology currently available. In addition, the law also requires that the uncertainty of available information about prices and costs shall be taken into account, in a reasonable manner, as raising the estimated liability.

The transfer of funds on the account of a licence holder to the State has already been mentioned. In this situation, the Fund has full rights to require the licence holder to pay its loans back to the Fund or, alternatively, to realize the securities. The interest of this capital is also available to the State and is assumed to compensate for inflation and related cost escalation. The State can also, if there is a need, realize the 10% supplementary securities.

## 5. CONCLUDING REMARKS

The Finnish nuclear waste management funding system has been in operation for almost 15 years and has worked smoothly, to the satisfaction of all parties. The real test is, however, still ahead. This will be experienced sometime in the future if and when a nuclear company has ceased to exist and neglects all its financial obligations. Then one will see whether society is willing to use all the strong means it has at its disposal under legislation to extract the necessary funds from the securities. It is also worth remembering that repayment of the funds loaned to the State have to be collected from the taxpayers.

## PANEL DISCUSSION

## FUNDING APPROACHES AND STRATEGIES

*Chairperson:* **J. Barceló Vernet** (Spain)

*Members:* **I. Dumchev** (Kazakhstan)
**T. Selby** (United Kingdom)
**O. Söderberg** (Sweden)

## Statement

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The BN-350, a multipurpose reactor, is located on the right bank of the Caspian Sea. Its period of operation was from 1972 to 1999. As a result of a Government decision on decommissioning, taken in 1999, several challenges are being faced. These include:

— strategy,
— planning,
— funding,
— social aspects.

The particular strategy chosen and planning carried out depend on the availability of funds. There are several ways to fund the decommissioning task in a safe and complete manner. Specifically, decommissioning can be financed by:

— funds from the company owning the plant,
— donor support,
— government funds.

In our case, we are using the following financial resources to put the BN-350 facility into a safe storage (SAFSTOR) condition:

— our company's own funds;
— direct investment from the Government (a Special Decree has been passed);
— support from donor countries, i.e. European Union member countries, the USA and Japan.

The Government of Kazakhstan has requested the IAEA to technically support Kazakhstan in the preparation of a detailed decommissioning and decontamination (D&D) plan, based on international standards. This plan will be presented to potential donor countries in order to convert the BN-350 reactor to SAFSTOR condition. This D&D plan will be released through an

IAEA special experts committee. It will be presented at a special donors conference foreseen for December 2003.

On the basis of the December 2003 conference, procedures to ensure that funds will be used transparently and with control will be agreed upon. A clear mechanism of how the money should be used will avoid waste and duplication of efforts. In our case, because the owner company is the Government, governmental control is absolutely necessary. However, the Government can delegate this authority to anybody to manage this activity.

**Statement**

# NUCLEAR DECOMMISSIONING: FUNDING ARRANGEMENTS

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I will speak about the United Kingdom's approach to funding civil nuclear decommissioning activities and explain proposed changes to the current arrangements. The UK has nuclear operators both in the private and public sectors and the approach to decommissioning funding differs. British Energy (BE), which operates a fleet of AGR power stations and a PWR, is in the private sector. On privatization, a segregated fund was established to cover BE's future decommissioning costs. The segregated fund is akin to a pension fund which holds investments. Money paid into the fund is invested and the accumulated assets used to meet future decommissioning and cleanup costs. Of course, predicting the precise amount of money that will be required to cover decommissioning costs is not an exact science. That is why the performance of the segregated fund is reviewed at five yearly intervals, at which stage BE's annual contribution can be adjusted as appropriate.

To ensure that the fund is managed effectively and investments are made wisely, the fund is managed by independent trustees jointly appointed by the Government and the company. So far, the fund is performing as expected and it is on target to cover BE's decommissioning costs.

Operators in the public sector include British Nuclear Fuels Limited (BNFL) and the United Kingdom Atomic Energy Authority (UKAEA). BNFL operates the fleet of Magnox power stations, a number of which are in various stages of decommissioning. BNFL also operates Sellafield (reprocessing, MOX and other operations) and Springfields (fuel manufacture). UKAEA is responsible for decommissioning the UK's former research reactor sites at Dounreay, Windscale (Cumbria), Harwell and Winfrith (Dorset).

Under current arrangements, taxpayers meet the cost of decommissioning and cleanup at UKAEA sites; taxpayers will also meet the costs associated with the decommissioning of Magnox power stations from 2008 onwards. BNFL has an investment portfolio (known as the Nuclear Liabilities Investment Portfolio (NLIP)) for its other decommissioning and cleanup activities, including at Sellafield. This operates along similar lines to the BE segregated fund.

The cost of cleaning up the UK's civil public sector nuclear 'legacy waste' has grown to an estimated £48 billion. Legacy waste is defined as:

— UKAEA and BNFL nuclear sites and facilities developed to support Government research programmes from the 1940s onwards, plus the associated wastes, materials and spent fuel;
— Magnox power stations (operational and non-operational), plus associated reprocessing, materials and waste.

As a result of the spiralling cost of decommissioning and cleanup, the UK Government announced in November 2001 its intention to make radical changes to current arrangements for nuclear decommissioning and cleanup funded by the taxpayer. That announcement underlined the UK Government's commitment to improving the way in which cleanup in the UK is managed.

In its White Paper 'Managing the Nuclear Legacy — A Strategy for Action', published on 4 July 2002, the UK Government set out its approach and outlined how the new arrangements will operate in practice. It:

— Reflects the scale of the technical and managerial challenges involved in nuclear cleanup and the Government's intention, through competition, to ensure that the best available skills and experience, from the public and private sectors, are brought to bear on the task;
— Makes clear that the Government's priority is to ensure that cleanup is carried out safely, securely, cost effectively and in ways which protect the environment for the benefit of current and future generations;
— Underlines the Government's commitment to ensuring that management arrangements are open, transparent and command public confidence.

The UK Government therefore proposes to set up a Liabilities Management Authority (LMA), responsible to Government, with a specific remit to ensure the nuclear legacy is clean up safely, cost effectively and in ways which protect the environment. Because it will be responsible for the legacy as a whole, the LMA will be able to: set the right framework for systematic and progressive delivery of the cleanup programme; promote synergies between different sites; encourage the development of best practices; and ensure that resources are deployed where they are most needed and can be used to best effect. It will be in a position to balance short, medium and long term considerations and reflect the fact that the cleanup programme has to be sustained over a period of 100 years or more.

This begs the question, "How will this be funded?" Well, the White Paper notes that there are a number of options, including the normal UK Spending

Review process that operates on a three year cycle. But, given the time-scales involved and the Government's determination to encourage competition for cleanup by giving companies, including new entrants, confidence that funding will be available over a period of years, two innovative approaches to financing nuclear cleanup are set out in the White Paper. These are:

— A segregated fund, similar to the BE segregated fund explained earlier. The fund's scope would be set out in legislation, but it is reasonable to assume that it would fund the LMA's cleanup programme and directly associated expenditure, for example research and skills programmes. It might also cover the LMA's own running costs.
— A statutory segregated account, akin to a 'savings account' established in legislation and kept by the Secretary of State for Trade and Industry. It can only be used to fund the LMA's cleanup programme and directly associated expenditure, e.g. research and skills programmes.

A statutory segregated account would be similar to a segregated fund in that a 'savings pot' of money would be identified by legislation which could only be spent on cleanup, However, rather than drawing money from a separate fund, the LMA would effectively be funded within the Consolidated Fund, the Government's 'current account' kept by the Treasury at the Bank of England, which funds almost all Government expenditure.

The Government's view is that a segregated fund offers few advantages over a statutory segregated account, constitutes an exception to normal Government accounting rules and would be more complex to operate. The Government's preference is therefore for a segregated account, but it has invited views on both options.

Whichever option is finally chosen the burden for paying for nuclear decommissioning and cleanup of public sector civil nuclear liabilities will fall on UK taxpayers. But, as noted earlier, different arrangements apply to those civil nuclear operators in the private sector.

This then is the way that the UK is approaching the funding of civil nuclear decommissioning and cleanup. The advent of the LMA will represent a major departure from the past. Legislation is required for the LMA to become operational and the Government intends to bring that forward at the earliest opportunity. In the meantime, a Liabilities Management Unit (of which I am part) has been set up within the Department of Trade and Industry to prepare the ground for the LMA.

**Statement**

# REFLECTIONS ON FUNDING APPROACHES AND STRATEGIES

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*Issues for discussion*

— How do you ensure that funds are available when needed and what are reasonable funding mechanisms?
— Who should control the funds collected to support decommissioning activities?
— How should inherited or abandoned facilities and sites that require decommissioning be funded?
— How does the transfer of ownership of a facility affect funding?

*Issue 1: Availability of funds, reasonable funding mechanisms*

Personally I believe that there are very good ethical reasons behind a system that forces the users of nuclear energy to carry all costs connected with the use of electricity from nuclear power plants, including future decommissioning. In principle, the generations that consume this electricity should not leave such an economic burden to their grandchildren. This is also one of the principles expressed in the 1999 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

The most practical way to ensure that such economic burdens do not crop up at a later stage is to create some sort of funding mechanism. Such funding can be organized in different ways according to the conditions in different countries. But regardless of the technical solution for a funding system, such as the Finnish and Swedish ones where the producer is legally responsible for providing funds, the costs will finally have to be carried by the consumers.

To ensure an effective funding mechanism, there has to be national legislation on how such a mechanism should be constructed. Different systems — with governmental institutions more or less involved — are possible. But any funding system, aiming at providing economic resources for decommissioning in a foreseeable future should meet the following requirements:

— Legal rules should be considered as stable. The legislation on funding has to have a high enough status among legislators to ensure that political pressures do not lead to decisions to change the legislation in order to allow assets to be used for other urgent purposes. Legal rules must ensure that funds collected for this purpose cannot 'disappear' as a consequence of a bankruptcy of an owner of a nuclear facility that needs to be decommissioned.
— Calculations of the future costs have to meet high demands of accuracy. This not only applies to the expected size of different costs, but also to the time when these costs will occur. One possible way to achieve a high level of accuracy is to demand regular and frequent reviews of all calculations.
— There has to be mechanisms ensuring that the real value of the assets of the fund at least is maintained in a situation where inflation is high.
— Last, but not least, there has to be a competent administration of the funding system.

While Sweden has a fairly well functioning funding system, there are vulnerabilities as well. To put the size of the assets of the fund in 2002 in perspective (more than SEK29 billion), it should be noted that another SEK20–25 billion is needed to cover all future costs until the 2050s (this fund is for decommissioning and disposal of spent nuclear fuel from the present Swedish nuclear power programme). The remaining sums will mainly be accumulated as financial income from investments within the funding system, but the nuclear power companies will pay fees as long as the reactors are able to produce electricity.

According to the last official estimated balance of the Swedish nuclear waste fund, presented to the Government by the Board of the Nuclear Waste Fund in March 2002, the overall picture seems reassuring —there will be about SEK5 billion left in the fund when the operation is finalized in the 2050s. Note the assumptions: SKB's current plans, meaning the start of site investigations in 2002, look to a repository starting operation on a small scale from 2015. Another important assumption is that the fund will, for the period 1996–2020, have an annual real return of 4% on an average, and 2.5% from 2020 onwards. We have also assumed that the costs we calculate today for this operation will prove to be correct.

Recurrent reviews will help in adjusting fees and time plans. As long as the reactor generates electricity the owner can pay fees. After ending reactor operation, adjustments within the system are not always effective or are more difficult. Some cost margin is useful. Securities (as in the Finnish and Swedish systems) will also help to meet uncertainties.

Based on these reflections I believe there is only one conclusion to be drawn. **A well functioning funding system is most helpful to ensure that**

**economic resources exist when decommissioning has to take place. But that is no guarantee. If the system does not work — and if society as a whole cannot raise the necessary economic resources in another way — our grandchildren might have reasons to complain about our shortsightedness.**

*Issue 2: Who should control the funds collected to support decommissioning activities?*

My personal view is that the final control of funds to support decommissioning activities should rest with a governmental institution of some kind. And the administration of such a fund should be made in a spirit of openness and genuine will to expose the funding system to public scrutiny. Of course, a fund controlled by the government and exposed to public scrutiny is not a guarantee per se that assets will be available when needed. But maybe the chances are better that such a funding system will fulfill its aims than if funding takes place in forms that are difficult for the government to control

What are the main reasons for government control of funds? Let me summarize some major points:

— Decommissioning and dismantling are operations that will take place over a considerable time period in the future. It is quite possible that these activities will occur in a situation where the present owner of the facility does not have the necessary economic resources or does not even exist (even if society tries to prevent such a situation from happening).
— The uncertainties with regard to collecting funds for decommissioning and dismantling are partly a result of the fact that the operation as such is a part of political decision making in the field of energy politics. Obviously, cost calculations are difficult in themselves. But various uncertainties depend on the fact that a timetable for the operation might not only be guided by purely technical considerations. There are also financial uncertainties that depend on the economic policy a country chooses to have.
— The very fact that considerable amounts are required for decommissioning and dismantling.

Perhaps a comparison with national pension systems is relevant. We do not completely leave it to the employer to build and administer pension funds. Many of us have a strong feeling that society is more trustworthy in the long run than private enterprises. There are also other long term issues (environment, climate, etc.), which are generally considered to be the prime responsibility of society or the State.

*Issue 3: How should inherited or abandoned facilities and sites that require decommissioning be funded?*

I believe that this formulation refers to facilities or sites that are 'inherited or abandoned' today or in the near future. In this case there is probably only one way, provided that the previous owner or user is not held to be responsible: **Today's generation has to pay,** has as taxpayers or as electricity consumers (part of the electricity bill, directly or indirectly). The alternative is to leave a radioactive debt as a legacy to future generations, possibly hoping that later generations will have better possibilities to pay the costs.

*Issue 4: How does the transfer of ownership of a facility affect funding?*

As I see it, funding should follow the facility, not the owner. If a change of ownership of a facility is the result of a pure business transaction or is the result of political decisions, there have to be rules ensuring that assets that have been reserved for decommissioning activities will be available for the new owner for that purpose. Legislation should also be clear on who is responsible, at any given moment, for the actual decommissioning operations and the financing of these operations.

*Concluding remarks*

— There are unavoidable uncertainties even in a well designed funding system.
— These uncertainties increase over time.
— Early decommissioning and dismantling operations will probably help to keep uncertainties at a low level.
— A funding system that is considered trustworthy in the eyes of the general public is probably an asset; when governments, regulatory authorities and utilities try to create trust while developing and implementing a nuclear energy policy.
— The consequences of a lack of economic resources for decommissioning can already be observed in certain countries.

**Panel Discussion**

## FUNDING APPROACHES AND STRATEGIES
**Session 2.C**

D.W. REISENWEAVER (IAEA): The IAEA considers that the removal of spent fuel and operational waste from a nuclear power plant after shutdown is a plant operation activity and should not be funded from the financial resources put aside for decommissioning. What is the situation in Germany and Finland?

C. MÜLLER-DEHN (Germany): For every activity there has to be financial provision, through an external fund or an internally managed fund. That is the important point.

A.E. VÄÄTÄINEN (Finland): The situation is constantly changing with changes in national policy, so it is impossible to say now how the removal of spent fuel and operational waste will ultimately be funded.

J.A. HOYOS PÉREZ (European Commission): In her oral presentation, Ms Väätäinen said that in Finland there was a switch in 1993 from internal to external administration of the financial resources being collected for future decommissioning activities. What was the reason for the switch?

A.E. VÄÄTÄINEN (Finland): The 1957 Atomic Energy Act contained no detailed provisions relating to waste management, and the provisions relating to waste management in the first operational licences were not very detailed. It came to be realized that a firmer legal basis for waste management was needed, and that firmer legal basis is provided in the 1988 Nuclear Energy Act. It was also realized that the system for making financial provisions needed to be clarified. There was a political debate on the subject, and both internal funding and external funding were considered. One of the main reasons why external funding was regarded as being better was that it seemed to be less dependent on the future economic situation of the utility. Also, in the case of internal funding, special legislation and rules for dealing with the possible economic problems — and even possible insolvency — of the utility would have been necessary. So, the 'external way' looked safer and simpler — especially where the distant future was concerned.

V. IVANOV (Russian Federation): How long is the spent fuel from Finland's reactors going to be kept in safe storage before final disposal?

A.E. VÄÄTÄINEN (Finland): Finland's final disposal facility is due to become operational in 2020, at which time the transfer of spent fuel to it will begin. The intention is that the facility will be closed after all the spent fuel has been placed in it. According to our present plans, that should be around the end of this century, after which no monitored store with physical protection features would be needed.

V. IVANOV (Russian Federation): What do you expect to be the annual cost of storing 1 kg of spent fuel?

A.E. VÄÄTÄINEN (Finland): The total cost of the final repository for all the waste is expected to be about €1200 million. The cost per kilogram of spent fuel will depend on how much spent fuel is disposed of. Finland's recent decision to build a further power reactor should be borne in mind in this connection; there will be much more spent fuel to be disposed of than was originally envisaged.

E. WARNECKE (Germany): What is the best way of managing the financial resources being collected for future decommissioning?

C. MÜLLER-DEHN (Germany): They can be managed by the operator, by the State, by a third party appointed for the purpose by the operator and/or the State — there are many possibilities. The main thing is that managers of financial resources should be competent. The fact that the operator is under an obligation to dispose of the radioactive material associated with decommissioning is, in my view, an argument for management of the financial resources by the operator.

O. SÖDERBERG (Sweden): As dismantling and decommissioning are operations which will take place over a long period in the future, perhaps at a time when the owner of the facility no longer exists, I think that governmental management of the financial resources — as in Finland and Sweden — may be preferable.

W. IRREK (Germany): There appear to be significant differences between the various funding systems in Europe. Do these differences not cause distortions in Europe's liberalized market and, if so, should the European Union not do something about those distortions?

C. MÜLLER-DEHN (Germany): Some years ago, a number of German electricity suppliers came out against the system of internal management of financial resources for future decommissioning on the grounds that it would cause market distortion in Europe. In response, it was — rightly in my view — pointed out that the system of internal management was being implemented with regard to all companies in Europe, so there could be no market distortion. There would be market distortion in Germany if all electricity suppliers in Germany except nuclear power plant operators could manage their financial resources for decommissioning internally.

E. WARNECKE (Germany): Should the financial resources for future decommissioning be kept separate from the financial resources earmarked for current operations?

C. MÜLLER-DEHN (Germany): I do not think that is necessary. It is sufficient if all the financial resources appear in the balance sheet, with every obligation matched by the financial resources required for meeting it.

J.L. SANTIAGO (Spain): In my view, it is not very important who manages the financial resources for future decommissioning provided that there are proper controls. In our case, ENRESA is managing them, but there is a separate control commission which has established the rules under which ENRESA must operate.

In Finland and some other countries, there is no discounting. In my view, however, if you are managing the financial resources for future decommissioning well and deriving income from them, the income should be used in discounting. ENRESA does that.

R.D. WENDLING (Germany): The financial resources for future decommissioning are normally not going to be needed for a long time, so that the discount rate set today is very important from the point of view of the amount of money that will have to be collected each year in the years to come. It would be helpful if a consensus could be reached among financial experts on what a reasonable discount rate would be.

J. BARCELÓ VERNET (Spain): We have been focusing on how the financial resources for future decommissioning should be managed in countries which have such financial resources. What about countries — mainly developing ones — which do not?

D.W. REISENWEAVER (IAEA): When an incident due to poor decommissioning occurs, in addition to the suffering of the immediate victims — as, for example, in the Brazilian city of Goiânia — there is a price that has to be paid by all those engaged in peaceful applications of nuclear energy. The IAEA would welcome suggestions on how it might help countries which need to decommission facilities but cannot accumulate the necessary financial resources.

G.C. JACK (Canada): One of the slides shown by Mr. Söderberg in his oral presentation suggested that, if there were a substantial delay (for example 20 years) in the start of decommissioning, the financial resources could run out before the decommissioning was completed. How might that happen? I would have thought that, with financial resources continuing to accumulate, there would be some to spare at the end of decommissioning.

O. SÖDERBERG (Sweden): It was assumed that after 2020 the rate of return on the accumulated financial resources would be much lower than the rate expected today. In that connection, it should be borne in mind that we are talking here not about exact calculations but about indications of possible trends of which we should be aware.

V. MASSAUT (Belgium): If the financial resources for future decommissioning are controlled by the government, there is always the risk that the government will at some point decide to use them for other purposes — as I believe happened in the United Kingdom some years ago.

T. SELBY (United Kingdom): I agree, such a risk always exists. In my view, if the legislation necessary for establishing a Liabilities Management Authority in the United Kingdom materializes, successive governments will — whatever their political persuasion — feel compelled to ensure that the financial resources being accumulated for decommissioning are used for that purpose.

V. MASSAUT (Belgium): Financial resources for future decommissioning which are in a segregated fund managed by trustees would, in my opinion, be more secure.

T. SELBY (United Kingdom): That would depend on how wisely the trustees invested the financial resources.

L. GOODMAN (USA): What are you doing in the United Kingdom about estimating the costs of future decommissioning?

T. SELBY (United Kingdom): The Liabilities Management Unit has been given the task of developing a common methodology to be used by all nuclear power plant operators in estimating the costs of decommissioning their plants. The cost estimates — made in the light of expected timing and decisions regarding end states — will, in my view, have to be reviewed and probably revised from time to time before and during the decommissioning period.

O. SÖDERBERG (Sweden): In Sweden, the cost estimates are reviewed every year by the nuclear industry, which presents its findings to the Swedish Nuclear Power Inspectorate. The methodology used in making the cost estimates is also under continuous review.

I. DUMCHEV (Kazakhstan): As we have no relevant experience, we requested assistance in estimating the costs of putting the BN-350 fast reactor into safe storage from the Italian company SOGIN (Società Gestione Impianti Nucleari), the Russian Research and Development Institute for Power Engineering (NIKIET, which designed the reactor) and the Japanese Radioactive Waste Management and Nuclear Facility Decommissioning Technology Center (RANDEC). The preliminary calculations took one and a half years to complete, but the results obtained by the three organizations with their three different approaches differed by only 10–15%, so we feel that it will be possible to estimate the costs of subsequent decommissioning stages with a fairly high degree of accuracy. All the same, we believe that such cost estimates should be reviewed once or twice a year.

J.L. SANTIAGO (Spain): From Ms Väätäinen's presentation I gathered that, in Finland, if a nuclear power plant were to be shut down unexpectedly early — for safety reasons, for example — the financial resources for future decommissioning already accumulated and the securities provided to the State would, at least in theory, be sufficient to cover the decommissioning costs. What is the situation in Sweden?

O. SÖDERBERG (Sweden): Our funding system is rather similar to the Finnish one. The aim is that the financial resources necessary for future decommissioning should be accumulated during the first 25 years of operation of the nuclear power plant. Any shortfall due to the plant being shut down before the end of the 25 year period would be covered by securities. However, one can imagine circumstances under which the accumulated financial resources and the securities would not be sufficient.

E. WARNECKE (Germany): From various statements made at this conference, it seems to me that even good funding systems have their weaknesses, which may be an argument for making a start with decommissioning as soon as possible after shutdown.

O. SÖDERBERG (Sweden): I agree with you.

E. WARNECKE (Germany): Would you care to make any recommendations regarding how the financial resources for future decommissioning should be invested?

O. SÖDERBERG (Sweden): I would not care to make any recommendations, but I am happy to express my personal opinion. In Sweden, we are allowed to invest such financial resources only in State bonds, which are considered to be very safe, but I do not think that one should be afraid of investing in stocks and shares if one is investing for the really long term. In Switzerland, there is a fund for the financing of decommissioning and one for financing the final disposal of spent fuel. The resources in the former fund are invested in State bonds while those in the latter are invested largely in stocks and shares, as the final disposal of spent fuel lies much further away in time than the planned decommissioning activities. With a very long term perspective, you can sustain losses on your investments in the short term — what counts is the average return on your investments over the long term.

If you are going to use the financial resources for different purposes, you should be able to invest them in different ways. It is important that the investments be widely regarded as being safe, however, for the sake of confidence not only in the funding system but also in the entire nuclear energy policy of the country.

T. SELBY (United Kingdom): With regard to Mr. Warnecke's comment about when to start decommissioning, the policy in the United Kingdom is that decommissioning should start as soon as reasonably practicable in the light of all relevant considerations, which include financial and technical ones. The policy is currently under review, however, and may well be modified. As to investments, there are uncertainties associated not only with stocks and shares but also with State bonds and with the governmental control of funding systems. In any case, whatever funding arrangements are being considered, they should be subjected to a thorough risk assessment, and all funding decisions should be based on the findings.

I. DUMCHEV (Kazakhstan): Although we believe that one should start decommissioning nuclear facilities as soon as possible after shutdown, we have not yet really started decommissioning our BN-350 fast reactor as we do not have enough financial resources. A decommissioning fund has been established, under governmental control, but we are unable to invest any of the financial resources on the stock market.

C. MÜLLER-DEHN (Germany): In Germany, operators are free to choose between immediate dismantling and safe enclosure, which is a good thing as they can take cost effectiveness into account when deciding which to choose. In the past, the big operators — for example, E.ON Energie AG and RWE Energie AG — opted for immediate dismantling, but in the absence of a final repository for decommissioning waste they will perhaps not opt for it in the future. The cost effectiveness of immediate dismantling is less if you have to build an interim store.

As to the investment question, one must bear in mind when the financial resources will become necessary and preserve their value. At E.ON Energie AG, we go in for asset oriented investment and regularly check the values of the assets in which we have invested.

A.E. VÄÄTÄINEN (Finland): I personally think that immediate dismantling is preferable, but — as in Germany — the operators in Finland are free to choose between immediate dismantling and safe storage. TVO, which operates the Olkiluoto nuclear power plant, was planning for 30 years' safe storage before decommissioning, but the Ministry of Trade and Industry recently requested it to give serious consideration to immediate decommissioning.

T. SELBY (United Kingdom): Like Germany, the United Kingdom does not have a final repository for decommissioning and other radioactive waste — and it is unlikely to have one for many years. In order to proceed with decommissioning and cleanup, therefore, we are going to have to decide in what forms the decommissioning waste is to be stored and for what periods of time.

V. MASSAUT (Belgium): Mr. Dumchev just said that a decommissioning fund, under governmental control, had been established in Kazakhstan. How are the financial resources invested?

I. DUMCHEV (Kazakhstan): They are deposited with a government owned bank, and the interest earned is credited to the fund.

V. MASSAUT (Belgium): How long will it be before the BN-350 fast reactor is in safe storage and how long will it remain there?

I. DUMCHEV (Kazakhstan): We expect that the process of putting the reactor into safe storage will be completed by about 2012, and that the reactor will remain in safe storage for some 50 years. In the United Kingdom and Italy, with changes of government there were changes in the approach to decommissioning, with decisions in favour of decommissioning immediately. Something of that kind could happen in Kazakhstan, if sufficient financial resources had been accumulated in the meantime. At present, however, our main concern is to ensure that the BN-350 fast reactor will be absolutely safe until decommissioning starts.

P.B. WELLS (USA): What should be the role of the IAEA in helping developing countries that need to decommission nuclear facilities?

I. DUMCHEV (Kazakhstan): The IAEA has helped Kazakhstan to plan for putting the BN-350 fast reactor into safe storage, and I believe that, with the experience which it is acquiring in Eastern Europe and elsewhere, it will play an important role in connection with the planning of nuclear facility decommissioning in developing countries.

T. SELBY (United Kingdom): The G-8 and the European Union are supporting the decommissioning of nuclear facilities in various countries, and I think the IAEA should do the same to the extent that it is able, since radiation from nuclear accidents and incidents does not respect national boundaries.

O. SÖDERBERG (Sweden): I think the IAEA should promote the sharing of experience and help countries to work out funding systems that fit their particular situations.

A.E. VÄÄTÄINEN (Finland): I agree. I think that the IAEA should also, in the interests of transparency, keep in touch with the general public and the business community.

G.C. JACK (Canada): There is a risk that if a large number of nuclear facilities are put into safe storage, politicians and other non-scientists will conclude that the final disposal problem has been solved,— and the motivation to solve that problem will disappear. In my view, therefore, the IAEA should endeavour to make politicians and other non-scientists aware of the continuing need for R&D in support of the establishment of final repositories.

T. SELBY (United Kingdom): I agree. Although I am not a scientist, I do not believe that safe storage is an acceptable solution in the long term. In the United Kingdom, the establishment of a final repository has been a major issue, and as long as I am with the Liabilities Management Unit I shall do all I can to ensure that it remains one.

O. SÖDERBERG (Sweden): I also agree with Mr. Jack. Very high priority must be given to the establishment of final repositories.

# CONSIDERATION OF SOCIAL ISSUES
(Session 2.D)

**Chairperson**

**C. PAPIERELLO**
USA

# SOCIAL AND ECONOMIC ASPECTS OF THE DECOMMISSIONING OF NUCLEAR INSTALLATIONS

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**Abstract**

Many countries are facing the task of decommissioning and dismantling their commercial nuclear power plants. The three major components of a decommissioning project are the: regulatory framework, including safety regulations; technological developments and the environmental implications; and socioeconomic aspects. The first two have global, national, regional and local dimensions, but the socioeconomic impact is restricted to local environment, affecting mainly the local communities living around a nuclear power plant. These plants contribute, during their construction and operation, to the social and economic development of the region around the sites; the shut down of the reactor and decommissioning of the nuclear power plant facilities will have negative consequences on the life and economy of the local communities. The type of socioeconomic impact varies according to the phase of the dismantling project: (a) the transition period; (b) preparation for safe enclosure; (c) safe enclosure; and (d) final dismantling. Among the issues of concern are: (1) the negative impact on the local demography, resulting in a decrease in the population; (2) decrease of economic activity in the area; (3) loss of jobs (unemployment, anticipated retirement); and (4) reduction in local incomes. Additionally, success in decommissioning nuclear facilities is linked to the ability to demonstrate that the actions taken, both by the licensee and the nuclear regulatory authority, are protective of public health and the environment. Therefore, it is important to stress the need to build public confidence as a key component of the decommissioning effort. The paper analyses the socioeconomic impacts on the local communities around the site and proposes some practical recommendations to mitigate the negative socioeconomic consequences of a decommissioning project from a generic perspective. It also offers conclusions and recommendations based on the experience and information gathered on the safe termination of operation of the Spanish nuclear power plant Vandellós 1, emphasizing the aspects of the project aiming to communicate with stakeholders (i.e. local communities, municipalities and regional and national governments and institutions) and to build up their confidence.

## 1. INTRODUCTION

The decommissioning of a nuclear installation produces a social and economic impact in the area in which the facility is located, this being greater the more the area in question depends on the activities of the decommissioned facility. However, the dismantling phase cannot be separated from the overall process of decommissioning of a nuclear installation. A complete evaluation of the impact should analyse the following three phases:

— Permanent shutdown,
— Decommissioning period,
— Post-closure.

These three phases are analysed below.

## 2. PERMANENT SHUTDOWN

There are two scenarios as regards the permanent shutdown of an installation: scheduled and non-scheduled. In the first case, actions may be planned to mitigate the social and economic aspects, while in the second (non-scheduled permanent shutdown) the situation becomes more complex. In both cases the consequences are similar, but have a different degree of impact.

The social impact of decommissioning of an installation is marked by loss of employment (direct and indirect). Direct loss of employment arises from the fact that activity ceases at the installation and there is less activity during the decommissioning. Although the individual impact of this loss is not particularly high (normally there are non-traumatic methods such as early retirement and paid redundancy), the overall effect is not insignificant and may be summarized in two ways:

— Demographic slump in the area. The reduction in employment leads to the relocation of people who are no longer going to work at the installation and who have no special ties to the area. This especially affects the younger, better trained generation, which has to look for work in other places. As a result, there is a migratory effect in the opposite direction from that which occurred on construction of the facility.
— Indirect loss of employment. Not only are the activities directly related to the installation reduced (auxiliary companies, refuelling work, etc.), activities linked to the community (commerce and services) are also affected.

As can be seen in Fig. 1, in the case of dismantling of the Vandellós I nuclear power plant (NPP), where the transition period between permanent shutdown and the beginning of the decommissioning phase has lasted ten years,

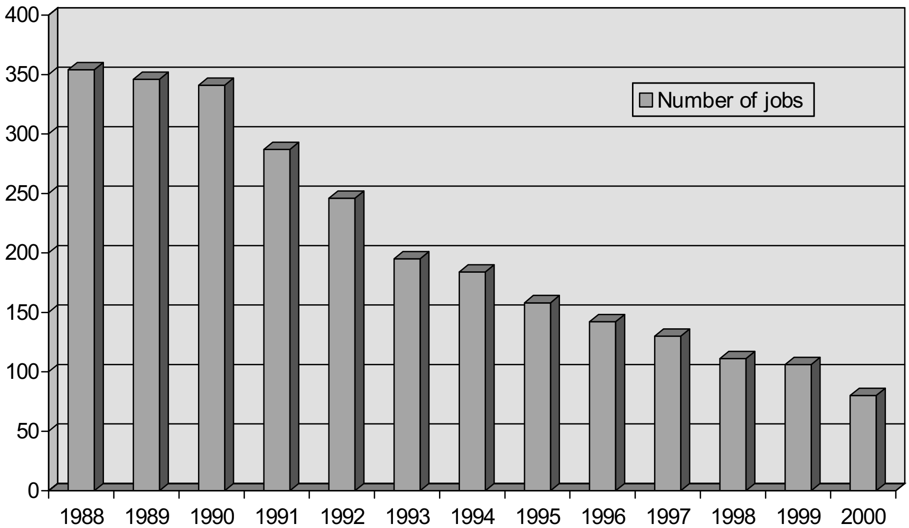


*FIG. 1. Direct loss of employment in Vandellós I.*

the direct loss of employment has meant the disappearance of almost 300 jobs in a community of some 4000 inhabitants.

The economic impact of decommissioning is closely linked to the social impact. Loss of income (due both to direct and indirect effects) has an important effect on the area of influence of the installation. This is due to the following:

— Reduction in economic activity in the municipal areas affected, caused by the disappearance or decrease of activities formerly carried out during the operation of the facility: these include services (maintenance, cleaning, subcontracting), refuelling outages and indirect activities (commercial and services).
— Reduction in revenues for the municipal administrations (tax rates and economic compensation), causing in turn a reduction in the activity of these administrations — these include lower investments and reduced activity.
— Blocking of the site for other uses, with the impossibility of promoting alternative activities.

The negative impact of decommissioning of the installation makes it preferable for the time lag between permanent shutdown and decommissioning to be as short as possible. As an example, in the case of the

Vandellós I NPP (see Fig. 2) ten years went by, this being a period of uncertainty and economic slow down in the area.

## 3. DECOMMISSIONING PERIOD

With the planning and performance of dismantling, a new stage begins, which may mean new activity for the area of influence of the nuclear installation. This does not have the characteristics of nuclear power plant construction and operation project (less time and lower costs), but for a number of years (five years in the case of dismantling of the Vandellós I NPP) it provides new impulse for the area.

The social impact of the decommissioning period is marked by the change that occurs in society compared to the era in which the nuclear power plants were built. The most noteworthy aspect of this change is the desire to access information and the need to participate in decision making affecting the area of influence.

During the phase of its approval the decommissioning project is subject to public hearings, negotiation with the local administrations and informative meetings with the media and the population of the area. This promotes participation by society and the local administrations throughout the entire process of project approval.

During the decommissioning period, and taking the Vandellós I NPP as an example, a commission (to handle information) is created, made up of representatives of the company in charge of dismantling, the administrations of the area of influence and other representative bodies. The purpose of this commission is to track the evolution of the dismantling process and receive information on it.

The following are particularly significant among the issues dealt with by the commission:

— Compliance with the conditions agreed on in the license (permit).
— Work progress, acquisition and growth of contracted personnel, etc.
— Waste management, materials accounting.
— Safety (training and accident rates) and environmental surveillance.
— Events.

The commission has proved to be a useful instrument for participation by the stakeholders in the area of influence of the dismantling project.

Also very important, in addition to this policy of communication, is the training policy, which serves not only to prepare the workers who are going to

| | | |
|---|---|---|
| OCT. | 1989 | Vandellós I Accident. |
| JUL. | 1990 | Permanent shutdown. |
| MAY | 1994 | Proposal of a decommissioning plan. |
| DEC. | 1996 | Start license procedure. |
| APR. | 1997 | License approval. |
| JAN. | 1998 | Decommissioning plan approval. |
| MAR. | 1998 | Start decommissioning phase. |
| MAR. | 1999 | CSN's authorization for dismantling and safe preparation |
| APR. | 1999 | Dismantling of radiological parts. Work start. |

*FIG. 2. The Vandellós I transition period.*

participate in dismantling but also helps to improve the knowledge and skills of people who might in the future undertake similar work in the same area. Figure 3 shows the activities carried out in the dismantling of the Vandellós I NPP, using as an example the training policy.

The economic impact during the dismantling phase is clearly positive. It cannot be compared to the activity that occurs as a result of the construction of a nuclear power plant, but it does significantly reactivate the local economy.

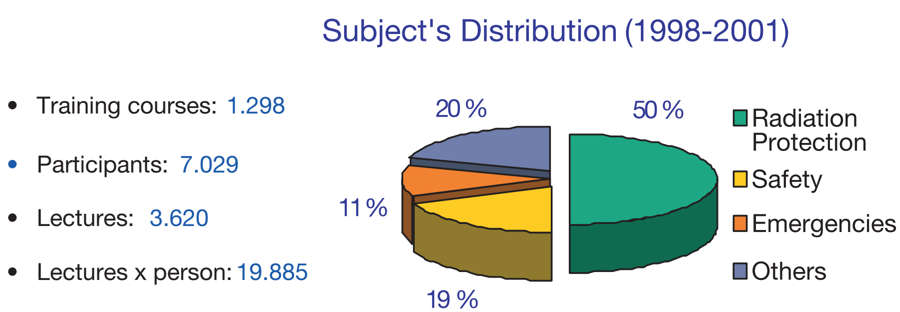


*FIG. 3. The Vandellós I training policy*

The most important economic impact is the generation of local employment, both direct and indirect. This generation of employment arises from both the direct contracting of workers and from the contracting of companies in the area.

In the case of the dismantling of the Vandellós I NPP, a total of 1800 people were contracted during the period 1998–2001, with a peak figure of 400 workers simultaneously on-site. The composition of this employment was 65% local and 35% from other areas. Table I shows the latest data on employment and on the companies that have participated in the dismantling process. Indirect employment, which is more difficult to quantify, arises from increasing activity in the area, especially in the services sector.

The other pillar supporting economic activity is the contribution made by dismantling to the local administration, evident through the following:

— Revenues from licenses and permits. Given the budget and activities involved in dismantling, these revenues are important.
— Compensation, in the form of a fee, for waste storage. In the case of the Vandellós I NPP, the period from the first part of decommissioning to final decommissioning is extended.
— Agreements with the administrations of the area to promote economic, cultural and sporting activities and investments in equipment.

In summary, the dismantling phase means an increase in economic activity and the promotion of employment and communication.

TABLE I. DATA ON EMPLOYMENT AND ON THE COMPANIES THAT HAVE PARTICIPATED IN THE DISMANTLING PROCESS

| | Local | Provincial | Remainder | Total |
|---|---|---|---|---|
| Employees (current) | 194 | | 112 | 306 |
| Companies (Nov. 1999) | 40* | 48 | 38 | 126 |

* In order to achieve this participation, a local business association was set up that acted as a go-between with those responsible for dismantling, and that allowed for participation in bidding and subcontracting processes.

## 4. POST-CLOSURE PERIOD

The completion of decommissioning means the end of the activities. All the advantages arising from having hosted a nuclear installation disappear and new economic alternatives are needed for the area to survive. The successful completion of decommissioning implies having planned for tomorrow and, therefore, having channelled the local economy towards activities at least allowing the standard of living to be maintained. Planning for the future must be based on the training of people and on the preparation of the companies and entrepreneurs in the area.

As regards training, advantage should be taken of the available resources to prepare the people participating in dismantling for their reinsertion into the job market, in posts similar to those they have been occupying. Likewise, advantage should be taken of training courses for the participation of other people in the area who do not have a job or who wish to improve their knowledge. There are three areas of training management:

— The local administrations, through agreements with other administrations (for training fund management) and with the companies responsible for dismantling (for the management of local employment), may generate job profiles that serve not only to provide work during the dismantling phase, but also offer alternatives in other sectors during and subsequent to dismantling, e.g. in construction and services.
— Universities, taking advantage of their collaboration in dismantling, may create a specialization for both teachers and students in areas requiring a high level of technology, and providing expectations for the future and for growth, e.g. the management of conventional and non-conventional wastes or environmental aspects.
— Companies, as a result of their own needs for training of the personnel working in dismantling, may promote the creation of groups of experts in a field as innovative as dismantling, thus allowing for the creation of stable jobs. Furthermore, the contracting of students and scholarship holders facilitates a professional outlook of the best trained people in the area.

As regards the preparation of companies and entrepreneurs in the area, advantage should be taken of the economic resources contributed by dismantling to the local administrations in order to promote economic activities, either through the strengthening of existing sectors (services, light industry, tourism, farming, etc.) or the creation of new activities relating to the environment or to dismantling itself.

Finally, the release of the site that the completion of dismantling leads to allows the resulting area to be used for new activities. The released site may house a wide variety of companies requiring space and services, since advantage can be taken of the infrastructure (i.e. electricity lines, water supplies, cooling systems, etc.) already existing at the site.

Consequently, the post-closure phase may be tackled with guarantees as long as the necessary efforts are first made by those responsible for dismantling and by the administrations to plan for the diversification of activities in the area of influence of the installation.

## 5. CONCLUSIONS

— Dismantling cannot be viewed separately, but should be part of a three-phase complete process: permanent shutdown, decommissioning and post-closure.
— Given the social and economic impacts that the decommissioning of a nuclear installation will have in its area of influence, it is necessary to prepare and manage an effective policy of communications allowing the entire process to be undertaken openly and with minimum social conflict.
— For the same reason, it is necessary for all stakeholders to participate effectively in the entire process of decommissioning and dismantling.
— All of the administrations involved in the process (state, regional, local, regulators, etc.) should collaborate in information related aspects, in speeding up the acquisition of licenses and permits, and in regulatory aspects in order to minimize the impact of decommissioning.
— From the moment the decision is taken to close a nuclear installation, the planning of alternative actions for the area should commence, in order to avoid or minimize the social and economic impacts that might occur.
— The lessons learned at one site should be publicized so that they may be used and improved upon by others.

# DECOMMISSIONING OF NUCLEAR FACILITIES: DISCUSSION OF SOCIAL CONSEQUENCES

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## 1. INTRODUCTION

In dealing with the subject of the decommissioning of nuclear facilities, the decommissioning of the Würgassen nuclear power station (KKW Würgassen) is used as an example. Some data and facts about the nuclear power station are presented:

— Reactor type: boiling water reactor, 670 MW (gross).
— Construction and operation:

| | |
|---|---|
| Application for licence | 1967-07-19 |
| Beginning of construction work | 1968-01-19 |
| First nuclear power generation | 1971-12-18 |
| Total power generation | 73 billion kilowatt-hours |
| Closure decision | 1995-05-29 |

— Closure and dismantling: Closed 1997-04-14, dismantling probably until 2009.

## 2. BACKGROUND TO THE DECISION TO SHUT DOWN THE WÜRGASSEN PLANT

During inspection work in 1994, cracks were found in the core shroud. Following this, the operator, PreussenElektra, spent a year examining the options of reconstructing the core shroud, which was technically feasible, or closing the nuclear power station. As a result of prevailing economic considerations, the decision was taken in May 1995 to close down the Würgassen power station — after more than 24 years of commercial power generation.

Various aspects had to be taken into consideration in order for the decision to be made about the closure options of safe containment or direct dismantling (Fig. 1). These included:

— Technical feasibility,
— Costs and economic feasibility,
— Human resource issues,
— Political issues.

In particular, the effects on the region, which was always in support of its nuclear power station, as well as human resources issues, played a major role in our decision to directly dismantle the plant.

In the case of safe containment, our activities at the location would have ended very shortly, with the relevant consequences for the region. Direct dismantling guarantees employment for over ten years after closure for approximately 150 of our staff and up to 350 external staff.

## 3. ADVANTAGES IN DETAIL

The advantages of this procedure are as follows:

— The plant-specific know-how of staff could be exploited;
— Infrastructure would be available (i.e. part of the existing systems will be used for the dismantling);
— Employment is guaranteed, making use of some of the skilled and experienced staff for more than ten years;
— Economic calculations are clear, provided licensing approval is granted in a short period of time;
— The region has time to adapt to the changed conditions (step by step job reduction in the nuclear power station, with employment of 300–350 people from external companies);
— Consequences of the closure are made less severe.

During its years of operation, the Würgassen nuclear power station was a major economic factor in this rural area. In 1994 alone, €20.8 million came into the region through wages and salaries (purchasing power), income tax and church tax. In addition to this were orders from the nuclear power station placed with companies in the area amounting to approximately €4.5 million annually, as well as approximately 30 000 overnight stays in the region's hotels and guest houses every year. In 1994, the nuclear power station employed 322 staff (Figs 2 and 3).

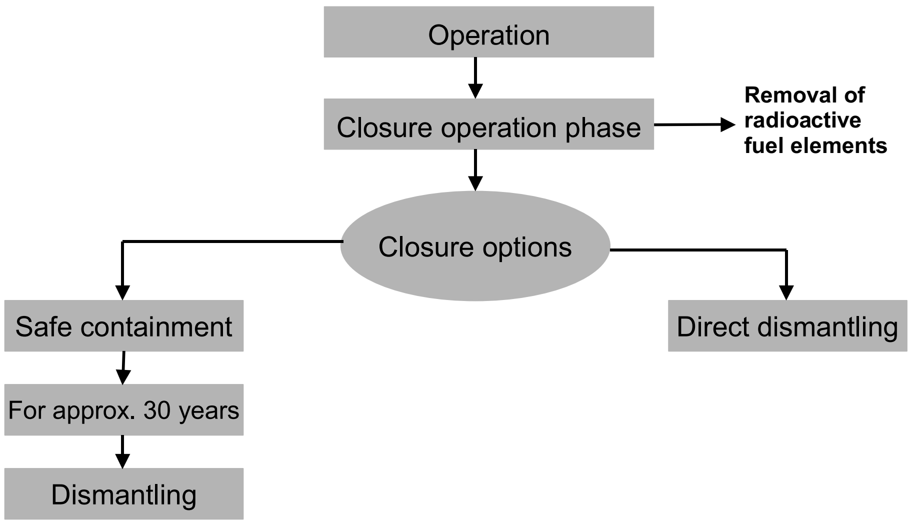


*FIG. 1. Different closure options.*

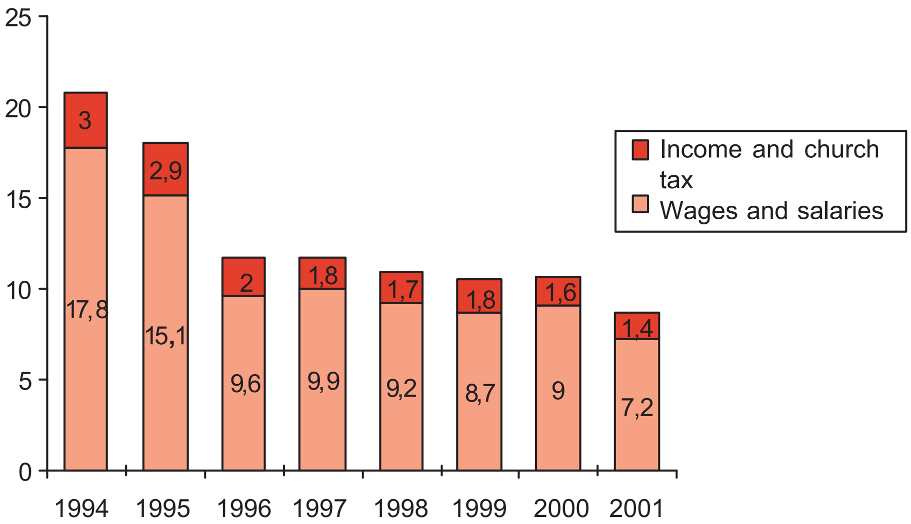


*FIG. 2. KKW Würgassen as a regional economic factor (status as of 2000-12-31; figures given in millions of euros).*

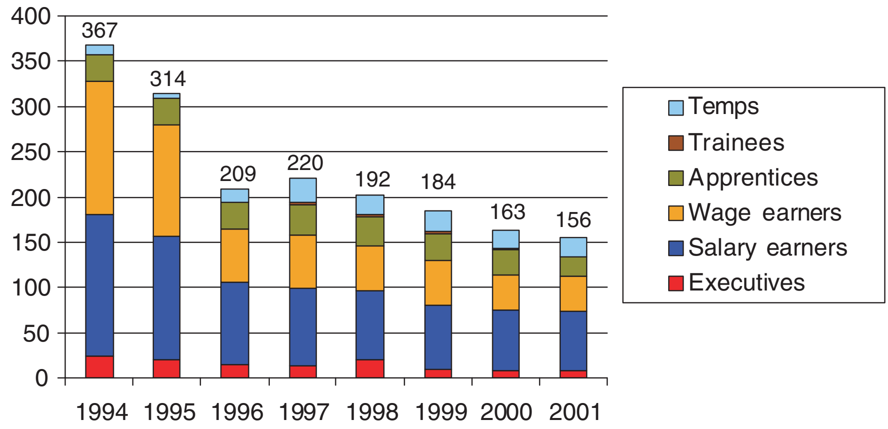


*FIG. 3. Number of staff, and breakdown by occupation, at KKW Würgassen from 1994.*

These figures speak for themselves. It is not surprising that the closure decision was welcomed by one particular side on the one hand, but led to a great deal of uncertainty in the region on the other.

The nuclear power station was well accepted in the region during its years of operation. This acceptance still exists during the dismantling process. The company has had an extensive information policy right from the very beginning. Various means of communication are used, all of which have the aim of creating transparency and seeking dialogue with the general public. For example, regular mailing campaigns are carried out in the form of letters distributed to all households in the region. These letters include information about the individual dismantling steps, disposal of various materials and other current topics of interest. In addition, the local pages of the daily newspapers are used for large advertisements containing up to date information and inviting the public to visit the information centre near the nuclear power station. Interested visitors can find information about the entire time frame of the dismantling process in an exhibition at the information centre, where lectures are also held. The dismantling work is being recorded by an internal camera team. The films can be viewed by visitors on a large screen in the information centre and are also available free of charge as a CD-ROM.

The only resistance worth mentioning came during the closure operation. During this phase, the radioactive fuel elements were removed (1996 and 1997). The resistance came, as is often the case, from opponents of nuclear power from outside the region. The direct dismantling process was supported by the parties at the local level and by the State of North-Rhine Westphalia. A pre-requisite for this process is that the fuel elements are removed. This fact was well known throughout the region — which is why Greenpeace activists received no local support.

As the dismantling of the plant will leave only ‘rabbits and grass’ in the end, local politicians are considering possibilities for the future development of the location. As early as July 1995, it was decided to form a working group made up of representatives from politics, company management and the works council of the nuclear power station, as well as the economic committee of the district council. The task set the work group was, in particular, to analyse the effects of the closure of the nuclear power station on the region and to draw up compensatory measures to create new jobs. The initial ideas of the politicians were based on the creation of new jobs directly on the site of the power station. The district council passed a resolution, for example, which stated that the construction of a successor power station on the basis of conventional or renewable energy sources, or other uses related to the power industry, was to be supported at the location of the nuclear power station.

However, since excess power station capacity actually has to be dealt with for some time, and the station site would only be available after a period of 12–15 years, the site of the power station has been ‘left out’ of further consideration of a new concept for the location.

The aim of local government is to use the time required for the dismantling process to carry out structural change in the region. In the town of Beverungen, an attempt is being made to achieve a compensatory effect by building up tourism and establishing new companies. This is making slow progress, however.

Decisive in keeping the negative effects in the region to a minimum during the dismantling process is the increase in the number of people employed from external companies (Figs 4 and 5). Only a small part of the dismantling work can be described as high-tech work that can only be carried out by special companies. For this reason, it is possible to commission local companies as suppliers or as service providers. Detailed investigation shows that the volume of orders being placed in the neighbouring districts is about the same as during the years the power station was in operation (Fig. 6). The number of overnight stays of staff from external companies in hotels and guesthouses has even increased. During the period of plant operation, such overnight stays were mainly necessary during inspection work (approximately 30 days). During dismantling work, however, it can be shown that employees from external companies require more than 300 overnight stays spread throughout the year — a rather positive development.

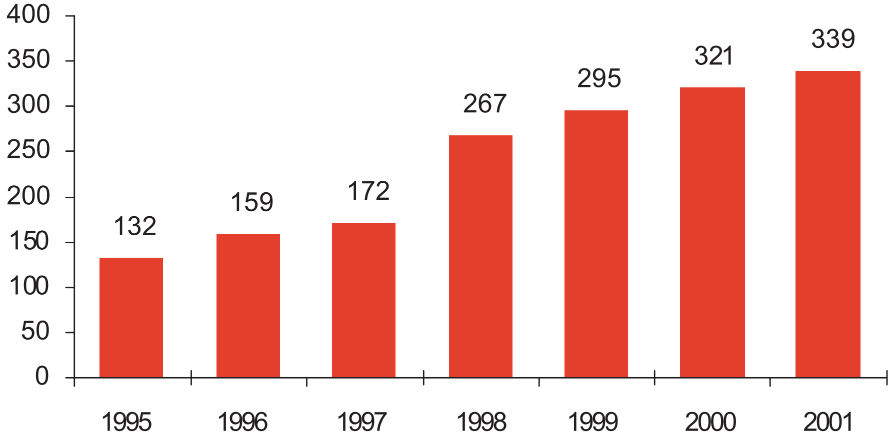


*FIG. 4. Average number of external staff at KKW Würgassen from May 1995.*

Although the effects on the region are not as dramatic as initially expected, several direct and indirect effects of the closure of the power station

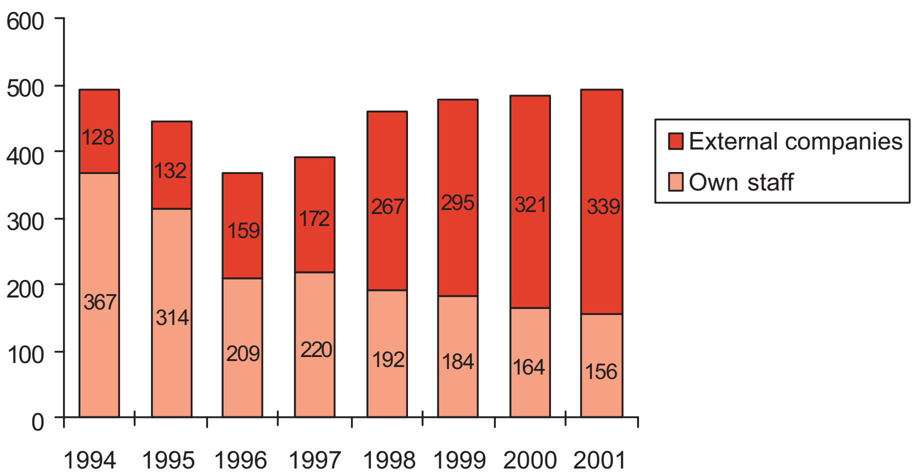


*FIG. 5. Number of staff, both own and external, at KKW Würgassen (status as of 2001-12-31).*

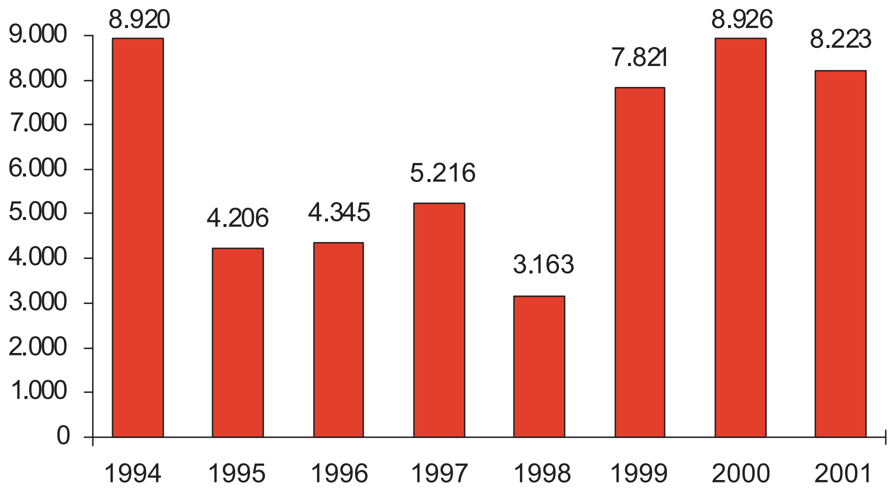


*FIG. 6. KKW Würgassen orders: overall turnover for the districts of Höxter, Holzminden and Kassel (in thousands of DM).*

can already be observed. These figures illustrate the direct and indirect effects of the closure of the power station on the town of Beverungen (Fig. 7). Due to the influx of foreign emigrants and the provision of moderately priced building land, the town of Beverungen has been able to avoid larger losses in the number of inhabitants (Figs 8 and 9) (note: different qualifications, income, etc.)

## 4. CONCLUSION

In summing up, the following points can be stated. The effects of the closure of the Würgassen plant for the location and the region are moderate so far. The massive intervention originally predicted, particularly with regard to finances and employment, has not taken place. The greatest advantage is that the direct dismantling process gives the community and the surrounding area a period of around ten years to adjust to the changed situation, counteract possible negative effects in good time and compensate for these. If this planned structural change is not carried out successfully during the dismantling phase,

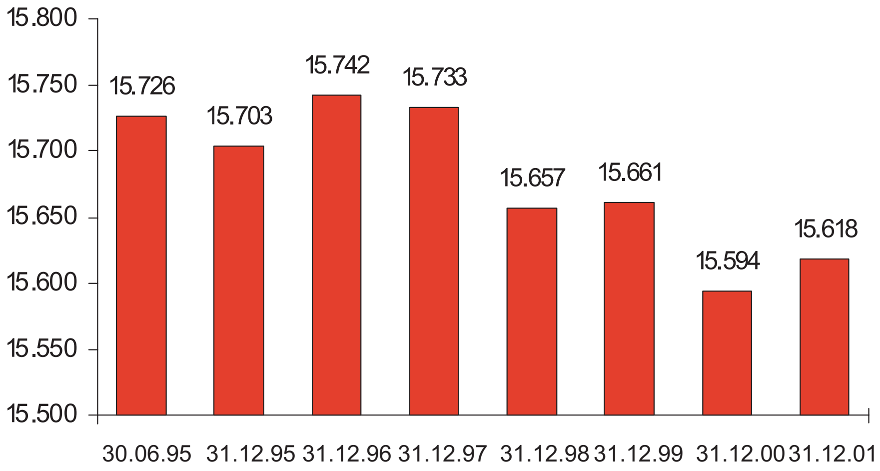


*FIG. 7. Number of inhabitants in Beverungen.*

however, it is to be expected that the negative effects in the region will become more apparent after the company has withdrawn from the region.

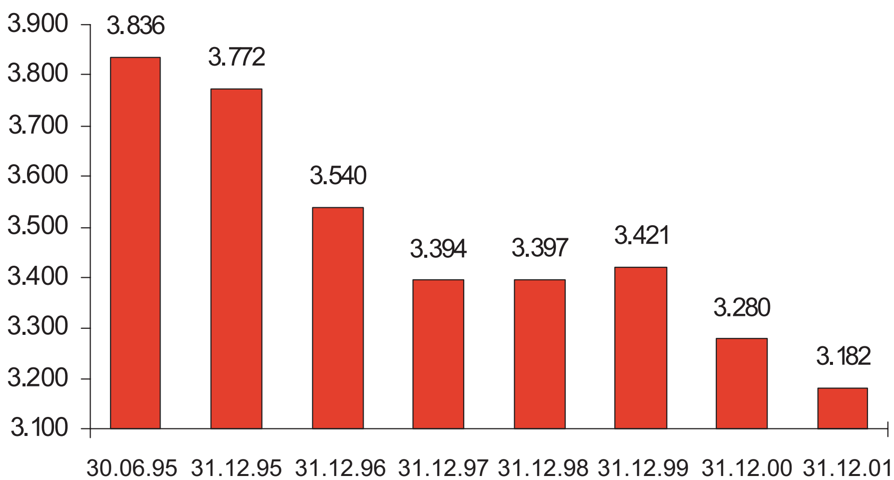


*FIG. 8. Number of employees in Beverungen subject to social insurance contributions.*

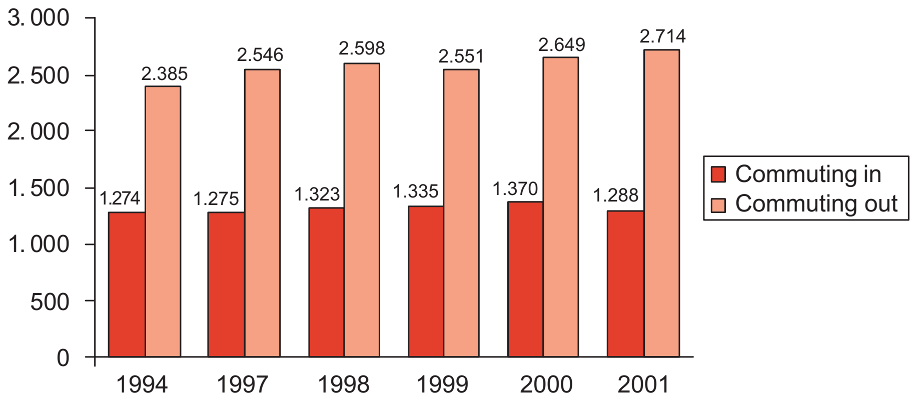


*FIG. 9. Number of commuters.*

## 5. CLOSING REMARKS

### 5.1. Cultural aspects

The figures in the charts do not reflect changes in the quality of cultural and social life in the region. Due to the transfer of well established and active members of the society to other regions of Germany, cultural and social life is suffering in some respects. The consequences of this situation have not yet been investigated thoroughly. But it can be stated so far that this seems to be developing into a special challenge for the regional and municipal authorities and politicians that needs to be dealt with.

## PANEL DISCUSSION

## CONSIDERATION OF SOCIAL ISSUES

*Chairperson:* **C. Paperiello** (United Kingdom)

*Members:* **A. Dainius** (Lithuania)
**V.I. Kholosha** (Ukraine)
**L. Milam** (United States of America)

**Statement**

# SOCIAL ISSUES INVOLVED IN THE DECOMMISSIONING OF THE IGNALINA NUCLEAR POWER PLANT

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The Ignalina Nuclear Power Plant (INPP) comprises two RBMK-1500 channel type, light water cooled, graphite moderated boiling water reactors. The design capacity is 4800 MW(th), 300 MW(e). Each reactor contains 1661 fuel channels and has two cooling loops. Unit 1 has been in operation from 1983, while Unit 2 started in 1987. The plant has 4500 employees.

The national legal structure governing decommissioning comprises the following:

— National energy strategy of 1999, which includes a decision on Unit 1 of INPP;
— Law on decommissioning of Unit 1, passed on 2 May 2000;
— National energy strategy of 10 October 2002, which includes a decision on Unit 2;
— Decommissioning strategy as part of the final decommissioning plan;
— Programme on decommissioning of Unit 1;
— Law on social guarantees (under adoption).

Some of the major tasks with regard to INPP include: ensuring the safe operation of the plant until final shutdown of Unit 2; organizing the decommissioning process in the most safe and economical manner; enhancing the motivation of the staff; and enhancing safety culture.

The following are some of the main problems in the region of the NPP: it is a one enterprise region; up to 80% of the population is Russian speaking, with very weak integration into Lithuanian society; the geographical position of the region is unfavourable; and there is a low level of entrepreneurship.

Major concerns of the public cover the price of electricity after closure of the NPP, whether Lithuania will retain its nuclear generation capacity, and emissions into the atmosphere from the use of fossil fuels. More localized concerns include the availability of jobs in the region (with the considerable benefits that they bring) after closure of the NPP, and the availability of social guarantees.

There has also been an attempt to involve the public, specifically through public discussions, encouraging the involvement of the local population and non-governmental organizations; frequent visits to central institutions; and implementation of measures for business development in the region.

A range of measures, both general and specific, has been taken or planned to minimize the impact of the decommissioning. General measures include: implementation of business support schemes; increased labour exchange; social monitoring. More specific measures cover: characterization of the site and preparation of 'business attraction maps'; public and private discussions with potential investors; and drawing up of attractive State support schemes for business development of the region.

**Statement**

# CLOSING OF THE CHERNOBYL NUCLEAR POWER PLANT: SOCIAL ASPECTS

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## 1. HISTORICAL DATA ON THE CHERNOBYL NUCLEAR POWER PLANT (NPP)

Construction started in 1970. Reactor Unit 1 was put into operation in 1977 and shut down in 1996; Unit 2 in 1978 and shut down in 1991; Unit 3 in 1981 and shut down in 2000. Unit 4 was put into operation in 1983 and was destroyed in 1986 due to the Chernobyl catastrophe. The construction of Units 5 and 6 was left unfinished.

Upto 26 April 1986, the Chernobyl NPP had generated 150.2 billion kW·h. After the accident the plant generated 158.6 billion kW·h. Total output reached 308.8 billion kW·h. On 15 December 2000, Ukraine demonstrated its good will by permanently closing the Chernobyl NPP prior to exhausting the planned resources, and is decommissioning the nuclear facility at present.

## 2. PUBLIC CONCERNS ASSOCIATED WITH THE PERMANENT CLOSING OF A NUCLEAR FACILITY

There are two aspects to the closing of a nuclear facility:

— Safe shutdown of the nuclear facility and conversion of the ‘shelter’ into an ecologically safe system (technical–economic aspect);
— Minimization of the social impact of the closing of the facility (social–economic aspect).

To minimize the impact of the closing of the facility on the local population, legislation has been passed as follows:

— The law of Ukraine, which includes general principles of the further operation and decommissioning of the Chernobyl NPP and conversion of the destroyed Unit 4 into an ecologically safe system;
— Plan of the Chernobyl NPP's decommissioning and programme for the safe maintenance of the 'shelter'.
— Programme of establishing extra jobs for Chernobyl NPP personnel and for the residents of the town of Slavutich.

The Ukrainian legislation provides a number of compensating measures to minimize the impact of the closing of the nuclear facility on the local population. The most important are:

— Subsidies from the State budget for the 'depressed' territory (the town of Slavutich) and establishment of a special economic zone;
— Social guarantees for those who work at the Chernobyl NPP and those released due to its shutdown;
— A programme to establish extra jobs.

The social guarantees for those who work at the Chernobyl NPP and those released due to its shutdown include the following:

— *For those who work:*
  The salary cannot be less than the average salary of the staff of the operating nuclear facilities, with all the fringe benefits provided by Ukrainian law.
— *For those who are released:*
  - Social security and insurance in accordance with Ukrainian legislation;
  - Privileged job placement through State employment agencies;
  - Medical care provided at the medical institutions of the nuclear facility at which the person used to work;
  - In case the working contract is terminated, dismissal pay equal to an average monthly salary;
  - A one time gratuity equal to 50 tax-free minimum wages, provided that the person changes the place of residence;
  - The right to retire two years prior to the legitimate retirement age and the right to receive specially granted, larger pensions;
  - Additional monthly payments to non-working pensioners;
  - More privileged (compared with other population groups) welfare conditions.

## 3. MAIN FEATURES OF THE PROGRAMME FOR ESTABLISHMENT OF EXTRA JOBS

The aim of this programme is to ensure employment for Chernobyl NPP personnel and for the residents of the town of Slavutich. To achieve this aim, it is planned that:

- Extra jobs in and beyond the bounds of Slavutich should be established;
- The infrastructure of the town should be kept and improved;
- Assistance in job placement of the released NPP employees should be provided.

The present conditions of employment of the residents of the town are characterized by:

- Lack of balance between the economic sectors and the residents' employment; job demand and supply imbalance; growing disparity in salaries and income between different groups of residents;
- Large number of people able to work, but a lack of jobs (especially highly qualified and well paid positions);
- Staff reductions at the Chernobyl NPP (well paid jobs) and an absence of corresponding demand for workers, not only in Slavutich but throughout the entire region.

The programme is planned for the eight year period 2001–2008, and will provide for 3877 jobs. To implement the programme, approximately \$60 million needs to be invested. Both State investment and investment in the framework of a special economic zone are provided to implement the programme.

## 4. CONCLUSION

The shutdown and decommissioning of nuclear facilities creates not only technical but also complicated social problems. To solve these problems successfully, public understanding and State support are essential.

**Statement**

**L. Milam**
Mayor, City of Idaho Falls,
Idaho, United States of America
E-mail: mayor@ci.idaho-falls.id.us

I am most pleased to be here today, and to join with you in discussions of these important issues. I serve as the Mayor of Idaho Falls, Idaho, host city to the Idaho National Engineering and Environmental Laboratory (INEEL). Established more than 50 years ago, INEEL's historical mission was to support development of many designs, systems, codes and safety features for nuclear power facilities around the world. It has also been a disposal site for radioactive and hazardous wastes, particularly those wastes associated with the US nuclear weapons programmes and the United States Navy's nuclear ships. As a result, we as a community have a compelling interest in the topics of this conference.

There are many public concerns when a nuclear facility closure is announced. The point that I would like to make today is that such an announcement should not come as unexpected news to the local communities. Communication between the operators of the facility and the local communities should be ongoing and should be an established function long before closure is anticipated to occur.

Locally elected and appointed officials are a direct route for involving local businesses and regulatory bodies, and for providing emergency services, long term document control, future land use planning, security and other needed services. Often, administering agencies or commercial entities do not contemplate closure until near the end of the life of the project. I would suggest that closure should be considered from the beginning regardless of what will happen after a facility is closed.

Facility closure could result in facility reuse or complete dismantlement. If a facility is to be dismantled, environmental contamination must be addressed to reduce risks to humans and the environment. If it is possible to reduce contamination to acceptable levels, a wide range of land uses may be possible. If not, provisions for long term stewardship must be made. Institutional controls restricting access to contaminated areas may be necessary to manage risks. In the case of long lived radioactivity, it is conceivable that contamination will outlast the entity that was originally responsible for the facility, and the community must take responsibility for ensuring that future generations know what occurred at the site and how it must be managed to be productive.

All of these possible outcomes provide opportunities for involving the community in planning for facility closure. If facility reuse is possible, the public can be engaged in identifying appropriate uses and in envisioning a way the facility could contribute positively to the future of the community. If effective cleanup is possible, the public could be involved in helping to define acceptable land uses. If dismantlement is preferred, the community can help set cleanup standards for addressing residual contamination. If cleanup adequate to allow unrestricted reuse is not possible, then the community must be involved in planning to offer safeguards to the broader community for many years to come. So, regardless of the nature of plans for post-closure, there are ways that the community can be involved in planning, which will help a community accept changes that cannot be avoided.

Establishing partnerships and providing access to information is not only important, it is crucial. Early discussions can lay the groundwork for understanding and acceptance. In cases where local government will be involved in the implementation of any of the factors involved in closure, monitoring, or provision of services, that interaction must be in a formal capacity. Adequate notice, technical capability and funding for local government responsibilities will need to be provided. Some of the issues that should be included in these ongoing discussions include the following.

Changes in employment and funding levels, whether for a commercial power plant or a government programme. Communities need to plan for social and economic impacts that will occur. Some of these impacts will surface well before closure, as workers become concerned about their futures and local businesses anticipate a downturn in their economic fortunes. Work force retraining and long term health care coverage may be appropriate.

Future land use plans, with provision for local involvement in the selection of cleanup remedies and a clear understanding of environmental restrictions on land that may be released from ownership of the controlling entity. While total cleanup may not be reasonably expected, the residual contamination and restrictions on future use must be understood and accepted by the local communities.

Documentation in a sustainable and secure format, in order to protect workers, the public and the environment, must be accessible to parties that will be responsible in the future. This documentation must be updated to reflect monitoring of conditions, or as changes in regulations occur.

Funding for adequate closure activities, for long term monitoring, and for necessary actions in the future needs to be ensured. This life-cycle funding needs to be guaranteed, in a trust fund or other fiduciary mechanism, so that a future owner or public entity is not left with an unanticipated and unwarranted cost.

Security arrangements need to be anticipated and agreed upon with local entities. This is particularly important because local governments are frequently the ‘first responders’ to incidents on or near the facility during its operational phases; that role will continue or be expanded upon post-closure. In the USA, as in many other countries, emergency services, such as fire, medical and police response, are traditionally the responsibility of local governments. The health and safety of the public as well as the emergency responders must be protected by advance knowledge of the particular problems that may arise from fire, intrusion, seismic activity, severe weather conditions, etc.

If these clear lines of communication have been established, if local entities are accepted as partners in the planning cycle, if provision for post-closure responsibilities has been established, and if funding has been identified, public acceptance problems that have been identified in the past may not occur in the future.

**Panel Discussion**

## CONSIDERATION OF SOCIAL ISSUES
## Session 2.D

S.A.B. KUTAS (Lithuania): Mr. Barceló Vernet mentioned a commission established for the purpose of tracking the dismantling of the Vandellós-1 reactor. I should be interested in hearing more about that commission.

J. BARCELÓ VERNET (Spain): The commission has been meeting two to four times a year as originally envisaged. There have been no unusual events necessitating additional meetings. Thanks in large part to the commission, there have been no disputes between the company in charge of dismantling and the representatives of the local communities. All current issues have been discussed very openly at the commission's meetings, at which there has been no lack of information — information which has been reaching all those interested in receiving it.

L.W. CAMPER (USA): Has there been a local citizens' group active at the Vandellós site trying, for example, to influence what the end state of the site will be?

J. BARCELÓ VERNET (Spain): No. There was just one public hearing, before the decommissioning project started. The opinions of local citizens have been conveyed largely through the commission that I was just talking about.

I would mention that the mayors of towns in those parts of Spain where there are nuclear power plants are together lobbying for greater local public involvement — on the basis of more information — in the taking of decisions connected with plant operations and ultimately with decommissioning, especially decisions with a bearing on safety.

P.B. WELLS (USA): Further to Mr. Camper's question, was there no public participation in the decision making process connected with the decommissioning of Vandellós-1?

J. BARCELÓ VERNET (Spain): Not in the way that you are accustomed to in the USA — a more open society, where local citizens tend to regard the site as 'their property' and therefore to interest themselves in the details of the use to which it will be put. In Europe, public participation is directed more towards ensuring that the decommissioning project is implemented in such a manner that social problems are minimized.

O. SÖDERBERG (Sweden): In the case of the Würgassen Nuclear Power Plant, did local politicians make any demands of the operating company regarding the local situation in the region after plant shutdown?

P. UHLMANN (Germany): Yes, they did initially, but we in the operating company made it clear to them that, while the company would inform people in the region about what was happening, its main concern would be for its own employees and that planning for the time after the end of nuclear power generation in the region was a task for the politicians — not for the company.

G.F. BISSMARCK (Sweden): In the light of subsequent experience, does your company consider that its decision to embark on immediate dismantling of the Würgassen nuclear power plant was the right decision?

P. UHLMANN (Germany): Yes, it does. Immediate dismantling is giving the local communities some ten years in which to adjust to the end of nuclear power generation in the region.

G.F. BISSMARCK (Sweden): I should like to ask Mr. Barceló Vernet whether there are things which were not done and which, in his view, should have been done in connection with the shutdown of the Vandellós-1 reactor.

J. BARCELÓ VERNET (Spain): In my view, more should have been done to prepare the local population for the shutdown, although admittedly the shutdown had not been planned but was decided upon following an accident. What one should do generally during the operation of a nuclear power plant is try to ensure that the local economy, while benefiting from the plant's existence, is sufficiently diversified not to be too dependent on it.

J.T. GREEVES (USA): I should be interested to know whether any utilities have thought of co-locating a nuclear power plant and a conventional power plant on a single site. Local communities might accept a nuclear power plant on a site if they knew that a conventional one was going to be built there as well, their hope being that, if the nuclear power plant had to shut down for some reason, they would not lose everything — the conventional power plant would still be there.

J. BARCELÓ VERNET (Spain): I do not know whether any utilities have thought of that or what the reaction of local communities would be. With regard to the reaction of local communities, I would mention that, while there was virtually no opposition to the construction of Spain's first nuclear power reactors and little opposition to the construction of later ones, there is considerable opposition to the idea of building a conventional power plant with combined-cycle gas turbines on the site becoming available after the decommissioning of Vandellós-1. If the opposition is successful, I hope that Spain's offer to host the International Thermonuclear Experimental Reactor (ITER) at the site will be accepted and that there will not be too much opposition to the construction of ITER.

K. SCHIFFER (Germany): Regarding the comment just made by Mr. Greeves, in Germany most sites are suitable for only one power plant and it is difficult to obtain licences to build nuclear power plants at the moment. Moreover, at present we do not have a shortage of electricity generating capacity

— in any case, decisions to build additional capacity are taken in the light of many factors.

I should be interested in hearing about the public outreach activities associated with the decommissioning of Vandellós-1.

A. RODRÍGUEZ (Spain): There is a visitor's centre at the site, with five guides and a technician. Also, we publish information material, much of which is distributed to the local communities, and organize — about twice a year — meetings for media representatives. The costs are not very significant compared with the total cost of the decommissioning project.

P.A. COLGAN (Ireland): When a largely rural community loses a major employer, the social and economic effects are much the same whether the employer produced electricity or, say, manufactured cars. A great deal of experience in helping to deal with the effects of the closure of conventional enterprises exists and, in my view, the nuclear industry should draw on that experience rather than trying to re-invent the wheel.

J. BARCELÓ VERNET (Spain): I agree that the social effects are much the same, but the loss of tax revenues is likely to be greater if it is a nuclear power plant that has been shut down.

P.A. COLGAN (Ireland): How much worse would things have been if Vandellós-2 had not continued operating?

J. BARCELÓ VERNET (Spain): The continued operation of Vandellos-2 has been a great help. Thanks to the resulting revenues, the local communities were able to offer jobs to about 100 Vandellós-1 employees. Having a number of power reactors starting up and later closing down at different times is better from a social and economic point of view than having just one power reactor, but in my view it is better still to have diversification — with a variety of major employers over and above the nuclear electricity generator.

R.D. WENDLING (Germany): I imagine that it is difficult for an engineer who has for many years been, say, in charge of maintaining the coolant system of a power reactor to switch to dismantling that coolant system. Have there been problems of motivation during dismantling at Würgassen?

P. UHLMANN (Germany): No, there have been no motivation problems. Such people saw that they still had some ten years of employment ahead — now in dismantling — and quickly adjusted to the new situation.

L. WARMING (Denmark): What about Würgassen employees who did not wish to become involved in dismantling?

P. UHLMANN (Germany): Most of those who were well qualified and young enough moved to other power plants operated by our company.

G.F. BISSMARCK (Sweden): What did the Ignalina nuclear power plant employees and the general public in Lithuania feel when told by the European Union that the plant was unsafe and should therefore be shut down?

A. DAINIUS (Lithuania): They felt that the decision to shut down the plant was a purely political decision. No plant — nuclear, chemical or other — is 100% safe.

L. WARMING (Denmark): How have employees at the Ignalina nuclear power plant reacted to the idea of becoming involved in decommissioning?

A. DAINIUS (Lithuania): We are finding it difficult to convince highly qualified employees that decommissioning can be a prestigious activity and that they will find enough work commensurate with their qualifications. I do not foresee major problems with people such as maintenance personnel.

V.I. KHOLOSHA (Ukraine): Not all operating personnel are people who can be successfully trained to undertake decommissioning tasks; in particular, the attitudes necessary for operating a plant differ from those necessary for decommissioning it. Ideally, the operating personnel of a nuclear power plant that has been shut down should be transferred to still operating plants, but in Ukraine all the operating nuclear power plants are fully staffed, so that the scope for transferring people is very limited.

G.F. BISSMARCK (Sweden): In southern Sweden, where the Barsebäck nuclear power plant is located, the situation is very different from the situation in most parts of the world where nuclear power plants are being shut down. There is strong industrial growth in the region, especially since the opening of the bridge linking it with Copenhagen, and the highly skilled members of the operating staff of the Barsebäck B-1 reactor could have found other jobs there without even moving house. It was therefore considered necessary to give them employment guarantees in order to retain them after the decision to shut down the reactor had been taken.

A. DAINIUS (Lithuania): For almost a year we have been discussing the question of a law on social guarantees for people working at the Ignalina nuclear power plant. The discussions are quite tough, but I hope that a law will be passed before the end of this year or early next year.

V. ŠTEFULA (Slovakia): With regard to decommissioning at the Bohunice site, the mayor of the town of Bohunice was for a long time the leader of the opposition to the construction of new plants at the site — and skilfully secured many concessions for the town in return for agreement to their construction. He is now leading the opposition to decommissioning at the site.

L. MILAM (USA): As a mayor, I have strongly supported the Idaho National Engineering and Environmental Laboratory (INEEL) at Idaho Falls as there were many other towns interested in hosting such institutions. In the mid-1990s there was a big reduction in the INEEL workforce. In order to reduce the workforce to the level considered appropriate without forced layoffs, INEEL contractors offered early retirement incentives and retraining and relocation support. By doing so, they lost a number of very skilled people whom they would have done well to retain. Consequently, they considered the skill mix that would be needed in the future and then provided retirement incentives and so on only for people working in those areas where the level of activity was declining, rather than across the board.

S.A.B. KUTAS (Lithuania): Are there in Spain and Germany legally prescribed social guarantees, such as early retirement provisions, for nuclear power plant workers, as opposed to social provisions arranged by the plant operator on a voluntary basis?

J. BARCELÓ VERNET (Spain): In Spain there are legally prescribed social guarantees relating to all sectors, not just the nuclear sector.

P. UHLMANN (Germany): The situation is similar in Germany.

D.W. REISENWEAVER (IAEA): The IAEA is developing decommissioning standards and guides with the help of outside technical experts. I should be interested in hearing views about how it might involve non-technical people in the development of such standards and guides.

L. MILAM (USA): The IAEA should perhaps seek out people in communities where the expected serious social and economic effects of nuclear power plant shutdowns has not materialized. In Idaho Falls, the expected serious social and economic effects of drastically reducing INEEL's workforce did not materialize largely thanks to the fact that the Department of Energy gave us ample warning of what was going to happen. The local authorities and the local private sector thus had time to attract new businesses to the Idaho Falls area with the help of an economic development organization which they established soon after they learned what was going to happen.

S. BARANOVSKY (Russian Federation): In my country, the IAEA should seek the non-technical people it needs among those engaged in public outreach — not public relations — activities in connection with the decommissioning of nuclear facilities. Public relations activities in connection with decommissioning are unidirectional, from the top down. Public outreach activities, pursued by organizations like Green Cross Russia, are a two way process. The organizations try not only to provide objective information to ordinary people but also try to bring ordinary people's reactions to that information to the attention of institutions like, say, MINATOM — and to obtain from those institutions a clear response which they can then pass on to the ordinary people. Such public outreach organizations make use of individuals who enjoy the respect of ordinary people and are independent of the authorities and the nuclear industry.

K. SCHIFFER (Germany): I should like to ask Ms Milam whether she would treat a proposal to construct a nuclear facility in her community any differently from a proposal to construct, say, a chemical plant.

L. MILAM (USA): Each kind of facility — nuclear, chemical or whatever — has its own set of potential problems, and the potential problems associated with nuclear facilities have been in many cases perceived rather than real. I would focus more on the potential benefits in terms of, for example, job creation and diversification of the local economy, taking into account factors such as the skills available within the community and the ability of the community's housing, schooling and transport infrastructure to cope with an influx of new residents.

T. ISHIKURA (Japan): In my view, there are going to be widespread problems due to the large amounts of concrete remaining after nuclear power plant decommissioning; local communities will refuse to accept the concrete because their landfill sites cannot accommodate it. The solution which I propose is recycling of the concrete within the nuclear power sector, the necessary technology for which already exists.

J. BARCELÓ VERNET (Spain): At Vandellós, dismantling created spaces where concrete material could be stored after any necessary decontamination. The local community had no problem with the concrete being retained at the site.

L.W. CAMPER (USA): In the USA, the Federal Government establishes site cleanup standards. I should like to know what Ms Milam considers to be a reasonable process whereby a local community can decide, on the basis of those standards, the level to which a particular site should be cleaned up.

L. MILAM (USA): I think the local community should consider the use to which the site is going to be put after cleanup. Perhaps it need not press for cleanup to a green field level if, say, a manufacturing plant is to be built on the site — a brown field level will suffice, as there are not going to be any homes, schools or vegetable gardens there. The citizens advisory board on which I have served has on a couple of occasions advocated less radical cleanup than that proposed, and its views were accepted and a lot of money saved.

# CRITERIA FOR REMOVAL OF CONTROLS

(Session 2.E)

**Chairperson**

**J.R. Cooper**
United Kingdom

# INTERNATIONAL CRITERIA FOR THE TERMINATION OF PRACTICES: RELEASE OF MATERIALS AND SITES FROM REGULATORY CONTROL

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**Abstract**

Important issues related to the decommissioning of nuclear facilities, which are not completely resolved, concern the establishment of an agreed international safety policy for deciding upon the release of materials, buildings and sites from regulatory control. Various approaches are being adopted in affected countries but, as yet, there is no well accepted common international approach. The paper summarizes the current international position with regard to establishing such criteria and indicates the areas where guidance remains to be developed at the international level. Proposals are made for a regulatory scheme which would allow the coherence of the overall radiation protection system to be maintained.

## 1. INTRODUCTION

An increasing number of nuclear facilities worldwide are reaching the end of their useful lives and there is a need for generally agreed procedures for removing them from regulatory control. The procedures should allow for the safe closure and dismantling of facilities, for the reuse and disposal of the resulting materials and for the return of the sites to unregulated use. Such procedures are described in IAEA safety standards covering the decommissioning of facilities [1–3]. An important element, not completely resolved, is the safety policy governing the release of materials and sites from regulatory control. This paper summarizes the current international position with regard to such criteria and indicates the areas where guidance remains to be developed at the international level. Proposals are made for a regulatory scheme which would allow the coherence of the overall radiation protection system to be maintained. This paper deals only with radiological criteria for the termination of practices. It does not address situations where the environment has been contaminated as a result of uncontrolled events and the relevant radiological protection concept of intervention.

## 2. INTERNATIONAL SYSTEM FOR RADIATION PROTECTION OF THE PUBLIC

### 2.1. General principles

The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) [4], are based upon the recommendations of the International Commission on Radiological Protection (ICRP), and they set out the principles for the protection of workers and the public from ionizing radiation.

According to the BSS, practices* which involve the use of ionizing radiation should be notified to the national Regulatory Authority and, where appropriate, the practice should be authorized by the Regulatory Authority, unless it can be exempted from regulatory control. At some stage during the operation of the practice, radiation sources which are part of the practice but which no longer constitute a significant risk to the health may be released from control (or cleared).

The international system for radiation protection is prescribed in the BSS. It applies to all practices that involve exposure of persons to ionizing radiation. In outline, it requires that practices, and sources within practices, should be:

— **Justified**. That is, the practice should produce a positive net benefit in terms of its effects on society.
— **Optimized.** Exposures to ionizing radiation and their likelihood should be as low as reasonably achievable (ALARA), economic and social factors being taken into account.
— **Risks** to individuals should be limited. Through the application of dose limits.

The optimization of protection and safety measures associated with any particular source within a practice is subject to dose constraints to ensure that the cumulative doses to individuals from all sources, both now and in the future, do not exceed the dose limit.

The international dose limits for members of the public are: an effective dose of 1mSv in a year and, in special circumstances, 5 mSv in a single year, provided that the average dose over five consecutive years does not exceed

* A practice is any human activity that introduces additional sources of exposure or exposure pathways or extends exposure to additional people or modifies the network of exposure pathways from exiting sources, so as to increase the exposure or the likelihood of exposure of people or the number of people exposed.

1 mSv per year. In addition, dose equivalents to the lens of the eye and to the skin are limited to 15 mSv and 50 mSv in a year, respectively.

The dose constraint is an assigned fraction of the dose limit. Current international guidance is that it should not exceed 0.3 mSv in a year for any single source of exposure [5, 6]. The scheme for the limitation of radiation doses to the public from a single source is shown in Fig. 1.

### 2.2. Principles for exemption from regulatory control

The principles for the exemption of practices and sources within practices from regulatory control were first established in IAEA Safety Series No. 89 in 1988 [7] and were subsequently adopted, with minor modifications, in the BSS. Practices and sources may be exempted from the requirements of the BSS,

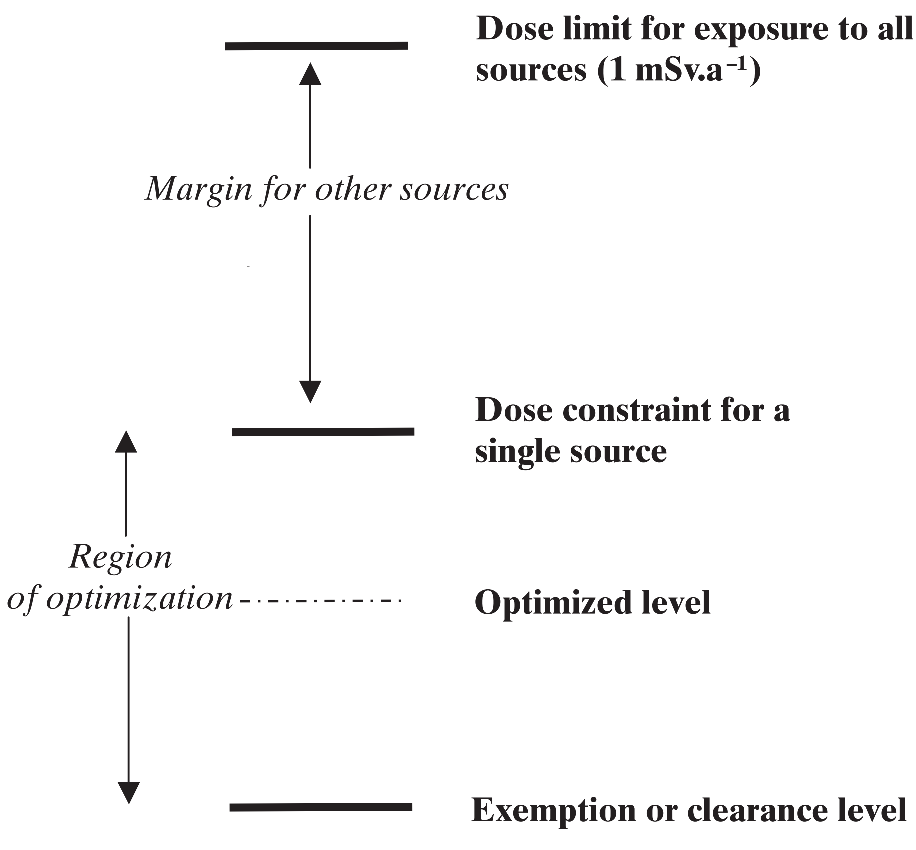


*FIG. 1. Scheme for the limitation of public dose.*

including those for notification and authorization, if the Regulatory Authority is satisfied that the sources meet the exemption criteria.

The general principles for exemption are that the:

(a) Radiation risks to individuals caused by the exempted practice or source be sufficiently low as to be of no regulatory concern;
(b) Collective radiological impact of the exempted practice or source be sufficiently low as not to warrant regulatory control under the prevailing circumstances;
(c) Exempted practices and sources be inherently safe, with no appreciable likelihood of scenarios that could lead to failure to meet the criteria in (a) and (b).

A practice or a source within a practice may be exempted without further consideration provided that the following criteria are met in all feasible situations:

(1) The effective dose expected to be incurred by any member of the public due to the exempted practice or source is of the order of 10 μSv or less in a year;
(2) Either the collective effective dose committed by one year of performance of the practice is no more than about 1 man·Sv, or an assessment for the optimization of protection shows that exemption is the optimum option.

### 2.3. Control of discharges to the environment

The BSS provides specific guidance on the control of radioactive discharges to the environment. Discharges should be controlled so that radiation doses to potentially exposed persons in the environment are appropriately limited. Exposures due to specific sources of discharge should be limited so that they are within the dose constraint. In addition, the radiation protection of members of the public should be optimized, that is, radiation doses to individuals and to the population as a whole should be kept ALARA. This involves consideration of the health benefits from dose reduction and the costs of achieving it. This protection strategy is broadly consistent with the general scheme set out in Fig. 1. The Regulatory Authority should set a discharge limit to be complied with by the operator of the source of discharge. The authorized discharge limit should be set taking account of the radiation protection considerations outlined above, together with consideration of any relevant operational factors relevant to the source of discharge.

### 2.4. Release of materials and sites from regulatory control

#### *2.4.1. Materials*

Sources, including substances, materials and objects within notified or authorized practices may be released from further requirements of the BSS subject to compliance with clearance levels approved by the Regulatory Authority. The clearance levels should be defined by the Regulatory Authority on the basis of the criteria specified in the BSS (and in Section 2.2. above) for exemption. Thus, the principles and basic radiological criteria for establishing clearance levels are well established internationally [4, 7].

The values of clearance levels, expressed in terms of activity concentration (Bq/g) or surface activity concentration (Bq/cm$^2$), based on the radiological criteria for exemption, have been published at the international level by the European Commission [8]. However, international consensus on clearance levels has proved to be difficult to obtain because of different national regulatory policies related to the control of slightly contaminated materials and, as yet, no IAEA document at the level of a safety standard has been issued on the subject of clearance levels.

#### *2.4.2. Sites*

The ICRP, in its Publication 82 [9], has provided advice on the release of sites of formerly operating practices from regulatory control. Essentially, the guidance is that sites may be released from regulatory control if predicted doses from all plausible future uses of the site are within the dose constraint. If the dose constraint is not satisfied, site release may still be possible, but under conditions which restrict the potential for public exposure, for example, by limiting the use of the site to industrial operations. As yet the IAEA has not developed guidance on this subject.

## 3. DEVELOPMENT OF GUIDANCE ON THE RELEASE OF SITES OF FORMERLY OPERATING PRACTICES FROM REGULATORY CONTROL

### 3.1. Considerations

A comparison between the safety impact of the release of materials from control and of the release of sites from control provides insights which are useful in the development of release policies. In the case of release of materials from control, because of the potential for the released materials to be used for a wide variety of purposes, for there to be multiple exposures to cleared materials and for them to be subject to movements within and outside the country of origin, the radiological criteria for establishing the clearance levels have been set very low.

In contrast, sites, by their nature, are fixed in position and the potential exposures from future use after release can be predicted with some certainty. No transboundary movements of the sites are possible and, furthermore, in the event of some unforeseen event remedial actions are possible (unlike in the case of released materials).

It is also necessary to take account of other related practices involving the release of radioactive materials to ensure that there is overall coherence in the local radiation protection policy. The practice of authorized discharge of radioactive materials to the environment has the potential to contaminate areas surrounding the discharge point, including, possibly, the site under consideration for release from control. The criteria for site release must therefore be compatible with the discharge criteria and vice versa.

### 3.2. A scheme for release of materials and sites

When all of the factors listed above are taken into account it may be concluded that:

— In the context of practice situations, the overriding policy for the release of materials and sites from control should be based on **constrained optimization** as established in the BSS for the control of the exposure of the public (Fig. 1).
— There should be coherence in the policies for release of materials, of sites and of discharges.

### 3.3. Discussion of the proposed scheme

The scheme outlined in Fig. 2 is developed from the basic scheme for protection of the public from single sources. For the release of sites, the ‘optimized site release level’ should be determined by a process of optimization, taking into account on the one hand the benefits, in terms of dose reduction, of remediating the site and, on the other hand, the costs of the remediation activity. The process should be constrained by the dose constraint of 0.3 mSv per year.

Sites at which the residual level is below the optimized site release level may be released for unrestricted use. For sites at which it is deemed not to be cost effective to reduce the contamination levels to below the optimized site release level, restricted site release may be possible. This may involve use restrictions being placed on the site by the Regulatory Authority and records being kept to ensure that restrictions are complied with in the future.

In setting the optimized site release level, account should be taken, where necessary, of the criteria established for local practices involving the discharge of radionuclides, especially where such discharges could affect radiation levels at the site under consideration.

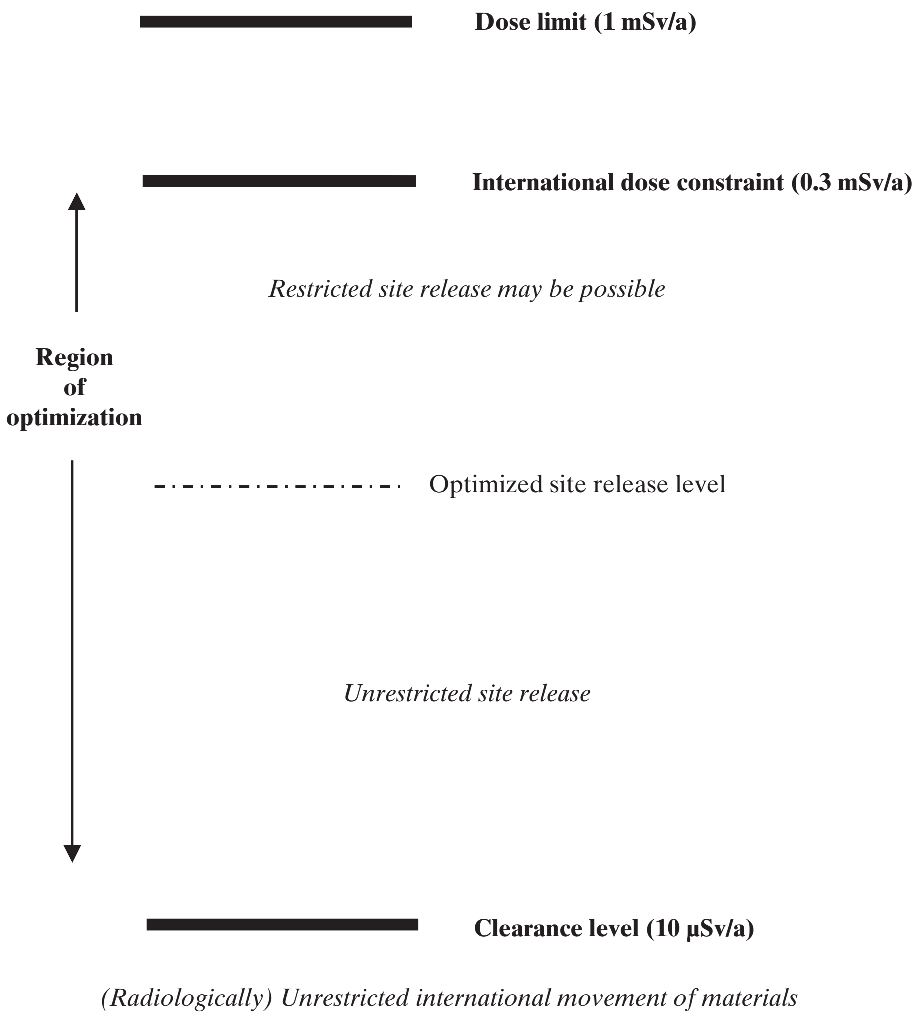


*FIG. 2. A scheme for the release of materials and sites.*

It is noted that this approach allows site specific or country specific values to be adopted. The optimized site release level has been fixed at various levels in different countries ranging from 10 μSv to 0.25 mSv per year.

In order to present a comprehensive scheme, the release of materials has also been included in Fig. 2. For the reasons set out in the previous section, the optimized release level for materials has been set at the clearance level of 10 μSv per year. The release of materials at associated dose levels higher than about 10 μSv per year may be permitted subject to restrictions being imposed on the use to which they are put.

The proposed scheme has the advantage of being flexible and allows, within dose limits and dose constraints, account to be taken of the difficulties of remediation in different situations and of variations in economic circumstances.

## 4. CONCLUSIONS

A complete scheme of criteria for governing the release of materials and sites of previously operating practices from regulatory control has not yet been established at the international level. IAEA standards exist on criteria for the release of materials from regulatory control, but not for the release of sites. Proposals have been made in this paper for criteria for the release of materials and sites of previously operating practices which are generally consistent with the existing international policy for protection of the public from ionizing radiation.

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# REMOVAL OF REGULATORY CONTROL: THE SPANISH EXPERIENCE

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## 1. INTRODUCTION

Decommissioning of nuclear installations will produce various amounts of radioactive materials with different activity levels. The management of the highly contaminated or activated material usually follows the well established radioactive waste route, being disposed of finally in an authorized repository after being properly conditioned. Not so well established are the management options for residual materials with a very low level of activity. A risk optimization analysis would indicate that residual materials with a very low level of activity need not be handled, processed or disposed of with any reference to their radioactivity content, in order to allow more beneficial allocation for limited social resources. These materials may be discharged or disposed of as normal wastes, using conventional methods, or can be reused as conventional materials outside of the regulated nuclear sector. The decommissioning of a former nuclear facility will in the end produce a site with very slight contamination in soil, which also has to be released from regulatory controls. An analysis similar to that mentioned above could be used for site release once a particular facility is decommissioned. Remedial or restoration actions for pieces of land to be released should be subjected to a similar radiological process for selecting the best strategy for remedial measures. In order to make these releases from regulatory control possible, it is necessary to establish conditions for the site or for these materials to be managed during their later reuse or final disposal. Authorization for this release or clearance of control is the responsibility of the competent authority and, in the case of Spain, is carried out by the Directorate General for Energy and Mining Policy of the Ministry of Economy, taking into account the safety report of the Spanish Nuclear Safety Council (CSN). Up to now, all clearance or release criteria applied in Spain have been issued on the basis of an ad hoc, case by case analysis.

Regulations on how to deal with such materials or sites will have to be enacted. These regulations should include a threshold for unconditional release and a requirement to ensure that the way in which materials subject to authorized releases have been recycled or reused, and how wastes have been disposed of, can be traceable. In the case of site release, fulfillment of certain conditions would be required, including some kind of institutional control, in order to ensure that these are accomplished in the future.

Authorization for the release or clearance from regulatory control of these materials is the responsibility of the competent national authority. In the case of Spain, this duty is now carried out by the Directorate General for Energy and Mining Policy of the Ministry of Economy, taking into account the report of the Nuclear Safety Council.

## 2. WASTE MATERIALS AND CANDIDATE SITES FOR RELEASE

We refer here to solid radioactive materials with very low levels of activity, or contamination generated as part of a regulated practice, that are candidates for management in a conventional and non-regulated manner. These are different from the established methods used in the management of solid radioactive waste. Not only economic factors, but also reasons related to the conservation of resources drive the search for alternative management methods for very low level contaminated materials. The recycling and reuse of materials offer the potential to extend the life of valuable natural resources, pollution can be reduced and recycling often results in a net energy saving. The economic benefit of recycling should also be considered in recovering valuable material.

Of greater value are the potential savings to be achieved in the cost of conditioning, packaging, storage, transport and disposal of very large quantities of 'nominally' active materials, taking into account the volume reduction of the waste streams to be disposed of in a regulated, low level waste repository. To make this full or partial release from regulatory control possible, it is necessary to establish conditions for these materials to be managed during their later reuse or final disposal. Numerous projects have been undertaken at the international level to attempt to define ways of carrying out this practical application. In parallel, various countries have undertaken their own individual initiatives and studies.

It is necessary to realize that once regulatory control is removed, it cannot be guaranteed that economically valuable transportable materials will remain within the country in which regulatory control has been lifted. Consistency among standards set by different countries is important in the case of movable items from cleared materials because they can be imported and exported, and differing standards could create confusion and economic disparities in commerce.

There are also licensed sites, or parts of licensed sites, currently under regulatory control, but which are no longer needed by the licensees. These would include the sites of decommissioned nuclear facilities, where potentially contaminated lands remain subject to the regulatory control system, as long as the competent authorities consider that their residual radioactivity represents a potential source of radiological hazard to the individuals affected or entails an unacceptable environmental risk.

## 3. RADIATION PROTECTION ANALYSIS

The analysis required to ensure the proper radiological protection of society can be done in the context of the current International Commission on Radiological Protection (ICRP) system of dose limitation. A decision on the radiological justification principle derives from considerations that are much broader than those based on radiation protection alone. But if a new practice, with authorized solid waste release, is introduced as a substitute for another previously justified practice, as might be the case, the resource saving of relinquishing control of a particular residual material, in comparison with its management as radioactive waste, will need to be taken into account as an important part of the decision making process. It can be easily demonstrated that this new practice is justified as long as the net benefit of the replaced practice plus the saving in protection measures (including radioactive waste management of the material) is large enough to compensate for the cost of the supplementary radiological detriment, if the profits and costs of both practices are equal.

Any free release of solid material to the environment has to demonstrate that the radiological detriment it causes is as low as reasonably achievable. We find here, as a particular case of the optimization process, the so-called 'general protection principles for exemption':

— The radiological risk to the individuals caused by the cleared material must be sufficiently low (so as not to be of any further regulatory concern);
— The exempted sources must be inherently safe, with a very low likelihood of scenarios that might lead to failure to meet the criteria previously mentioned;
— The collective radiological impact of the clearance policy must be sufficiently low so as to not warrant regulatory control under the prevailing circumstances.

The practical meaning of the radiological optimization philosophy when releasing areas or sites currently under regulation is essentially the same. The sites should be remedied to reduce the residual risk as far as it is reasonable to do so, bearing in mind the cost and risks associated with the remedial measures.

If the justification and optimization of protection have been conducted effectively, the next step will simply be to corroborate that the individual related dose limits for members of the public are being met to prevent unacceptable individual detriment:

— Effective individual dose <1 mSv in a year,
— 15 mSv per year for the eye lens,
— 50 mSv per year averaged over 1 $cm^2$ of skin.

It is necessary to keep in mind that benefits and detriment are not equally distributed through society and that there is always the possibility of cumulative exposures due to several sources. For this reason, the ICRP considers it necessary to incorporate a restriction on the individual dose limit to be applied to the averaged individual dose to the critical group of the affected population. The use of these constraints simplifies the formal radiological optimization process and tries to avoid the possibility that cumulative exposures due to several and non-related sources exceed the established individual limits.

A dose constraint in the range of 1/100 to 1/10 of the individual effective dose limit can well be applied to the average individual of the critical group of the affected population when clearing residual materials. The radiation protection philosophy, when releasing lands or sites that are currently under regulatory control, is essentially the same. The sites should be remedied to reduce the residual risk as far as reasonable to do so, taking into account the cost and risks associated with the remedial measures.

A simplified approach, based on the triviality of individual and collective risks, is usually used for the clearance of residual materials. A practice or a source may be exempted without further consideration provided that the following criteria are met in all feasible situations:

— The effective dose expected to be incurred by any member of the public due to the exempted practice or source is of the order of 10 mSv or less in a year.
— The collective effective dose from one year of performance of the practice is no more than about 1 man·Sv.

In summary, the release of solid materials generated within a regulated facility or the release of land of the facility itself, can be authorized on the grounds of the trivial risk methodology if the individual and collective doses to be incurred are so low that they may be reasonably neglected in all feasible situations. Or if an optimization analysis indicates that extra protective measures would not be warranted by any significant reduction in doses, and that the doses in the most probable scenario are well below the dose constraint imposed.

## 4. SPANISH REGULATORY FRAMEWORK

The Spanish Royal Decree 1836/1999 of 3 December [1], whereby new regulations for nuclear and radioactive facilities were approved, addresses for the first time a specific administrative framework for licensing the decommissioning process for nuclear facilities. An official document addressed in this regulation is the “Radioactive Waste Management Plan”, which contains the criteria adopted for material declassification or clearance. Another official document in this new regulation is the “Site Restoration Plan”, which contains the cleanup criteria to release the site once the decommissioning process has finished.

The above mentioned new regulation establishes that the disposal, recycling or reuse of radioactive substances or materials containing radioactive substances coming from any nuclear installations shall be subject to authorization by the General Directorate for Energy and Mining Policy of the Ministry of Economy, following a report by the Nuclear Safety Council.

Nevertheless, the disposal, recycling or reuse of such substances or materials may be exempted from this requirement, as long as such substances contain or are contaminated by radionuclides in concentrations or levels of activity equal to or lower than those established by the Ministry of Industry and Energy. This is in relation to the definition of radioactive waste referred to as, “Any waste product or residual material for which no further use is foreseen and which contains or is contaminated with radionuclides in concentrations or activity levels higher than clearance values, as defined by the Regulatory Authorities”.

Up to now, the Ministry has not yet implemented any clearance levels for residual materials or any cleanup criteria for lands or sites to be applied in a general way. However, there have been particular ministerial authorizations linked to decommissioning projects for certain facilities (Andujar uranium mill factory, uranium mining sites, restoration projects, etc.) which lay down declassification levels for residual material and radiological criteria for site release that are only valid for these projects.

The Vandellós 1 Nuclear Power Plant Decommissioning Project is the main decommissioning project that is being carried out in Spain. The project can be seen as an example of the current removal of control policy to be implemented in Spain.

The Vandellós 1 Decommissioning Project has three authorized basic possibilities for the application of clearance of residual materials: unconditional clearance ($N_1$ level), generic conditional clearance ($N_2$ level), and specific conditional clearance ($N_3$ level). Different sets of radionuclide specific figures for unconditional clearance levels ($N_1$) and for generic conditional clearance levels ($N_2$) have already been established for some generic materials such as building and concrete demolition debris.

No official cleanup criteria exist for the release of the site of Vandellós 1 nuclear power plant (NPP). Up to 60% of the nuclear site will be released at the end of the current decommissioning phase, leaving the remaining 40%, including the reactor building, under regulatory control in a dormant facility.

As part of the licensing procedure of the Vandellós 1 NPP Decommissioning Project, Empresa Nacional de Residuos Radiactivos (ENRESA) has recently submitted a “Site Restoration Plan” for the partial release of the Vandellós 1 nuclear site. CSN technical staff is currently reviewing the radiological criteria and different scenarios considered in the proposal.

## 5. CLEARANCE LEVELS

A framework consisting of three basic possibilities to apply clearance is used in the Vandellós 1 NPP Decommissioning Project (Table I):

- A first set of unconditional clearance levels $N_1$, expressed in terms of gross activity concentration and surface contamination, has been issued for the unrestricted release of materials. Derived unconditional generic clearance levels, based on published international guidance, are also accepted.
- Generic use of derived conditional clearance levels $N_2$, based on ‘ad hoc’, internationally published guidance, has been established for particular waste streams managed in well defined, non-regulated practices (metallic scrap recycling and concrete demolition debris).
- The applicant may also propose candidate materials for other non-regulated route management practices, for which CSN can issue conditional clearance levels $N_3$.

### 5.2. Unconditional clearance levels

A first set of unconditional clearance levels, expressed in terms of gross activity concentration and surface contamination, has been issued for the free release of material:

TABLE I. MANAGEMENT OPTIONS FOR RESIDUAL MATERIALS IN THE VANDELLÓS 1 NPP DECOMMISSIONING PROGRAMME

| Classification | Management |
|---|---|
| Radioactive waste | Radioactive waste management |
| $N_3$ | SPECIFIC CONDITIONAL CLEARANCE |
| Specific material or waste stream (to be proposed) | Specific management route (to be proposed) |
| $N_2$ | GENERIC CONDITIONAL CLEARANCE |
| Defined material or waste stream | Defined management route |
| $N_1$ | UNCONDITIONAL CLEARANCE |
| No contaminated material | Conventional management |

– Total $\beta/\gamma$: 0.2 Bq/g;
– Total $\alpha$: 0.1 Bq/g;
– Surface contamination, total $\beta/\gamma$: 0.4 Bq/cm$^2$;
– Surface contamination, total $\alpha$: 0.1 Bq/cm$^2$;
– Surface contamination, weak $\beta/\gamma$: 4 Bq/cm$^2$.

It should be pointed out that these figures are not supported by any specific radiological study but are issued in order to avoid inconsistencies with other generic licensing documents, such as transport regulations or radiological protection manuals in different facilities within the country.

A second set of radionuclide specific clearance levels taken from IAEA-TECDOC-855 [2] may also be used for the unconditional clearance of solid materials (Table II). Compliance with these clearance levels will ensure that the individual dose criterion of 10 μSv per year will not be exceeded, irrespective of the user or application of material after its release.

### 5.3. Conditional clearance levels

The aforementioned authorization allows the licensee to propose the clearance of residual materials to be managed in a conventional way. The CSN might consider the proposal and other different conditional clearance levels

TABLE II. UNCONDITIONAL CLEARANCE LEVELS FOR RADIONUCLIDES IN SOLID MATERIALS

| Range of activity (Bq/g) | Radionuclides | | | | | Representative single value (Bq/g) |
|---|---|---|---|---|---|---|
| 0.1 | | | | | | |
| | Na-22 | Nb-94 | Eu-152 | Th-230 | Np-237 | 0.3 |
| | Na-24 | Ag-11m | Pb-210 | Th-232 | Pu-239 | |
| | Mn-54 | Sb-124 | Ra-226 | U-234 | Pu-240 | |
| | Co-60 | Cs-134 | Ra-228 | U-235 | Am-241 | |
| | Zn-65 | Cs-137 | Th-228 | U-238 | Cm-224 | |
| 1 | | | | | | |
| | Co-58 | Sr-90 | In-111 | Ir-192 | Po-210 | 3 |
| | Fe-59 | Ru-106 | I-131 | Au-198 | | |
| 10 | | | | | | |
| | Cr-51 | Tc-99m | I-125 | I-129 | Tl-210 | 30 |
| | Co-57 | I-123 | Tc-99 | Ce-144 | Pu-241 | |
| 100 | | | | | | |
| | C-14 | Cl-36 | Sr-89 | Cd-109 | | 300 |
| | P-32 | Fe-55 | Y-90 | | | |
| 1000 | | | | | | |
| | H-3 | S-35 | Ca-45 | Ni-63 | Pm-147 | 3.000 |
| 10 000 | | | | | | |

might be issued if the final destination of the residual materials can be assured and an ‘ad hoc’ assessment can demonstrate that the radiological protection of the population is guaranteed.

In these cases, the possible release authorization is constrained twice. Firstly, because the fate of the material being considered in the clearance is known, so that only a limited number of reasonable possible exposures routes have to be considered in deriving the clearance levels. Secondly, because the CSN imposes source related dose constraints, based on the triviality of doses, for the most exposed individual of the proposed practice (individual dose $\cong$10 μSv/a) and for the collective dose committed per year of the proposed practice (collective dose $\leq$1 man · Sv).

Individual dose limits are also taken into consideration. The CSN imposes an annual limit for a skin dose lower than 50 mSv/a, averaged over any area of 1 $cm^2$, and an individual effective dose for public exposure lower than 1 mSv/a for potential doses due to events in the proposed practice having low probability.

As part of the licensing procedure, ENRESA submitted a plan for the conventional management of the metallic scrap produced during the

Decommissioning Project. The study was carried out in support of a proposal of clearance levels applicable to this material. Another study supporting the exemption of the rubble produced during the dismantling of the facility was also submitted. Two different types of management were considered for the concrete debris: disposal and recycling or reuse of the buildings.

The CSN, considering that the licensee's proposal did not have any geographical constraint, and in order to avoid the necessity of any further radiological controls on the cleared material, decided to adhere, to the extent possible, to the international consensus available at the time of issue.

The current Vandellós 1 decommissioning authorization states the acceptability, as generic conditional clearance levels ($N_2$), of the figures drawn up by the groups of experts set up under the term of Article 31 of the EURATOM Treaty.

Accepted radiological criteria for the clearance of metallic materials, buildings and building rubble assume that the effective dose to be incurred, by any individual member of the public, is of the order of 10 μSv or less in a year, and the collective dose committed during one year is no more than about 1 man·Sv. For an unforeseen future use of a very conservative scenario is considered, yielding a worst case dose of 1 mSv. In addition to the dose criterion for the effective dose, a limiting equivalent dose to skin of 50 mSv/a has been introduced to exclude the possibility of deterministic effects.

No radiological conditions are considered after the act of clearing the material. The conditions imposed refer only to the management route chosen and to the properties of the material itself before clearing. All potentially reusable metallic parts must comply with the most restrictive set of clearance levels for direct reuse of metallic equipment and components, unless recycling by melting in a foundry is reasonably assured. The most restrictive occupational scenarios should be applied, together with the activity concentration clearance levels for concrete recycling to those buildings that might be demolished in the future.

Higher specific conditional clearance levels ($N_3$) can also be issued by CSN in consideration of some future route to be proposed by the licensee.

### *5.3.1. Metallic material release*

Generic conditional clearance levels ($N_2$) for metal scrap recycling and direct reuse of equipment, components and tools in the Vandellós 1 decommissioning authorization are the figures recommended in European Commission (EC) document RP 89 (Table III) [3]. The total activity is averaged over a few hundred kg (100 cm$^2$) and the surface and mass criteria apply together, the surface activity including fixed and non-fixed activity.

TABLE III. NUCLIDE SPECIFIC CLEARANCE LEVELS FOR METAL SCRAP RECYCLING

| Radionuclide | Specific activity (Bq/g) | Surface contamination (Bq/cm$^2$) | Radionuclide | Specific activity (Bq/g) | Surface contamination (Bq/cm$^2$) |
|---|---|---|---|---|---|
| H3 | 1000 | 10000 | Ag 110m | 1 | 10 |
| C 14 | 100 | 1000 | Cd 109 | 10 | 100 |
| Na 22 | 1 | 10 | Sn 113 | 1 | 100 |
| S 35 | 1000 | 1000 | Sb 124 | 1 | 10 |
| Cl 36 | 10 | 100 | Sb 125 | 10 | 100 |
| K 40 | 1 | 100 | Te 123m | 10 | 100 |
| Ca 45 | 1000 | 100 | Te 127m | 100 | 100 |
| Sc 46 | 1 | 10 | I 125 | 1 | 100 |
| Mn 53 | 10000 | 100000 | I 129 | 1 | 10 |
| Mn 54 | 1 | 10 | Cs 134 | 1 | 10 |
| Fe 55 | 10000 | 10000 | Cs 135 | 10 | 1000 |
| Co 56 | 1 | 10 | Cs 137 | 1 | 100 |
| Co 57 | 10 | 100 | Ce 139 | 10 | 100 |
| Co 58 | 1 | 10 | Ce 144 | 10 | 10 |
| Co 60 | 1 | 10 | Pm 147 | 10000 | 1000 |
| Ni 59 | 10000 | 10000 | Sm 151 | 10000 | 1000 |
| Ni 63 | 10000 | 10000 | Eu 152 | 1 | 10 |
| Zn 65 | 1 | 100 | Eu 154 | 1 | 10 |
| As 73 | 100 | 1000 | Eu 155 | 10 | 1000 |
| Se 75 | 1 | 100 | Gd 153 | 10 | 100 |
| Sr 85 | 1 | 100 | Tb 160 | 1 | 10 |
| Sr 90 | 10 | 10 | Tm 170 | 100 | 1000 |
| Y 91 | 10 | 100 | Tm 171 | 1000 | 10000 |
| Zr 93 | 10 | 100 | Ta 182 | 1 | 10 |
| Zr 95 | 1 | 10 | W 181 | 100 | 1000 |
| Nb 93m | 1000 | 10000 | W 185 | 1000 | 1000 |
| Nb 94 | 1 | 10 | Os 185 | 1 | 10 |
| Mo 93 | 100 | 1000 | Ir 192 | 1 | 10 |
| Tc 97 | 1000 | 1000 | Ti 204 | 1000 | 1000 |
| Tc 97m | 1000 | 1000 | Pb 210 | 1 | 1 |
| Tc 99 | 100 | 1000 | Bi 207 | 1 | 10 |
| Ru 106 | 1 | 10 | Po 210 | 1 | 0,1 |
| Ag 108m | 1 | 10 | Ra 226 | 1 | 0,1 |

TABLE III. (cont.)

| Radionuclide | Specific activity (Bq/g) | Surface contamination ($Bq/cm^2$) | Radionuclide | Specific activity (Bq/g) | Surface contamination ($Bq/cm^2$) |
|---|---|---|---|---|---|
| Ra 228 | 1 | 1 | Pu 244 | 1 | 0,1 |
| Th 228 | 1 | 0,1 | Am 241 | 1 | 0,1 |
| Th 229 | 1 | 0,1 | Am 242m | 1 | 0,1 |
| Th 230 | 1 | 0,1 | Am 243 | 1 | 0,1 |
| Th 232 | 1 | 0,1 | Cm 242 | 10 | 1 |
| Pa 231 | 1 | 0,1 | Cm 243 | 1 | 0,1 |
| U 232 | 1 | 0,1 | Cm 244 | 1 | 0,1 |
| U 233 | 1 | 1 | Cm 245 | 1 | 0,1 |
| U 234 | 1 | 1 | Cm 246 | 1 | 0,1 |
| U 235 | 1 | 1 | Cm 247 | 1 | 0,1 |
| U 236 | 10 | 1 | Cm 248 | 1 | 0,1 |
| U 238 | 1 | 1 | Bk 249 | 100 | 100 |
| Np 237 | 1 | 0,1 | Cf 248 | 10 | 1 |
| Pu 236 | 1 | 0,1 | Cf 249 | 1 | 0,1 |
| Pu 238 | 1 | 0,1 | Cf 250 | 1 | 0,1 |
| Pu 239 | 1 | 0,1 | Cf 251 | 1 | 0,1 |
| Pu 240 | 1 | 0,1 | Cf 252 | 1 | 0,1 |
| Pu241 | 10 | 10 | Cf 254 | 1 | 0,1 |
| Pu 242 | 1 | 0,1 | Es 254 | 10 | 1 |

**Nuclide specific clearance levels for direct reuse of metals items**

| Radionuclide | Surface contamination ($Bq/cm^2$) | Radionuclide | Surface contamination ($Bq/cm^2$) |
|---|---|---|---|
| H 3 | 10000 | Mn 53 | 10000 |
| C 14 | 1000 | Mn 54 | 10 |
| Na 22 | 1 | Fe 55 | 1000 |
| S 35 | 1000 | Co 56 | 1 |
| Cl 36 | 100 | Co 57 | 10 |
| K 40 | 10 | Co 58 | 10 |
| Ca 45 | 100 | Co 60 | 1 |
| Sc 46 | 10 | Ni 59 | 10000 |

TABLE III. (cont.)

| Radionuclide | Surface contamination (Bq/cm$^2$) | Radionuclide | Surface contamination (Bq/cm$^2$) |
|---|---|---|---|
| Ni 63 | 1000 | Eu 154 | 1 |
| Zn 65 | 10 | Eu 155 | 100 |
| As 73 | 1000 | Gd 153 | 10 |
| Se 75 | 10 | Tb 160 | 10 |
| Sr 85 | 10 | Tm 170 | 1000 |
| Sr 90 | 10 | Tm 171 | 10000 |
| Y 91 | 100 | Ta 182 | 10 |
| Zr 93 | 100 | W 181 | 100 |
| Zr 95 | 10 | W 185 | 1000 |
| Nb 93m | 1000 | Os 185 | 10 |
| Nb 94 | 1 | Ir 192 | 10 |
| Mo 93 | 100 | Ti 204 | 100 |
| Tc 97 | 100 | Pb 210 | 1 |
| Tc 97m | 1000 | Bi 207 | 1 |
| Tc 99 | 1000 | Po 210 | 0,1 |
| Ru 106 | 10 | Ra 226 | 0,1 |
| Ag 108m | 1 | Ra 228 | 1 |
| Ag 110m | 1 | Th 228 | 0,1 |
| Cd 109 | 100 | Th 229 | 0,1 |
| Sn 113 | 10 | Th 230 | 0,1 |
| Sb 124 | 10 | Th 232 | 0,1 |
| Sb 125 | 10 | Pa 231 | 0,1 |
| Te 123m | 100 | U 232 | 0,1 |
| Te 127m | 100 | U 233 | 1 |
| I 125 | 100 | U 234 | 1 |
| I 129 | 10 | U 235 | 1 |
| Cs 134 | 1 | U 236 | 1 |
| Cs 135 | 100 | U 238 | 1 |
| Cs 137 | 10 | Np 237 | 0,1 |
| Ce 139 | 10 | Pu 236 | 0,1 |
| Ce 144 | 10 | Pu 238 | 0,1 |
| Pm 147 | 1000 | Pu 239 | 0,1 |
| Sm 151 | 1000 | | |
| Eu 152 | 1 | | |

TABLE III. (cont.)

| Radionuclide | Surface contamination ($Bq/cm^2$) | Radionuclide | Surface contamination ($Bq/cm^2$) |
|---|---|---|---|
| Pu 240 | 0,1 | Cm 246 | 0,1 |
| Pu 241 | 10 | Cm 247 | 0,1 |
| Pu 242 | 0,1 | Cm 248 | 0,1 |
| Pu 244 | 0,1 | Bk 249 | 100 |
| Am 241 | 0,1 | Cf 248 | 1 |
| Am 242m | 0,1 | Cf 249 | 0,1 |
| Am 243 | 0,1 | Cf 250 | 0,1 |
| Cm 242 | 1 | Cf 251 | 0,1 |
| Cm 243 | 0,1 | Cf 252 | 0,1 |
| Cm 244 | 0,1 | Cf 254 | 0,1 |
| Cm 245 | 0,1 | Es 254 | 1 |

Release for direct reuse requires a conservative assessment of surface contamination in the case of non-accessible surfaces. Allowance shall be made for alpha–beta activity under paint or rust. Clearance levels for reuse are in general lower than for recycling; thus, reusable parts must be cut into pieces before recycling clearance levels can be applied. No mass specific activities for reuse are given. Activated materials can be accounted for as if they were surface activity.

### *5.3.2. Building release*

Generic conditional clearance levels ($N_2$) for building reuse, or building demolition in the Vandellós 1 decommissioning authorization, are in EC document RP 113 (Table IV) [4]. Three main situations are considered in three different generic conditional clearance levels:

(1) Clearance of building for any purpose (reuse and future demolition).
The clearance levels relate to the total activity in the structure per unit surface area. After clearance, the building can be used for non-nuclear purposes or be demolished. The surface specific clearance levels apply to the total activity on the surface to be measured divided by its area. The total activity is the sum of the fixed and non-fixed activity on the surface plus the activity that has penetrated into the bulk.

TABLE IV. RADIONUCLIDE SPECIFIC CLEARANCE LEVELS FOR BUILDING REUSE OR DEMOLITION

| Radionuclide | Clearance level (rounded) (Bq/cm$^2$) | Radionuclide | Clearance level (rounded) (Bq/cm$^2$) |
|---|---|---|---|
| H 3 | 10000 | Ag 110m | 1 |
| C 14 | 1000 | Cd 109 | 100 |
| Na 22 | 1 | Sn 113 | 10 |
| S 35 | 1000 | Sb 124 | 1 |
| Cl 36 | 100 | Sb 125 | 1 |
| K 40 | 10 | Te 123m | 10 |
| Ca 45 | 1000 | Te 127m | 100 |
| Sc 46 | 1 | I 125 | 100 |
| Mn 53 | 10000 | I 129 | 10 |
| Mn 54 | 1 | Cs 134 | 1 |
| Fe 55 | 10000 | Cs 135 | 100 |
| Co 56 | 1 | Cs 137 | 10 |
| Co 57 | 10 | Ce 139 | 10 |
| Co 58 | 10 | Ce 144 | 10 |
| Co 60 | 1 | Pm 147 | 1000 |
| Ni 59 | 100000 | Sm 151 | 1000 |
| Ni 63 | 10000 | Eu 152 | 1 |
| Zn 65 | 1 | Eu 154 | 1 |
| As 73 | 1000 | Eu 155 | 100 |
| Se 75 | 10 | Gd 153 | 10 |
| Sr 85 | 10 | Tb 160 | 10 |
| Sr 90 | 100 | Tm 170 | 1000 |
| Y 91 | 1000 | Tm 171 | 10000 |
| Zr 93 | 1000 | Ta 182 | 10 |
| Zr 95 | 1 | W 181 | 100 |
| Nb 93m | 1000 | W 185 | 1000 |
| Nb 94 | 1 | Os 185 | 10 |
| Mo 93 | 100 | Ir 192 | 10 |
| Tc 97 | 100 | Ti 204 | 100 |
| Tc 97m | 100 | Pb 210 | 1 |
| Tc 99 | 100 | Bi 207 | 1 |
| Ru 106 | 10 | Po 210 | 0,1 |
| Ag 108m | 1 | Ra 226 | 0,1 |

TABLE IV. (cont.)

| Radionuclide | Clearance level (rounded) (Bq/cm$^2$) | Radionuclide | Clearance level (rounded) (Bq/cm$^2$) |
|---|---|---|---|
| Ra 228 | 1 | Pu 244 | 1 |
| Th 228 | 0,1 | Am 241 | 1 |
| Th 229 | 0,1 | Am 242m | 1 |
| Th 230 | 0,1 | Am 243 | 1 |
| Th 232 | 0,1 | Cm 242 | 1 |
| Pa 231 | 0,1 | Cm 243 | 1 |
| U 232 | 0,1 | Cm 244 | 1 |
| U 233 | 1 | Cm 245 | 0,1 |
| U 234 | 1 | Cm 246 | 1 |
| U 235 | 1 | Cm 247 | 1 |
| U 236 | 1 | Cm 248 | 0,1 |
| U 238 | 1 | Bk 249 | 100 |
| Np 237 | 1 | Cf 248 | 1 |
| Pu 236 | 1 | Cf 249 | 0,1 |
| Pu 238 | 1 | Cf 250 | 1 |
| Pu 239 | 0,1 | Cf 251 | 0,1 |
| Pu 240 | 0,1 | Cf 252 | 1 |
| Pu 241 | 10 | Cf 254 | 1 |
| Pu 242 | 1 | Es 254 | 1 |

**Note**: If the contribution of the radionuclide is more than 10% of the dose, use the following value: (0.013).

**Radionuclide specific clearance levels for building demolition.**

| Radionuclide | Clearance level (rounded) (Bq/cm$^2$) | Radionuclide | Clearance level (rounded) (Bq/cm$^2$) |
|---|---|---|---|
| H 3 | 10000 | Ca 45 | 100000 |
| C 14 | 10000 | Sc 46 | 10 |
| Na 22 | 10 | Mn 53 | 10000 |
| S 35 | 10000 | Mn 54 | 10 |
| Cl 36 | 100 | Fe 55 | 10000 |
| K 40 | 10 | Co 56 | 10 |

TABLE IV. (cont.)

| Radionuclide | Clearance level (rounded) (Bq/cm$^2$) | Radionuclide | Clearance level (rounded) (Bq/cm$^2$) |
|---|---|---|---|
| Co 57 | 100 | Ce 144 | 100 |
| Co 58 | 10 | Pm 147 | 10000 |
| Co 60 | 1 | Sm 151 | 10000 |
| Ni 59 | 100000 | Eu 152 | 10 |
| Ni 63 | 100000 | Eu 154 | 10 |
| Zn 65 | 10 | Eu 155 | 100 |
| As 73 | 10000 | Gd 153 | 100 |
| Se 75 | 100 | Tb 160 | 10 |
| Sr 85 | 100 | Tm 170 | 10000 |
| Sr 90 | 100 | Tm 171 | 10000 |
| Y 91 | 100000 | Ta 182 | 10 |
| Zr 93 | 1000 | W 181 | 1000 |
| Zr 95 | 10 | W 185 | 1000000 |
| Nb 93m | 100000 | Os 185 | 10 |
| Nb 94 | 10 | Ir 192 | 100 |
| Mo 93 | 1000 | Ti 204 | 1000 |
| Tc 97 | 1000 | Pb 210 | 1 |
| Tc 97m | 1000 | Bi 207 | 10 |
| Tc 99 | 100 | Po 210 | 100 |
| Ru 106 | 100 | Ra 226 | 1 |
| Ag 108m | 10 | Ra 228 | 10 |
| Ag 110m | 10 | Th 228 | 1 |
| Cd 109 | 10000 | Th 229 | 1 |
| Sn 113 | 100 | Th 230 | 1 |
| Sb 124 | 10 | Th 232 | 1 |
| Sb 125 | 10 | Pa 231 | 0,1 |
| Te 123m | 100 | U 232 | 1 |
| Te 127m | 10000 | U 233 | 10 |
| I 125 | 10000 | U 234 | 10 |
| I 129 | 10 | U 235 | 10 |
| Cs 134 | 10 | U 236 | 10 |
| Cs 135 | 10000 | U 238 | 10 |
| Cs 137 | 10 | Np 237 | 10 |
| Ce 139 | 100 | Pu 236 | 10 |

TABLE IV. (cont.)

| Radionuclide | Clearance level (rounded) ($Bq/cm^2$) | Radionuclide | Clearance level (rounded) ($Bq/cm^2$) |
|---|---|---|---|
| Pu 238 | 1 | Cm 245 | 1 |
| Pu 239 | 1 | Cm 246 | 1 |
| Pu 240 | 1 | Cm 247 | 1 |
| Pu 241 | 100 | Cm 248 | 1 |
| Pu 242 | 1 | Bk 249 | 1000 |
| Pu 244 | 1 | Cf 248 | 10 |
| Am 241 | 1 | Cf 249 | 1 |
| Am 242m | 1 | Cf 250 | 10 |
| Am 243 | 1 | Cf 251 | 1 |
| Cm 242 | 100 | Cf 252 | 10 |
| Cm 243 | 10 | Cf 254 | 10 |
| Cm 244 | 10 | Es 254 | 10 |

**Radionuclide specific clearance levels for building rubble**

| Radionuclide | Clearance level (rounded) ($Bq/cm^2$) | Radionuclide | Clearance level (rounded) ($Bq/cm^2$) |
|---|---|---|---|
| H 3 | 100 | Ni 59 | 1000 |
| C 14 | 10 | Ni 63 | 1000 |
| Na 22 | 0,1 | Zn 65 | 1 |
| S 35 | 1000 | As 73 | 100 |
| Cl 36 | 1 | Se 75 | 1 |
| K 40 | 1 | Sr 85 | 1 |
| Ca 45 | 1000 | Sr 90 | 1 |
| Sc 46 | 0,1 | Y 91 | 100 |
| Mn 53 | 1000 | Zr 93 | 100 |
| Mn 54 | 0,1 | Zr 95 | 0,1 |
| Fe 55 | 1000 | Nb 93m | 1000 |
| Co 56 | 0,1 | Nb 94 | 0,1 |
| Co 57 | 1 | Mo 93 | 100 |
| Co 58 | 0,1 | Tc 97 | 10 |
| Co 60 | 0,1 | Tc 97m | 10 |

TABLE IV. (cont.)

| Radionuclide | Clearance level (rounded) (Bq/cm$^2$) | Radionuclide | Clearance level (rounded) (Bq/cm$^2$) |
|---|---|---|---|
| Tc 99 | 1 | Po 210 | 1 |
| Ru 106 | 1 | Ra 226 | 0,1 |
| Ag 108m | 0,1 | Ra 228 | 0,1 |
| Ag 110m | 0,1 | Th 228 | 0,1 |
| Cd 109 | 100 | Th 229 | 0,1 |
| Sn 113 | 1 | Th 230 | 0,1 |
| Sb 124 | 100 | Th 232 | 0,1 |
| Sb 125 | 1 | Pa 231 | 0,1*[a] |
| Te 123m | 1 | U 232 | 0,1 |
| Te 127m | 100 | U 233 | 1 |
| I 125 | 100 | U 234 | 1 |
| I 129 | 0,1 | U 235 | 1 |
| Cs 134 | 0,1 | U 236 | 1 |
| Cs 135 | 1000 | U 238 | 1 |
| Cs 137 | 1 | Np 237 | 0,1 |
| Ce 139 | 1 | Pu 236 | 0,1 |
| Ce 144 | 10 | Pu 238 | 0,1 |
| Pm 147 | 1000 | Pu 239 | 0,1 |
| Sm 151 | 1000 | Pu 240 | 0,1 |
| Eu 152 | 0,1 | Pu 241 | 1 |
| Eu 154 | 0,1 | Pu 242 | 0,1 |
| Eu 155 | 10 | Pu 244 | 0,1 |
| Gd 153 | 10 | Am 241 | 0,1 |
| Tb 160 | 0,1 | Am 242m | 0,1 |
| Tm 170 | 100 | Am 243 | 0,1 |
| Tm 171 | 1000 | Cm 242 | 1 |
| Ta 182 | 0,1 | Cm 243 | 0,1 |
| W 181 | 10 | Cm 244 | 0,1 |
| W 185 | 1000 | Cm 245 | 0,1 |
| Os 185 | 1 | Cm 246 | 0,1 |
| Ir 192 | 0,1 | Cm 247 | 0,1 |
| Ti 204 | 100 | Cm 248 | 0,1*[b] |
| Pb 210 | 0,1 | Bk 249 | 10 |
| Bi 207 | 0,1 | Cf 248 | 1 |

TABLE IV. (cont.)

| Radionuclide | Clearance level (rounded) ($Bq/cm^2$) | Radionuclide | Clearance level (rounded) ($Bq/cm^2$) |
|---|---|---|---|
| Cf 249 | 0,1 | Cf 252 | 0,1 |
| Cf 250 | 0,1 | Cf 254 | 0,1 |
| Cf 251 | 0,1 | Es 254 | 0,1 |

**Note**: If the contribution of the radionuclides is more than 10% of the dose, use the following values: (a) 0.0035 Bq/g, (b) 0.026 Bq/g.

(2) Clearance of buildings for demolition only.
Buildings at a decommissioned nuclear site will often be demolished and the resulting rubble either recycled or conventionally disposed of. Either the standing structure of the building to be demolished can be cleared using surface contamination clearance criteria or the building rubble resulting from the demolition can be cleared using mass specific clearance criteria. The advantage of clearing the standing structure is that high level surface contamination is not mixed with the uncontaminated interior of the building structure. The clearance levels are expressed as total activity in the structure per unit surface area, and are generally greater than those proposed for reuse.

(3) Clearance criteria for building rubble.
Provided measures are taken to remove surface contamination, a possible option is to clear the material after the building or major part of it has been demolished. In this case mass specific clearance levels can be applied. Records should be kept of the dismantling operations in order to demonstrate that high activity and contaminated materials have been kept separate.

### 5.4. Verification of clearance levels

Once clearance levels are established, another very important responsibility of the regulatory authority is to ensure that the authorized clearance levels will be properly implemented. A very strict control programme is needed to support and verify compliance with the aforementioned criteria prior to the release of any residual materials from the Vandellós 1 NPP premises.

On the basis of a documented preliminary radiological survey, it has to be decided whether the material is potentially clearable and the measuring efforts for its clearance are determined. Some key aspects to be analysed in this preliminary characterization of the candidate material for clearance are:

— Radionuclide spectrum and key nuclides,
— Scaling factors to be used to determine activity of very difficult to measure radionuclides,
— Activity distribution and location of potential 'hot spots'.

The goal of keeping doses in the range of a few mSv per year implies that the dose rates to be detected are a small fraction of the natural background, as a result of which it is necessary to operate at a very low limit of detectability. Aspects such as the measurement equipment to be used, the calibration procedures and the influence of the background must be specifically reviewed.

A well documented decision process with a quality control programme is very important from the regulatory point of view. Materials cannot be deliberately diluted in order to meet the clearance levels, and in order to secure the management route of the cleared material contractual arrangements with the first recipient should be required.

## 6. SITE RELEASE

As has been mentioned previously, there is no generally applicable radiological criterion to support cleanup restoration or site release in Spain. Some decommissioning projects already finished, like the stabilization of some uranium concentrate mill tailings and the restoration of old uranium mines sites, have been governed by particular criteria included specifically in the licence or authorization granted to each individual holder to whom the clearance or release applies.

The criteria that governed the decommissioning programme at the Andujar mill tailings stabilization project were taken from the standards given by the US Environmental Protection Agency for the rehabilitation of uranium mill tailings in the UMTRA programme and Spanish groundwater protection regulations. These criteria can be summarized as part of an effective equivalent dose to individuals in the critical group below 100 μSv, and an additional reduction in the residual concentration of $^{226}Ra$ on land, so the background level is not exceeded by more than 0.2 Bq/g (in the upper 15 cm of soil) and 0.6 Bq/g (in the 15 cm thick layers of soil more than 15 cm below the surface).

It is worth noting here the establishment in 1995 of a CSN working group to derive radiological criteria for the decommissioning and restoration of uranium ore processing sites. The report, which included the criteria for site restoration and site release, never came into force and never went beyond the draft stage. The proposed criteria were, nevertheless, subsequently included in later authorizations granted for new restoration and remediation projects.

The document indicated, basically, that intervention to decontaminate the site was justified if the effective dose to individuals in the critical group is above 100 μSv/a. Intervention was not justified in any case below an effective dose of 10 μSv/a. Intervention in the range of 10–100 μSv/a will be necessary if the individual exposure in any hypothetical and conservative scenario implies an individual effective dose above 1 mSv/a, the dose limit for the public.

Consideration was given to suitable options for using the land after clearance, which must be realistic for the location in question, as well as to the relevant exposure pathways. This analysis stated that the agricultural/residential scenario (family farm) was the most restrictive scenario resulting in a guideline concentration for soil contamination of 0.1 Bq/g of $^{238}$U, in equilibrium with all the radionuclides of its natural decay chain. Higher values derived from other generic exposure assessments, requiring some special additional conditions, were established for three restricted and more plausible scenarios:

| | |
|---|---|
| — Agricultural/residential | (up to 0.1 Bq/g), |
| — Forestry/grassland use | (up to 1 Bq/g), |
| — Recreational area | (up to 1 Bq/g and H < 0.1 Gy/h), |
| — Industrial use | (up to 1 Bq/g and H < 0.3 Gy/h), |
| | (closed building only in soils < 0.1 Bq/g), |
| | (radon concentration inside buildings < 200 Bq/m$^3$). |

Radiological criteria for the partial release that is being considered for the Vandellós 1 nuclear site have been proposed in the site restoration plan submitted by ENRESA to the CSN. The main features of the proposal can be summarized as follows:

— Relevant radionuclides that are considered in the analysis are: $^{3}$H, $^{14}$C, $^{59}$Ni, $^{63}$Ni, $^{60}$Co, $^{90}$Sr, $^{94}$Nb, $^{125}$Sb, $^{137}$Cs, $^{152}$Eu, $^{154}$Eu, $^{239}$Pu and $^{241}$Am.

— Industrial scenario in the next 30 years: external exposure, inhalation and soil ingestion pathways.

— Residential scenario after 30 years: external exposure, inhalation and limited ingestion of vegetables and water, including inadvertent soil ingestion.

Dose release criteria (100 μSv/a) have been translated into corresponding derived concentration guideline levels using the RESRAD code for the two different scenarios. Site specific parameters have been used in the calculations and, for each radionuclide, the most restrictive concentration obtained in both scenarios is taken as the proposed concentration level. Typical values obtained for key radionuclides are as follows: 0.4 Bg/g for $^{60}$Co, 0.3 Bq/g for $^{137}$Cs, 0.15 Bq/g for $^{90}$Sr, and 0.3 Bq/g for $^{14}$C.

The radiological surveys to be conducted to demonstrate compliance with the derived concentration limits are based on the MARSSIM approach (NUREG-1700 and NUREG-1727) and include the planning, implementation, assessment and decision making phases required for a final status survey.

A historical site assessment and a scoping survey are initially performed to provide the necessary information to design the characterization survey. The characterization survey integrates scanning surveys with direct measurements and sampling and includes the classification of areas, the definition of survey units and the determination of the required data points. Appropriate statistical tests are finally used to demonstrate compliance for each survey unit.

Another interesting project that is going to be implemented in Spain in the near future is the rehabilitation of the Centre for Energy-related Environment and Technical Research (CIEMAT), which is the main Spanish energy research centre and includes the former Spanish Nuclear Energy Board (JEN), created with a view to promoting the development and use of nuclear energy in Spain. The contamination existing inside the facilities, although low in level, means the continuation of a situation of risk without any benefit and causes difficulties to some other non-nuclear projects foreseen in the centre.

The rehabilitation of the Centre requires an integrated safety improvement programme, part of which includes the restoration of pieces of land. According to the preliminary results of the characterization studies, there are some areas and buildings that have levels of contamination that are not acceptable for the activities to be performed at the Centre in the future.

Different radiological criteria are proposed for the rehabilitation of areas with surface contamination and subsoil areas affected by activities carried out in the past that originated underground contamination. In this latter case, a set of actions that should be qualified as non-emergency interventions are being considered.

## 7. CONCLUSIONS

Exemption criteria or clearance levels have been used in one way or another by all regulatory agencies concerned with risk management. This is the case also for radiological risk, for which, exemption and clearance policies are fully available options derived from a strict and responsible application of the existing radiation protection system. The matter is now well under regulatory control, and it is precisely for this reason that regulators might consider the risks implied to be too small to justify the use of extra resources for their control, so as to allow other more beneficial, allocations for them.

It is clear that there is a need to define derived, practically applicable, criteria for clearance at the international level. More than just values, what is needed is a clear and well defined technical and administrative framework to guide the responsible management of residual materials with very low level radionuclide content, by using clearance. In this respect, it is strongly recommended that whatever effort may be necessary be made to establish a consistent but pragmatic approach for exemption and clearance. Many positive goals would be achieved by using the same derived values, at least for the unconditional application of clearance.

A basic component of any responsible policy on clearance is the guarantee that the cleared materials comply with the defined criteria. In this sense, measurements of radioactivity content and characterization of materials are, and will continue to be, a key issue.

It should be recognized that public acceptance may be a critical constraint in the implementation of a general clearance policy, and should be an important consideration in any proposed approach. It may be helpful to describe the clearance policy as a consequence of resource optimization analysis, considering that the risks implied by this policy have too low priority to be further regulated, rather than presenting those risks as having an acceptably low level.

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# REMOVAL OF CONTROLS FOR DECOMMISSIONING: A GRADED APPROACH

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**Abstract**

Decommissioning of nuclear facilities poses some of the most imposing policy and technical challenges facing the nuclear industry and regulators today. In addition to concerns about the appropriate level of residual radioactivity that may be present at a site at the completion of decommissioning, concerns have surfaced about the appropriate level of radioactivity that may be present in building materials and on equipment that are released from a site during decommissioning (i.e. clearance), as well as the manner in which the appropriate level of residual radioactivity will be established, the appropriate modelling approach, and the way in which the site and regulatory authority will ensure that public health and safety are maintained after the material is released. To deal with the diversity of decommissioning projects, a flexible, graded approach (e.g. ICRP 82) is needed to maintain a balance in implementing decommissioning requirements that focuses on the scope and extent of the hazards associated with the facility type and its potential for harm. In addition, many facilities may not be able to decommission to levels that permit unrestricted use after decommissioning. For these sites, issues relate to establishing appropriate long-term controls and the manner in which the licensee can ensure that adequate resources are available to maintain the controls for the necessary time frame. Issues also routinely surface during the actual decommissioning with respect to characterization, confirmatory surveys and dose modelling. Finally, there are issues of how to ensure that future regulatory efforts or actions by legislators or the public do not require the regulatory authority to re-examine the basis for terminating the license. ‘Finality’ must be addressed and clearly understood by all stakeholders. All of these issues are expected to surface during the First Review Meeting of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

## 1. INTRODUCTION

The decommissioning of nuclear facilities poses some of the most challenging policy and technical issues facing regulators and the nuclear industry today. In addition to concerns about the appropriate level of residual radioactivity that may remain at a site upon completion of decommissioning, concerns have surfaced about the appropriate level of radioactivity that may be present in building materials and on equipment that are released from a site during decommissioning (i.e. clearance).

Although the USA has established dose based criteria [1] for the release of nuclear sites at the end of site use, it has not yet established national requirements for the clearance of materials and commodities. The regulatory framework for decommissioning and material release is not complete. This has resulted in US regulators having to evaluate licensees' clearance requests on a site specific basis, as opposed to relying on a uniform, national clearance standard. This approach is time consuming and inefficient, does not guarantee that consistent dose standards are applied by the various Federal and State regulatory authorities, and does not meet our goal of maintaining the public's confidence that it is adequately protected from ionizing radiation. Much of this information is documented in a recent National Academies of Sciences report [2].

Adequate public health and safety standards that are based on the risk of the release and encompass a graded approach to implementation are needed to address the safety, technical and resource challenges associated with decommissioning, site release and clearance. It is also important to have realistic implementation approaches in order to address these challenges. The international community faces a daunting challenge when addressing these issues. The need for a graded approach has long been recognized, especially from the perspective of radiation protection principles, in order to address the inherent differences in emergency response, worker protection and limits to public exposure. We must balance expending the operator and regulatory resources needed to avert doses that lie far below the recognized and recommended safe range [3] with the associated cost and consequences to society.

## 2. ADEQUATE STANDARDS AND IMPLEMENTATION

In order to fully comprehend the challenges associated with setting standards for decommissioning, site release and clearance, we must be prepared to answer the following question: What is the cost of such actions and what is the benefit or return? The Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management [4] can provide a forum for bringing harmony to the regulatory systems either in place or those being developed or modified to address environmental cleanup and clearance. In addition, the international community is developing recommendations on radiological criteria for the removal of regulatory control from materials, equipment and sites (publications of the European Commission, IAEA, etc.). The United States Nuclear Regulatory Commission (NRC) and other US Federal agencies have been very active in the international arena in terms of clearance and the control of radioactive sources. The NRC is evaluating a graded approach for clearance for materials in the range of a few tens of μSv/a. This would establish a complete radiation protection framework that would include separate criteria for environmental remediation and clearance of materials.

In the area of environmental remediation of sites and release of sites from regulatory control, the NRC established risk informed, dose based standards in 1997 [1]. The NRC requires that residual radioactive material at sites not result in a dose to the average member of the critical group of more than 0.25 millisievert per year (mSv/a) from all environmental pathways and that these doses are as low as is reasonably achievable (ALARA). This approach is consistent with International Commission on Radiological Protection (ICRP) Publication 82 [3]. The NRC believes that remediation of sites to levels that permit unrestricted use is the preferable alternative. However, it is recognized that flexibility is needed in the remediation of nuclear sites because all sites may not be able to reach an unrestricted release status. Therefore, the NRC also provides for license termination with restrictions on future site use if it can be justified to the regulator. Restrictions can be graded according to the risk on a site specific basis.

We support separate environmental site cleanup and clearance standards because our experience indicates that a single standard for environmental remediation and clearance will not meet the need for adequate protection without undue burden on operator and regulatory resources. In our view, a graded risk informed/performance based approach should be used in conjunction with threshold limits. Our experience also supports the philosophy of not placing clearance and environmental remediation in the same dosimetric range, because the benefits may not support the environmental costs. For example, at sites with soil or groundwater contamination, remediation may cause excessive environmental damage to comply with a 10 μSv/a dose constraint. Finally, because there is an inherent difference in the implementation strategy between complex site cleanup and the release of commercial products that contain slight amounts of radioactivity, the use of a single standard is not appropriate. Cleanup is associated with land, natural resources and real estate. Clearance involves the movement of material, equipment, and physical property. A summary of the interrelated factors that influence implementation is given below.

## 3. DECOMMISSIONING

The NRC regulates (10 CFR Part 20) the decommissioning of materials and fuel cycle facilities, research and test reactors, and power reactors, with the ultimate goal of license termination. The current NRC dosed based unrestricted release limit is 0.25 mSv/a (total effective dose equivalent) to the average member of the critical group from all exposure pathways and demonstration that the residual contamination levels are ALARA. Dose cannot be directly measured. In order to demonstrate compliance with a dose constraint, licensees typically establish a surrogate value that can be measured. In the case of NRC licensees, this value is called a derived concentration guideline level (DCGL).

The NRC regulations allow for license termination either for unrestricted use, or restricted use. If a site is released for unrestricted use, the site has met the NRC's dose criteria, and there are no further restrictions on how the site may be used after license termination. The licensee is free to continue to dismantle any remaining buildings or structures and to use the land or sell the land for any type of application.

If a licensee cannot remediate its site to a level that permits unrestricted use after license termination, NRC regulations allow for license termination with restrictions on future site use. This approach requires that licensees establish mechanisms to ensure that potential doses to the average member of the critical group do not exceed 0.25 mSv/a with restrictions in place and that doses do not exceed 1 mSv/a or 5 mSv/a if restrictions fail. The necessary level of protection is ensured by mechanisms such as access to the site, limiting the amount of time that an individual spends on the site, by restricting the use of drinking water, or other institutional control mechanisms. In order to request license termination under a restricted use approach, the licensee must demonstrate that further reductions in residual activity would result in net public or environmental harm, or residual levels are ALARA. The licensee must make provisions for legally enforceable institutional controls (restrictions placed on the deed for property describing what the land can and cannot be used for) which provide reasonable assurance that the radiological criteria will not be exceeded. Institutional controls may range from simple deed restrictions to permanent government control. The licensee must have provided sufficient financial assurance to an independent ‘third party’ to assume and carry out responsibilities for any necessary control and maintenance of the site. In addition, licensees must obtain input from the affected parties in the vicinity of the site about various aspects of the proposed license termination.

The NRC’s staff also has certain obligations to fulfill with respect to public outreach at sites requesting a restricted use approach. Four sites have proposed or are considering restricted release at this time, two of which have submitted decommissioning plans for NRC approval. Currently, these plans are being evaluated by the NRC. The area of institutional controls has been found to be problematic for materials sites. To date, no nuclear reactor licensees have requested restricted release. The NRC’s staff is in the process of evaluating its requirements for restricted use for materials sites to determine whether other options need to be developed. We have successfully transferred institutional control to the US Department of Energy (DOE) for two remediated uranium tailings cells under another regulatory structure (10 CFR Part 40) that explicitly provides for transfer to the DOE.

A large number of the sites that need to be cleaned up are complex sites, significantly contaminated with long lived radionuclides, and with evidence of contaminated natural resources, such as groundwater. Almost uniformly, the challenges in the area of remediation of soil and groundwater contamination have been underestimated. Significant regulatory resources are required to independently review these sites. The NRC is finding that it is difficult to remediate complex sites, even with a 0.25 mSv/a dose based standard, due to the inherent complexity of dose modelling, uncertainty about future site use, and the ability of the licensee to adequately fund remediation. Using a much lower standard (e.g. 10 μSv/a) would result in filling up scarce disposal site capacity sooner, require much more regulatory resources to complete the review and put more operators in danger of bankruptcy for little or no safety benefit. Under some circumstances cleaning up to such a low standard can cause environmental harm. One solution is to utilize more realistic scenarios and dose modelling.

Stakeholders (e.g. the US Environmental Protection Agency , States, the public, etc.) also can influence technical efforts, resources and the time frame required for cleanup. For example, generally, public interest groups request the licensee to go beyond the NRC’s regulatory requirements, including ALARA, in reducing residual exposure on-site. Additionally, State legislation can be enacted to establish lower dose based standards for radioactive material remaining at a decommissioned reactor site, as in the case of the State of Maine. Efforts associated with incorporating agreements and stakeholder comments can lead to additional changes to dose assessments, final status survey methodology, ALARA evaluations, dismantlement activities and data collection and analysis, all of which can significantly increase cost and extend the time required to complete the decommissioning.

For complex sites, funding can be a central issue. There have been cases where contamination occurred before NRC financial assurance requirements were established and funding is inadequate to address the current contamination at the site. There are licensees who have significantly underestimated the amount of funds needed to clean up. The reasons for this oversight include poor planning, incomplete or inadequate site characterization, and the discovery of groundwater contamination after the first stage of cleanup planning. Also, some licensees have experienced bankruptcies, which have restricted their ability to remediate their site.

## 4. CLEARANCE

The issue of the disposition of slightly radioactive solid material has been ongoing in the USA since the 1970s. It remains controversial and, to date, the USA has not developed a clearance standard. Slightly contaminated radioactive solid material consists of objects that contain radionuclides from licensed sources used or possessed by the NRC or State licensees. These materials typically contain radionuclides at low concentrations and are generally released under license specific conditions.

Currently, a better technical basis for establishing radionuclide concentrations in surficially and volumetrically contaminated materials, which might be suitable for clearance, needs to be developed. The IAEA has been in the process of developing guidance regarding commodities recycled from materials used in nuclear facilities in a safe and responsible manner. Experts from the NRC and other agencies have participated in technical meetings to develop guidance and technical protocols for addressing this subject. During the past several years, the NRC has been developing a technical basis [5] for releasing these types of materials, either for unrestricted use or in certain restricted applications (shielding in nuclear facilities). Following a series of public workshops and Commission exchanges with various private and public stakeholder groups, it was decided to defer any decision on modifying the current case specific approach to clearing materials such as metals having low residual radioactivity. The NRC requested the National Academies of Sciences (NAS) to review the current approach to the control of such material and to provide the NRC with recommendations on dealing with such materials. The NAS's recommendations were published in the spring of 2002 [2]. The Commission is deliberating on how to proceed in this matter. If it is determined that rule making should be initiated, the NRC would evaluate the environmental impacts and cost–benefit of alternatives. Specifically, the NRC would evaluate the implications of a rule with regard to the National Environmental Policy Act of 1969. Such an evaluation would consider both radiological and non-radiological impacts associated with alternative dose criteria for the release of materials for unrestricted and restricted use. Public participation and stakeholder comment would play a significant role in the decision making process.

Although the USA has not yet established national requirements for general clearance of materials and commodities, the NRC does provide its licensees with regulatory guidance and direction for the release of surficially contaminated materials. Materials licensees can release materials from regulatory control if the levels meet agreed upon surface contamination limits [6], typically specified in license conditions or technical specifications.

Materials that are volumetrically contaminated pose a unique challenge. At this time, the NRC does not have pre-established volumetric concentration limits, nor has guidance been developed to aid in determining if it is appropriate to release the materials from licensed activities. Standards for the release of volumetrically contaminated materials need to be developed and the effects of the implementation of such standards on other regulatory areas (e.g. disposal of ordinary waste, transportation and surficially contaminated materials) must be considered. For example, reconcentrating processes and exposures from parts of many commodities or materials needs to be assessed. Some scenarios could result in doses greater than a proposed dose criterion of 10 μSv/a. This needs to be carefully analyzed. Furthermore, there is a risk that neighbouring states and countries could reject commodities when regulatory implementations are inconsistent with their own.

During decommissioning for authorized release under NRC rules, the dose constraint is based on an all pathways dose limit of 0.25 mSv/a to the individual occupying the site after license termination. If a licensee decides to leave anything on a site, such as equipment, materials, subsurface piping, or buildings standing at the time of license termination, the amount of residual radioactivity present on the equipment must be factored into the all pathway dose estimate. However, the clearance of materials from any operating licensed facility, based on much lower limits such as 10 μSv/a, would be derived using assumptions and parameters different from those used to develop the site specific DCGLs for decommissioning. Questions can be raised about further disposition of residual volumetrically — or surficially — contaminated material, after license termination, as opposed to before license termination. Experience shows that the contamination left at sites that have unrestricted release is remediated to levels much lower than the DCGL set based on a constraint of 0.25 mSv/a. Any subsequent removal of such material is likely to result in further dilution and mixing.

Another concern relates to State governments in the USA that regulate sanitary landfills and their prohibitions on disposing of radioactive material in these landfills. These States may establish more stringent criteria than the NRC's release limits. As such, if a site with buildings meeting the NRC's decommissioning limits were demolished, the resulting waste would still have to pass the landfill's waste acceptance requirements. In addition, owners of sanitary landfills may not be willing to accept 'cleared' material unless the levels of residual radioactivity meet their State or local regulator's requirements, which may be more stringent than those required by the NRC. Therefore, regardless of the limits set by the NRC for either decommissioning or clearance, other regulatory authorities may impede the disposition of material from decommissioning in anything other than a licensed radioactive waste disposal facility.

There is also an overriding non-technical issue that must be considered when discussing clearance, i.e. the interest of the ultimate users of the cleared material. Groups such as manufacturers of commodities using recycled or reused materials, users of commodities, State governments, landfill owners, and other Federal government agencies may express interest in the process and may become central to the ultimate fate of the material or site. Experience in the USA has shown that industries, in general, do not support the clearance of slightly radioactive solid materials for unrestricted recycling, no matter how restrictive the clearance standard might be. For example, steel from former nuclear facilities undergoing decommissioning has not been readily accepted by steel recyclers, due to the stigma of being slightly contaminated and the potential that they will not be able to market the recycled steel. Therefore, if the ultimate customer finds the clearance levels unacceptable based on perceived risk, then the economic viability of a company's products is at risk and little support for clearance will be seen.

## 5. SUMMARY

In summary, the international community is at a crossroads regarding setting environmental standards and clearance practices. If 10 μSv/a is set as an environmental remediation standard, our experience shows that it would be extremely difficult to meet for complex sites. Furthermore, experience indicates that this low level could potentially result in harm to the environment, unnecessarily expend scarce resources which could be directed towards more urgent societal problems (e.g. security for radioactive sources), and absorb already scarce regulatory resources in order to reduce already low doses. Therefore, it is important in developing site release limits to consider the consequences associated with setting standards at very low levels. The international community should consider a graded approach that accounts for the need to reasonably apply scarce resources when dealing with small numbers to avert doses that lie far below the recommended safe range [3]. We should not implement standards that could result in adverse impacts to the environment and expend scarce regulatory resources simply to adhere to the concept that lower doses are always better.

We know from experience that decommissioning is often more expensive and takes longer than originally estimated. We believe that a uniform release standard of 10 μSv/a, for all sites and situations, will not work effectively, and we advocate using a graded approach in conjunction with threshold limits. It is necessary to harmonize regulatory policies on a global basis and obtain generally agreed requirements for the release of sites in order to optimize resources used to address public health and safety and protection of the environment. Even with an appropriate dose based standard, the challenges facing sites undergoing decommissioning are daunting. Resources need to be focused on remediating sites and returning them to beneficial uses instead of expending resources to reduce already safe exposures to levels that have not been shown to provide any additional protection. In addition to this meeting, the momentum established by the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management [4] fosters a regulatory environment for bringing harmony to the regulatory systems either in place or those being developed. This ultimately should lead to a complete radiation protection framework that would include separate criteria for environmental remediation and clearance of materials.

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# RELEASE OF RADIOACTIVE MATERIAL, EQUIPMENT, BUILDINGS AND SITES FROM STATE SUPERVISION

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**Abstract**

The decommissioning and, above all, the dismantling of nuclear facilities generate large amounts of radioactive residues and wastes. The volume of waste can be reduced by certain conditioning technologies, for example high pressure compression, drying or solidification by cementation. However, the largest reduction can be achieved by the recovery of radioactive residues within the economic cycle. In this respect, the clearance of parts contaminated only to a minor degree, and their recycling, is an important factor. Thus, the clearance of radioactive residues is of great practical significance.

## 1. PRACTICAL SIGNIFICANCE OF CLEARANCE OF RADIOACTIVE MATERIAL IN THE FRAMEWORK OF RELEASE FROM STATE SUPERVISION UNDER NUCLEAR LEGISLATION

### 1.1. Former legal basis in Germany

In Germany, the owner of a nuclear facility is responsible for the 'harmless' recovery (or making safe) of radioactive residues or for their proper disposal as radioactive waste. In this respect, the owner of the facility has a right of choice between safe recovery and proper disposal as waste. Accordingly, safe recovery has been permissible in Germany from the outset.

However, it has always been disputed under which conditions an intended use or recovery of radioactive residues, buildings, plants, plant equipment or sites can be regarded as harmless. Harmless means that there is no damage either now or in the future. The criterion to assess harmlessness is the state of the art in science and technology. However, opinions among scientists vary, so that there is often uncertainty about the state of the art.

In this uncertain situation, the Supreme Court in Germany conceded a scope of discretion to the executive organs within the range of scientifically acceptable opinions. Compared with the legislative sector, the executive organs were considered to be ‘much better’ prepared for such a decision. After all, the executive organs carry the burden of assessing the harmlessness, or safety, of a planned recovery of radioactive residues within the range of scientific opinions. The executive organs act through their authorities, which are the supreme authorities of the Federal Government and the Länder. So, the nuclear regulatory authorities have the executive power to define and assess the safety of an intended recovery of radioactive residues.

The authorities have made use of these assigned powers. By licences or so-called declaratory administrative acts, they have specified which legally relevant properties an object must have to be regarded as harmless. In concrete terms, it has been determined in each individual case up to which limiting value certain radioactive residues can be recovered safely.

In Germany, there was a discussion on whether the authorities can make such decisions, although until recently there has been no clear legal basis for the clearance of radioactive residues. This is because in a constitutional state the principle is that the authorities can only issue legal regulations if they can refer to a corresponding legal basis of authorization. Until recently, there has been no such basis of authorization.

On the other hand, a specific basis of authorization for the actions of the authorities is not always required in a constitutional state. A legal authorization only becomes necessary if the administrative act constitutes a burden for the citizen. This means, for example, interference with civil liberties, private property, health or even the life of a person. If, however, the administrative act is legally beneficial without any infringement of other people’s rights, the authority does not need a legal authorization for this administrative act.

Consequently, the nuclear authorities were allowed to make clearance decisions if they were able to demonstrate that these decisions were legally beneficial and they would not infringe the rights of any other person. For the plant owner, the legal benefit is obvious, since it was allowed to recover radioactive residues with specified limiting values under certain conditions. However, this recovery could be detrimental to third parties. If, for example, a third party is exposed to radiation which exceeds the natural exposure by only a little, this may have health effects — even though to a marginal degree — if calculations were based on the existence of a dose–effect relation.

Roman law, however, has greatly influenced Europe. In many cases, German law also has its roots in Roman law. The Romans long ago had an exception for the so-called trivial, for the insignificant. Matters of no relevance were to be left unconsidered in the application of laws. So, the principle ‘de minimis non curat lex' had already been applied in ancient Rome. Literally translated, it means that the law does not apply to trivial matters. This principle is widely used in German law, with many examples in civil law but also in public law.

According to international standards, the so-called 'trivial' dose amounts to 10 μSv per year and per exposure in a single event. For this reason, recovery of radioactive residues may be regarded as being harmless in terms of a trivial risk if it only leads to an additional individual radiation exposure of 10 μSv per year and per exposure pathway at a maximum.

With which activity limit values such a minimum exposure has to be presumed is determined by the competent nuclear authority in the form of an administrative act, e.g. by a licence, if and as long as the limit values of such a minimum exposure have not been regulated by the law yet. Of course, such administrative acts require a detailed substantiation by means of scientific expert opinions.

The trivial dose already mentioned has been established by the IAEA. According to it, a radiation exposure of 10 μSv per exposure pathway and per year is internationally regarded as 'de minimis', meaning that a harmless recovery can be presumed. On the basis of this value, so-called clearance levels are derived. Below these levels, clearance measurements can be performed for the respective material, which can then be returned to the economic cycle, which means that it can be reused or recycled.

## 2. RIGHTS OF THE LICENSEE FOR CLEARANCE OF RADIOACTIVE RESIDUES

### 2.1. Amended legal basis since 1 August 2001

Since 1 August 2001, a completely amended Radiological Protection Ordinance (Strahlenschutzverordnung — StrlSchV) has applied in Germany. For the first time, it regulates the so-called 'clearance of radioactive residues', such as movable objects, buildings and sites. This regulation is detailed and comprehensive.

The new Radiological Protection Ordinance contains a separate section exclusively dealing with clearance issues. According to it, the holder of a licence issued under nuclear or radiological protection legislation, which also comprises licences for the decommissioning or dismantling of a nuclear power plant, may use, recover, dispose of and possess radioactive material or transfer it to third parties as non-radioactive material under certain conditions. The same applies to activated or contaminated movable objects, buildings, sites, plants or plant equipment. The prerequisites for clearance are the so-called ‘clearance notice’ issued by the respective authority and demonstration that the requirements of the clearance notice have been fulfilled by the licensee.

The holder of a licence issued under nuclear or radiological protection legislation has a legal claim to the requested clearance notice, since according to the respective provision, the competent nuclear authority has to grant the clearance in writing. The authority has no scope of discretion if the effective dose to an individual does not exceed the range of 10 μSv per calendar year.

From a legal point of view, the clearance notice is an administrative act which releases radioactive material as well as movable objects, buildings, sites, plants or plant equipment activated or contaminated with radioactive substances from regulations under the Atomic Energy Act and its ordinances, in particular the Radiological Protection Ordinance. Legally, this clearance notice (which constitutes an administrative act) has the effect that the substances or objects released from state supervision are no longer regarded as radioactive material despite their existing radioactivity, or that they are no longer contaminated. This represents a ‘judicial fiction’. Although something is radioactive as a matter of fact, it is legally declared as non-radioactive. The legislator is allowed to effect such a judicial fiction. Occasionally, this occurs in other sectors as well. The ministries issuing ordinances are entitled to a judicial fiction if it is based on a formal legal authorization.

Due to this special legal point that radioactive material is no longer to be regarded as radioactive material after clearance according to the law, the clearance notice issued by the authorities is not a declaratory administrative act but an administrative act which forms the legal situation, since this regulatory decision leads to a new legal situation insofar as a material which is radioactive is to be regarded as non-radioactive material from a legal point of view.

Consequently, the owner of a nuclear facility may use, recover, dispose of and possess radioactively contaminated objects, materials, buildings, sites, plants or plant equipment, or transfer it to third parties on the basis of the clearance notice, which he/she can claim according to the law under certain conditions, if it has been demonstrated that he/she fulfilled the requirements of the clearance notice in detail. So, the licensee has many options for the use, recycling or disposal of materials with minor contamination, due to the new legal situation.

## 2.2. Types of clearance

A distinction is made between two types of clearance of contaminated materials: in the case of unrestricted clearance, contaminated materials can be brought into the economic cycle for any purpose. There is no stipulation for a special type of use or recovery. Compared to this, the purpose restricted clearance is directed at a special type of recovery or use, so that clearance of these materials may only be granted for a specified recovery or use.

### *2.2.1. Unrestricted clearance*

This clearance is only permissible for the following five materials: solid material, liquid material, building rubble and excavated soil, sites and buildings for the purpose of reuse and further use.

The following requirements have to be fulfilled with regard to solid materials: specified clearance levels have to be observed for each individual radionuclide. The contamination of a material with $^{60}$Co must not exceed 0.1 Bq/g. In addition, certain provisions have to be observed which are laid down in a special annex to the new Radiological Protection Ordinance. This is of particular importance in the case of more than one radionuclide. For this case, a special molecular formula has to be used, since it has to be ensured for a solid surface that the surface contamination will not exceed the values specified in Annex II to the Radiological Protection Ordinance. For $^{60}$Co this value amounts to only 1 Bq/cm$^2$.

If all these conditions are fulfilled, the competent nuclear authority may presume that the unrestricted clearance of solid materials will only lead to an effective dose to an individual ‘in the range of 10 μSv per calendar year’. Consequently, the nuclear authority has a right of presumption that the so-called ‘trivial dose’ of 10 μSv per year will not be exceeded when applying the mentioned limit values and calculation formula in the annexes to the Radiological Protection Ordinance. Since the legal wording refers to an “effective dose in the range of 10 μSv per year”, it is harmless if a dose exceeds 10 μSv per year in the individual case. Even the Federal Government presumes in its official statement that in fact up to about 20 μSv may be reached in a calendar year. After clearance, the materials are no longer radioactive materials.

With regard to liquid materials, other clearance levels have to be adhered to. For $^{60}$Co it is again the value of 0.1 Bq/g.

For building rubble and excavated soil with an expected volume of more than 1000 tonnes per calendar year, lower clearance levels have to be adhered to. For $^{60}$Co, this only amounts to $9 \times 10^{-2}$ Bq/g. In addition, the molecular formula mentioned above has to be used again for several radionuclides, because the averaging mass for the clearance measurement of building rubble must not exceed 1 tonne as a rule. If these requirements have been met, the authority issues the clearance notice.

For sites, other clearance levels have to be used. For $^{60}Co$ it is $10^{-2}$ Bq/g. The averaging surface for the surface contamination must not exceed 100 $m^2$.

Likewise, specific clearance levels are applicable to buildings for reuse and further use. For $^{60}Co$ it is only $4 \times 10^{-1}$ $Bq/cm^2$. In addition, the molecular formula mentioned earlier has to be used. Moreover, the averaging surface must not exceed 1 $m^2$. In this connection, it is also important to mention that after clearance of a building, the building rubble from later demolition does not require a separate clearance procedure.

As a result, the competent nuclear authority has a right of presumption regarding the observation of the so-called trivial dose "in the range of 10 μSv per calendar year" if the above mentioned conditions have been fulfilled and, in particular, if the specified clearance levels are adhered to. However, the right of the authorities to presumption is not to be equated with a presumption obligation. According to the legal provisions of the German law, the authority is entitled to exercise this right to presumption, but there is no obligation for it. The authorities have power of discretion which, however, according to the German legislation, has to be exercised in relation to a specific purpose and without any faults.

In practice, this means that in general the authority will exercise the right to presumption. Only if there are concrete indications in the individual case that the so-called trivial dose in the range of 10 μSv per calendar year to an individual could be exceeded despite adherence to the specified clearance levels and other provisions, may the authority reject the right to presumption. In this case, further expert opinions will probably be commissioned. Possibly, the authority will then fix even lower clearance levels. However, this situation will only arise in a few exceptional cases.

### *2.2.2. Purpose restricted clearance*

In the case of purpose restricted clearance, the materials cannot be used without restrictions. Clearance can only be granted for a specific purpose.

Regarding the clearance of solid materials for disposal, higher clearance levels are applicable in comparison with unrestricted recovery. For $^{60}Co$, the clearance level amounts to 4 Bq/g. In the case of more than one radionuclide, the calculation has to be performed by means of the molecular formula. Recovery or reuse of the materials outside the disposal site has to be excluded. Moreover, solid materials may only be stored at a disposal site without biological or chemical pre-treatment. In the case of a solid surface, specific levels have to be observed regarding surface contamination. For $^{60}Co$ it is again 1 $Bq/cm^2$.

If liquid materials are to be burned, the applicant again has to observe specific levels. For $^{60}Co$ it is 4 Bq/g.

Specific clearance levels also apply to buildings for demolition. For $^{60}Co$ it is 3 Bq/ $cm^2$. In addition, the applicant has to use the above mentioned molecular formula in the case of more than one nuclide.

Regarding the clearance of metal scrap for recovery, the applicable levels are particularly low. For $^{60}Co$ it is 0.6 Bq/g. These low clearance levels are based on a recommendation of the national commission on radiological protection. Another requirement is that the metal scrap may only be released for recycling if it is intended to melt it down.

#### 2.2.2.1. Clearance in special cases

The German law also includes provisions for special cases. If, for example, certain legal requirements cannot be fulfilled in the individual case due to special circumstances, a clearance decision nevertheless has to be made. Or there are no clearance levels for specific radionuclides. In all of these cases, the competent nuclear authority may also verify the observation of the trivial dose of 10 μSv per calendar year 'by other means', as is stated in the ordinance. The authority can, for example, commission an expert's opinion to verify that only a minor dose occurs in the case of a specific clearance path. Besides, the situation may arise that a certain recovery or disposal path is chosen which is not provided for in the ordinance. For such atypical individual cases, the nuclear authorities have a certain scope of discretion. In this case, however, the trivial dose must not exceed 10 μSv per calendar year.

Finally, there is another special case. In general, the holder of a licence issued under nuclear or radiological protection legislation applies for the clearance of specific radioactively contaminated materials. Occasionally, it may occur that a clearance for radioactive materials is granted although there is no licensee who could apply for such a clearance. In this case, it is stipulated in the German law that the competent authority may officially issue the clearance notice even without an application, provided of course that the effective dose to an individual does not exceed the range of 10 μSv per calendar year. This regulation may become important in connection with so-called 'nuclear aftercare' if, for example, radioactive material is found for which ownership cannot be determined.

### 2.2.2.2. Practical implementation of clearance

In general, the clearance procedure begins with the application by the holder of a licence issued under nuclear or radiological protection legislation. On the basis of this application, the competent authority first checks if the prerequisites for an administrative right to presumption are fulfilled. Therefore, the authority has to examine if the corresponding clearance levels can be observed, and if the other requirements are met. If this is the case, the authority has the right to presumption that the clearance will only cause an effective dose to an individual in the range of 10 μSv per calendar year.

As a next step, the authority issues the clearance notice, in which the authority often establishes the so-called 'clearance measurement procedure'. In this respect, the authority has a certain range of options. For example, it can request supplementary expert's opinions or stipulate a certain technique for the clearance measurement. This clearance measurement is of particular importance with regard to complex building structures, sites and building rubble.

After receipt of the clearance notice, in which the clearance measurement procedure is specified, the applicant can begin with the actual clearance measurement. If requested by the authority, the specific clearance measurements have to be attended by authorized experts. The results of the clearance measurements have to be documented.

The clearance measurement procedure ends with the statement of the person responsible for radiation protection, or the radiation protection officer of the plant concerned, that the requirements stipulated in the clearance notice have in fact been fully met by the clearance measurement. In some cases, the authority demands an attestation of an authorized expert which then, of course, has to be submitted. Only then can the respective material, or parts of it, be used, recovered, disposed and possessed, or transferred to third parties as non-radioactive material. Within the framework of State supervision, the authority checks — at least by sampling — if it was always demonstrated, as prescribed by law, that the respective cleared batch actually complied with the requirements of the clearance notice.

It has to be emphasized that only the clearance notice represents an administrative act. The later attestations, if requested, given by the expert and/or the authority do not constitute administrative acts because it is not a matter of a regulation in the individual case, but only ascertaining that everything has proceeded in an orderly way in accordance with the stipulations of the clearance notice.

## 3. ASSESSMENT OF CLEARANCE IN THE NEW GERMAN LEGISLATION

It is to be welcomed that finally we have a clear legal basis for the clearance of radioactive material in Germany. In the past, the nuclear authorities could only refer to general legal principles and not to specific legal regulations for their clearance decisions.

Another improvement is the authorities' right to presumption under observation of specified criteria, because it provides a high degree of legal certainty for the nuclear authorities and the applicants. For individual cases, however, the regulations are very complicated, but this is probably due to the complexity of the technical subject matter. Thus, the advantages for clearance resulting from the new legal regulations prevail in the final assessment.

# PANEL DISCUSSION

# CRITERIA FOR REMOVAL OF CONTROLS

*Chairperson:* **J.R. Cooper** (United Kingdom)

*Members:* **J. Averous** (France)
**K.D. Crowley** (United States of America)
**C.M. Maloney** (Canada)
**M. Schrauben** (Belgium)

## Statement

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*1. A clearance system based on universal clearance levels is not sustainable.*

Universal criteria based on radioactivity limits for the removal of control will lead to problems with the public if unexpected or unaccounted for uses lead to significant exposures, or exposures that are not justified.

Universal clearance levels are usually based on the hypothesis of waste dilution in recycling processes (such as for steel). It is prone to criticism and will have to be reevaluated, in particular if extended dismantling programmes are carried out in a country or through unique steel recycling companies, leading to changing clearance levels. Moreover, in some cases, industrial processes can lead to radionuclide concentration in some materials, like slag, that can lead to disposal or recycling problems.

Social demands can lead to changes in the impact levels accepted in the future, leading to difficulties. In France, a system has been implemented that is not based on clearance levels for release in the public domain. Provided that it is implemented on a coherent, nationwide basis, this system does not lead to an excessive burden for the industry, and has led to a wide social acceptance of the system.

*2. Clearance on a case by case basis is feasible*

On the other hand, it is possible to clear material on a case by case basis, provided that the clearance pathway of the material is well defined, and an impact study is provided. The clearance pathway has to be authorized after an open discussion has taken place between involved stakeholders, including representatives of the public and of antinuclear associations. A follow-up system has to be provided to be able to identify items involving cleared materials, should concern arise afterwards. If the material is recycled, clearance impact criteria do not have to be taken into account, and the impact study has to be made on a case by case basis.

### 3. *Segregation between 'conventional' and 'radioactive' waste is achievable*

The objective is to achieve a segregation between 'nuclear waste' (waste susceptible to be or to have been contaminated by radionuclides or activated) and 'conventional waste' (waste that is not susceptible to be or to have been contaminated nor activated). Note that this distinction is made without using any screening level to distinguish between 'nuclear' and 'conventional' waste categories. The definition of 'nuclear waste' is quite wide and clearly contains a measure of precaution.

This segregation between nuclear and conventional waste has to be made without any measurement basis in order to provide a valid additional line of defence in the whole system; hence other arguments are needed to make this distinction. These arguments are:

— An analysis of the functions achieved by the materials within the facility, which determines if they can ever be contaminated or activated;
— An analysis of the past operating history of the facility, including incidents and accidents, in order to determine whether this material has served another purpose or could have been contaminated during an incident or an accident, which are situations in which the facility is operated beyond its normal operating boundaries.

It can be seen that these arguments are strongly linked to the physical position of the object or material in the facility; hence the distinction between 'nuclear' and 'conventional' waste can be made on a geographical basis. A corresponding facility waste zoning can be implemented.

Linked with appropriate radioactivity measurements, that increase confidence that conventional waste is indeed conventional, this system can provide a high level of confidence in this segregation. This system has been implemented successfully in France, and has been shown to not put an unbearable burden on the operators, provided that it is included in a nationwide, coherent policy, including available and cost efficient waste elimination options (e.g. repositories) for very low level waste.

## Statement

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In the short time allotted for my comments I would like to cover two topics: The first is to briefly summarize the results of a recent National Research Council report on establishing clearance standards for the release of radioactively contaminated materials. The second is to offer some personal observations related to the first question posed to the panel on the definition of release criteria.

*National Research Council report.* This report, The Disposition Dilemma: Controlling the Release of Solid Materials from Nuclear Regulatory Commission-Licensed Facilities, was undertaken at the request of the US Nuclear Regulatory Commission (NRC) to help inform its deliberations on the development of a new standard. The Research Council was asked to provide advice on the following issues:

— The sufficiency of the technical bases needed to establish a standard;
— How to incorporate the concerns of stakeholders in the standard setting process;
— Changes, if any, that should be made to the NRC's current clearance system.

The principal finding of the report is that the NRC's current case by case clearance approach is workable and protective of public health, but that it is inconsistently applied, not risk based, and it has no specific guidance for the clearance of volumetrically contaminated materials.

Accordingly, the report recommends that the NRC:

— Proceed forthwith to evaluate alternatives to the current system;
— Involve stakeholders in a broad based evaluation process of alternative approaches;
— Adopt a dose based standard as the primary standard and consider the establishment of a separate collective dose standard;

— Use 10 μSv per year as a starting point in establishing a dose based standard;
— Continue to review, assess and participate in ongoing international efforts to manage the disposition of slightly contaminated materials.

*Definition of release criteria.* The question "How clean is clean enough?" arises frequently in my organization's work for the Federal Government on cleanup of the US nuclear wapons complex, which includes some 135 sites. The cleanup programme is a good laboratory for understanding some of the release issues being discussed here and has helped to shape my thinking.

My comments apply primarily to the situation in the USA, and most of my comments relate to the regulator–stakeholder (public, political bodies, other regulators) interface, which increasingly is seen to be the rate limiting part of the process.

In the USA, criteria for the release of nuclear sites are defined using a dose based standard: 0.25 mSv per year with as low as reasonably achievable (ALARA). Most experts agree that this standard, if implemented appropriately, is protective of public health.

It will not come as a surprise to this audience that there is resistance to this expert view, and also resistance to efforts by US regulators to establish criteria for releasing radioactively contaminated materials. I believe that there are at least two reasons for this resistance, both of which are related to stakeholder trust and confidence:

— The criteria that have been implemented or proposed are difficult for most stakeholders to comprehend, and many are unwilling to rely on the assurances of regulators that the criteria are protective.
— Disagreements between the two primary regulatory authorities (the US Environmental Protection Agency and the NRC) over the numerical values of criteria for unrestricted site release (the so-called 15 versus 25 millirem debate) has not inspired public confidence. It also has led some to conclude that the numerical difference between these standards is significant.

This lack of confidence is being expressed, as it often is in democratic societies, through political action: Several US States have adopted unrestricted release standards that are more protective than the Federal standard, and the legislature of our largest State (California) recently directed its regulators to develop such standards. The news media has reported that some California legislators favour a 1 millirem (10 μSv) per year standard. Implementing such a standard would be an expensive and technically daunting challenge.

Can criteria be defined in a way that will improve their likelihood of wider public acceptance? Our thinking on this issue has evolved considerably over the past decade, and several reports of the National Research Council have suggested that the explicit use of *risk based standards* by regulators could improve stakeholder acceptance.

The use of risk based standards has several distinct advantages:

— They provide opportunities for stakeholders to provide meaningful input because they allow the proposed standards to be compared with standards for other societal hazards. This provides for the possibility of harmonization.
— They require regulators to make explicit all of their assumptions about the relationships between radionuclide concentrations and human health risk.
— They also require regulators to acknowledge uncertainties in the knowledge base.

I should point out that risk based standards can be expressed in terms of dose. The difference is the way in which the standard is derived and presented to stakeholders: A risk based standard is derived from an explicit analysis of the relationship between concentrations and health risk, information about the analysis is provided to stakeholders (preferably in an understandable form), uncertainties are acknowledged, and the final standard is set by taking into consideration acceptable risks for other societal hazards through a broad based stakeholder participation process.

Regulators in the USA are taking some steps in the right direction in this regard. The NRC, for example, is adopting what it calls a *risk informed* approach for regulating nuclear activities. The US Department of Energy is also beginning to show an interest in using risk based approaches for decision making in its cleanup programme.

Experience in the USA suggests that the establishment of a clearance standard is likely to be a long and painful process. I would like to suggest that the NRC and the international community give careful consideration to the use of risk based approaches as they evaluate alternatives for establishing these standards.

Thank you for your attention.

**Statement**

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In Canada, we have not yet decommissioned a nuclear power plant, although there are some prototypes in safe store. However, we have decommissioned a commercial isotope production facility and a small research reactor facility, and the sites were ultimately released from regulatory control. We are currently involved in regulating the decommissioning of Atomic Energy of Canada's research facility at Whiteshell in Manitoba and various small infrastructure programmes at the Chalk River National Laboratories. For these type of projects, IAEA guidance forms the basis for our regulatory decisions. Clearance of materials is based on IAEA guidance criteria. These criteria are used for material contaminated with artificial radiation or with technologically enhanced naturally occurring radioactive material.

We have not established clearance criteria for material bound for recycle or reuse for the simple reason that the industries that would receive such material have taken a 'zero tolerance' stance. Scrap steel recyclers are loath to take material with any level of contamination in case it cannot be passed on.

The main decommissioning or remediation experience in Canada is with historical uranium mines and their associated tailings, and with contaminated lands associated with the historical use of radium and uranium. These are really intervention activities.

While Canadian nuclear regulation does not contain explicit criteria for the release of buildings or sites from regulatory control, our current regulatory scheme does specify that the regulator may order the cleanup of unlicensed sites that could give rise to doses greater than 1 mSv/a We have therefore taken that criterion of a potential dose of 1 mSv/a to be the upper bound for cleanup for historically contaminated sites and then apply as low as reasonably achievable (ALARA) considerations to establish site specific clearance levels.

Since many of these sites are in rural areas with a very low population density and varying traditional uses, we take site specific approaches to assessing potential doses. For example, as well as establishing maximum acceptable gamma dose rates, we acquire information on local hunting, fishing and product gathering practices and estimates of the typical times that could be spent on the land in question. As you can imagine, this requires extensive consultation with the local population. We believe this approach is a good one as it helps build confidence in the local population that their situation is understood, and is particularly important when we are dealing with communities which still obtain a significant portion of their diet directly from the local area.

In some situations, sites have been released completely from regulatory control. In other situations, regulatory controls could be reduced to requirements for posting of warning signs, public education programmes and filing of information on recommended restrictions with the local government land registry.

In summary, Canada is taking a site by site approach to decommissioning and remediation projects using criteria consistent with international guidance.

**Statement**

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The question of clearance of materials, buildings and sites from regulatory control is one of the most controversial and discussed questions, if not the most, at all conferences, workshops and working groups dealing with decommissioning. In fact, the aspects of clearance, recycling and reuse have a major influence on global decommissioning costs. Furthermore, these questions involve different stakeholders: on the one hand the owner and operator of the plant, on the other hand the general public and, between both, the regulator. Finally, the recent evolution of the regulations related to the use within the non-nuclear industry of materials containing natural radioactivity and to the cleanup of contaminated sites from post activities leads necessarily to the comparison of criteria to be handled in both industries.

What are the differences between these industries? One difference is certainly the public relationship to those industries, and thus the public perception of the risk from the material handled in both industries. On the one hand, it is fissile material, which must be dangerous; on the other hand it is fertilizer, which nearly everybody spreads over his or her land. That cannot be dangerous, it is accepted because it is part of normal life such as driving a car, and the risk is considered normal. But one more becquerel in a car arising from cleared steel from the nuclear industry is not normal, and thus not accepted. The nuclear industry is thus faced with a public perception leading to a public acceptance of zero additional doses from that industry, while a non-negligible additional dose from medicine and normal life such as flying are accepted.

Another difference is certainly the type of material contaminated with radionuclides and the type of radioactivity. On the one hand, we have mainly metals and concrete contaminated or activated. And there is even a difference between contaminated and activated structures. In fact, existing decontamination techniques make it more or less easy to decontaminate most structures with only surface contamination, whatever are the clearance limits; it is possible to recover the basic material behind the removable contaminated layer. In the case of activated shielding structures, however, the thickness of the layer considered as radioactive depends greatly on the clearance criteria. On the other hand, stakeholders have to deal with enormous amounts of slightly contaminated raw material or process residues, mostly with isotopes from the U and Th families.

I would like to finish this introduction with a few observations from a remediation project of a storage area where Ra contaminated residues and debris from a former non-licensed Ra production facility are stored. The authorities in my country are now dealing with this remediation programme. The disposed amount of contaminated material is in the range of 220 000 $m^3$, between three and four times the amount of low level waste arising from all the licensed practices in the country since the beginning of nuclear activities and including future waste from the decommissioning of existing plants. The activity concentration of the Ra storage area is of the order of 10 000 Bq/g at some places, but the average concentration is somewhere between 10 and probably 100 Bq/g.

Should we now treat this material in the same way as contaminated material from controlled areas? Or should we manage the waste from decommissioning as we will manage that from this Ra contaminated storage? Or should we use different strategies? These are some of the questions for discussion.

**Panel Discussion**

## CRITERIA FOR REMOVAL OF CONTROLS
## Session 2.E

S. THIERFELDT (Germany): In his oral presentation, Mr. Linsley said that the criteria for the clearance of a site should be compatible with the criteria applied in authorizing discharges from the site into the environment. In my view, however, discharges authorized during the operation of a facility do not relate to the subsequent clearance of the facility site. For example, some short lived radionuclides present during the operation of the facility may not be present at the time of site clearance, when, moreover, there will no longer be any direct irradiation from the operating facility.

G. LINSLEY (IAEA): You seem to be assuming that there is only one facility on the site, so that there will be no authorized discharges from the site once that facility has been shut down. In the case of a site with two or more facilities of which only one has been shut down, however, the facility or facilities still operating may be discharging radioactive substances into the zone which you are trying to clean up — for example, discharging at a rate of 0.3 mSv/a while you are trying to clean up to the 10 μSv/a level.

S. THIERFELDT (Germany): In my view, 250–300 μSv/a is more appropriate than 10 μSv/a as a clearance level for sites.

G. LINSLEY (IAEA): I thought that in Germany the policy was now to clean up sites to 10 μSv/a.

S. THIERFELDT (Germany): You are quite right. The site clearance levels contained in Germany's Radiation Protection Ordinance have been calculated on the basis of 10 μSv/a, and it is fairly easy to meet the 10 μSv/a requirement in the case of most sites in Germany (the Wismut sites are an exception and are being treated differently). In other countries, a value higher than 10 μSv/a may be more in line with the ALARA principle.

K. SCHIFFER (Germany): Mr. Lentijo spoke about a range between 10 μSv/a and 100 μSv/a in which intervention might be necessary. I like the idea of such a range. Would Mr. Lentijo care to elaborate?

J.C. LENTIJO (Spain): This range is only for hypothetical or improbable events that could in the future give rise to individual doses of 1 mSv/a or more. Its use is contrary to the normal approach based on 100 μSv/a that is followed in considering realistic scenarios for the future use of the site. If you use an improbable scenario and it leads to an individual dose in the future of 1 mSv or more, you have to intervene at the site.

J.L. REVILLA (Spain): Further to what Mr. Lentijo just said, I would mention that, if we consider, say, a forestry scenario, we take 100 µSv/a, but we can also consider a hypothetical residential scenario some time farther in the future — for example, if we have some hot spots in the area and have to intervene at those hot spots. This kind of intervention is taken into account in the figures.

H. EFRAIMSSON (Sweden): Regarding levels for conditional clearance at Vandellós, you said that you had a limit of 1 mSv/a for potential individual doses in connection with low probability events. Do you quantify the probability of the events, and how does this comply with the European Directive of 1999?

J.C. LENTIJO (Spain): We have not yet quantified this probability. The hypothetical, improbable scenario is (as I tried to explain) not realistic. In the analysis, we request the licensee to provide us with possible scenarios. That means that there are one, two or more realistic scenarios. For example, at Vandellós they are considering an industrial scenario for 30 years and after that a combined industrial and residential scenario. These are being considered in the context of the realistic approach, for 100 µSv/a. But you can imagine other scenarios, like the ones Mr. Revilla just mentioned. We cannot calculate their probability, but know that they are not probable.

G. LINSLEY (IAEA): Reference was just made to the European Directive of 1999, in which there are the same exemption levels as in the International Basic Safety Standards. The exemption levels take account of the fact that some scenarios have to be considered unlikely but cannot be completely ignored. The 1 mSv/a criterion is used for unlikely scenarios. It is contained already in the calculated exemption levels in the International Basic Safety Standards. So it is not a new concept. It is always difficult to judge what is probable and what is not, but probabilistic thinking is part of the process of deriving levels.

J. GINNIVER (United Kingdom): In Germany does material from decommissioning, which has been decontrolled for unrestricted use, carry any indication that it was once radioactively contaminated?

H. SCHATTKE (Germany): No, it does not. Such an indication might well suggest that there was something wrong with the material and unnecessarily deter potential users.

K. SCHIFFER (Germany): In the USA what is done about sites that have been released with restrictions - 'brown field' sites?

J.T. GREEVES (USA): The US Nuclear Regulatory Commission (NRC) issues almost every year a report containing a list of such sites and indicating those about which it is concerned. In extreme cases, the State where the site is located or the Federal Government may assume ownership of the site, but neither individual States nor the Federal Government are keen to assume ownership of large numbers of sites. The NRC is considering a “graded approach” to situations ranging from that extreme to the opposite one, complete de-restriction. In doing so, it hopes to match restrictions to risks in such a way as to avoid unnecessary burdens on society at large and on licensees.

V. MASSAUT (Belgium): Could Mr. Greeves give examples of adverse impacts of excessively stringent cleanup requirements?

J.T. GREEVES (USA): In one case, a licensee who had budgeted about $25 million for decontaminating a building and about $1 million for removing a small amount of soil was suddenly confronted with cleanup requirements necessitating the removal of far more soil — at a cost of some $100 million. The licensee was almost bankrupted. The moving of huge amounts of soil is a major haulage operation, in the course of which accidents may occur, and the soil may well fill up the low level waste disposal site — a valuable resource. In addition, trying to ensure compliance with excessively stringent cleanup requirements is not a sensible use of the time and energy of the regulatory body.

G. LINSLEY (IAEA): In my oral presentation, I did not put sufficient emphasis on the need for an international agreement regarding clearance criteria for materials which might become the subject of trade between different countries. Without such an agreement, a country may find itself being asked to accept materials from abroad which would not be cleared within its own territory but have been cleared in another country.

C. PAPERIELLO (USA): At this conference there have been references to concentration numbers which, if introduced into the screening models that I use, would give doses much higher than those mentioned in the presentations.

Regarding the question of clearance, what crosses international borders is concentration, not dose, so for me concentration limits are more important than dose limits. The variation in the literature of the parameters used in the models for deriving concentrations is sufficiently large for you to increase the concentration by factors of ten or more through your choice of parameters (for example, soil-to-plant transfer factors, resuspension factors, deposition velocity and ergodynamic diameters). Furthermore, you can have assumptions about how the material is going to be used, which may also introduce big variations. In the USA, we have found that the models used by different Federal agencies give concentrations varying by as much as a factor of ten for the same dose, so we are now trying to develop a unified model. Besides an international consensus on dose, we perhaps need an international consensus on the models.

J.R. COOPER (United Kingdom): That is an interesting observation. With a consensus on the dose and on the models, it might be possible to arrive at a consensus on the derived quantities.

S. THIERFELDT (Germany): From what has been said here by Mr. Linsley, Mr. Reisenweaver and others, I thought that a consensus on the models had already been reached. In Europe, there has been the exercise described by Mr. Lentijo, and the European Commission's recommendations regarding the release of slightly radioactive residues from nuclear facilities (RP 89, RP 113 and RP 122) provide clearance levels that are appropriate for European countries. The IAEA has used a similar approach in the development of the clearance levels that are in its draft safety guide on 'Radionuclide Content in Commodities not Requiring Regulation for Purposes of Radiation Protection', and these levels are considered to be appropriate worldwide as they are based on a very cautious approach. So, I think that at least part of what Mr. Paperiello just called for has already been done.

W.A. BIRKHOLZ (Germany): Before releasing land on the site of the Greifswald nuclear power plant, we shall have to determine the levels of artificial radionuclides of caesium, cobalt, nickel, iron and other elements. The only problematic element will be caesium, owing to contamination from the Chernobyl accident and the atomic bomb tests of the 1950s and 1960s; caesium-137 will have to be taken into account. That is not difficult, however, as the relationship between the caesium and cobalt carried out of a nuclear power plant by air can be calculated and measured — and cobalt is very easy to measure.

When the land is released, it will be released for unrestricted use, although initially it will be used for industrial purposes. The reason why the land will be released for unrestricted use is that, as the site is near the Baltic Sea, we imagine that after 50–60 years people may well want to build sanitoria and similar facilities there. It is not easy to have unrestricted release of nuclear power plant sites, which is written into the German Radiation Protection Ordinance, with the same clearance levels as for materials.

J.R. COOPER (United Kingdom): Do you mean by "unrestricted release" that the annual doses will be less than 10 μSv?

W.A. BIRKHOLZ (Germany): The unrestricted release of land is based on the 10 μSv/a clearance criterion.

J.R. COOPER (United Kingdom): So you advocate the same criterion?

W.A. BIRKHOLZ (Germany): Yes.

J.T. GREEVES (USA): That criterion could probably be met in the case of most reactors in the USA. We release some 300–400 sites a year. At a few of them (not reactors normally) there are problems due to the contamination of large amounts of soil and/or to groundwater contamination, and it would cost a further $100 million per site to clean up to 10 μSv/a. However, it is possible to meet the 250 μSv/a criterion at these sites with about the level of effort being expended at Greifswald. We therefore subscribe to the ALARA concept.

G. LINSLEY (IAEA): Regarding the question of whether we should have the same clearance criteria for both land and materials, I think that from a general radiation protection point of view it is dangerous if we adopt a 10 μSv/a standard for everything — we will have very little flexibility in dealing with unexpected future situations. The scheme which I described in my oral presentation is consistent with the current ICRP and IAEA schemes for the protection of people, and I think we should use those schemes, which allow countries to adopt optimized levels within the dose constraint, choosing to use 10 μSv/a if they wish.

H. SCHATTKE (Germany): I should like to raise three points regarding Mr. Averous's oral presentation.

Firstly, I gathered from his oral presentation that, in Mr. Averous's opinion, it is impossible to measure the activity of land surfaces. I disagree with that opinion. We have performed such measurements at Greifswald. You cannot measure becquerels per gram, but you can measure becquerels per square centimetre using a different measurement method.

Secondly, I disagree with Mr. Averous's opinion that universal clearance levels are unnecessary. I believe that such levels are necessary in a world where there is transborder trade in materials derived from the decommissioning of nuclear facilities.

Thirdly, Mr. Averous seemed to doubt whether it is possible to measure the activity in materials. Again I disagree. At Greifswald there is equipment which is used in taking measurements for the purpose of determining whether materials can be released. The equipment is able to detect even very tiny hot spots in materials that are being measured.

J. AVEROUS (France): I did not mean to imply that in my view it is impossible to measure the activity in material. In my view, however, it is very difficult. For example, you may be performing bulk measurements on dismantled pipes, applying surface contamination and bulk contamination criteria. A problem arises if there is surface contamination inside the pipes. Unless you open up or chop up the pipes and look inside them, you will not detect that surface contamination and the material will be declared to be conventional — and it may later give rise to contamination. So, if you are dealing with dismantled pipes from a part of the plant where there was probably radioactive contamination, you cannot rely solely on your Bq/g measurement results however good is your measuring equipment. You need a special system for resolving the problem.

I. AULER (Germany): For over ten years there has been equipment available for measuring 'hidden' radioactivity inside tubes — something which we have been doing for 12 years. Currently we are measuring 1200 tonnes of very small tubes which are contaminated inside, and so far we have measured 200 tonnes with good results. The secret is to have the right procedures.

J. AVEROUS (France): This is what I meant when I spoke about a special system for resolving the problem.

J.R. COOPER (United Kingdom): Is there broad agreement, then, that any values developed for the clearance of materials should be linked to some measurement protocol?

J. AVEROUS (France): I would go further than that, especially as I think that the clearance levels are too low. In many industrial cases, the values are so low that it is difficult to perform measurements in step with dismantling. Also, there are a lot of alpha contaminated facilities besides reactors. How can you perform bulk measurements on them?

J.R. COOPER (United Kingdom): I accept that point, but in my view it is covered if we agree that any values developed for the clearance of materials should be linked to some measurement protocol.

J. AVEROUS (France): I agree.

G.C. JACK (Canada): There is a basic difference between land and materials — land does not move, whereas materials may move around a lot, including internationally. Perhaps individual countries should be allowed plenty of flexibility in establishing national release criteria for land, while we aim for internationally agreed levels for the release of materials. That pragmatic approach would, in my view, make life easier.

J.R. COOPER (United Kingdom): I agree.

J. AVEROUS (France): In this connection, I would like to make a clear distinction between, on the one hand, universal clearance levels and, on the other, international trade, about which I said nothing.

As regards the issue of international trade in commodities, I would accept that you define, at the international level, some limit values below which the responsibility of the producer of the commodity will not be questioned in international trade. However, I believe each country should at the same time have the right to choose whether or not to permit the importation of the commodity. If a country wishes to have clearance levels that are more restrictive than the internationally agreed ones, it should be allowed to.

C.M. MALONEY (Canada): An argument for treating land and materials differently is that if you release land and subsequently realize that you should not have, you can place the land back under regulatory control, whereas that may be very difficult in the case of materials which have been released. In Canada, we are having difficulties in regaining control of radiation sources which we now think should not have been released.

L. GOODMAN (USA): A problem with a release level for land of 10 μSv/a, besides the cost of cleanup to that level, is the cost of carrying out surveys to prove that that level — which may be lower than background — has been reached. I know of cases where as much as $20 million are being spent on the final surveys at sites in the USA — and that is with our clearance criteria.

As regards materials, on the other hand, besides moving around they may also accumulate. So for them I do not think that a clearance level higher than what we have been talking about is appropriate.

R. SHWEIKANI (Syrian Arab Republic): In my view, we do not need internationally agreed release criteria for land but we do need internationally acceptable models for assessing land contamination which can be used in most countries — including desert countries like the Syrian Arab Republic, where the contamination pathways differ from those in, say, countries with substantial forest cover. Perhaps the IAEA could help to develop such models.

V. ŠTEFULA (Slovakia): In Slovakia, we have a clearance level for land of 10 μSv/a, which is regarded as a target. Operators are allowed to optimize, it being understood that they will do their best and spend a reasonable amount of money on dose reduction. The monetary expenditure is treated as 'justifiable expenses'.

J.R. COOPER (United Kingdom): In the United Kingdom, the National Radiological Protection Board has moved away from that approach. From comments made this week, I think there is a feeling here that countries should be able to deal with the question of land release as they see fit, since land does not move, and that it would be useful if, with IAEA assistance, models were developed for assessing exposures from contaminated land.

J.T. GREEVES (USA): I would urge the IAEA to establish an international standard of the kind referred to by Mr. González in the Opening Session and by Mr. Linsley just now in his oral presentation. Without such a standard — for example, 300 μSv/a — we are going to have harmonization problems. That does not mean that a country would not be able to use a lower number.

M. SCHRAUBEN (Belgium): How do you explain to the public that it is considered safe to drink milk on one side of an international border and unsafe to drink the same kind of milk on the other side? Such problems arose after the Chernobyl accident, and I therefore believe that it is important even in the case of land to have standardization of clearance levels and a common explanation of what constitutes risk and what is dangerous.

J. FORD (IAEA): Explaining risk related matters to the public is a matter for professional communicators. In a forum like this conference, the focus should be on the technical question of whether land really differs from materials as far as clearance is concerned.

J.L. REVILLA (Spain): A problem with materials that does not exist in the case of land is the fact that a critical group can be affected by materials cleared at different facilities — for example, a foundry receiving scrap metal simultaneously from different decommissioning projects.

H. SCHATTKE (Germany): Situations may arise where people are afraid to live near a site which has been released because they know that the clearance levels in their country are higher than in other countries. In my view, therefore, we need international standards for the clearance of land.

R. MECK (USA): Is the IAEA in a good position to establish international clearance levels? I would suggest that it is, since the scope of the International Basic Safety Standards is radiological protection, the scope of IAEA Safety Standard No. 89 is also radiological protection and the concept of clearance is defined within the scope of radiological protection and is applied only to practices.

Because there appears to be international consensus on Safety Standard No. 89, within the scope of radiological protection and trivial dose, there is an implied international consensus on clearance. We recognize that there can be criteria which are outside the scope of radiological protection. Our experience in the USA is that when we apply a rigorous and high quality process to identify which materials are candidates for clearance, then the materials are actually clean - they are not different from materials in general commerce. This conclusion is based on quality control measurements carried out to check the process. This experience is consistent with paper CN-93[51] in the collection of contributed papers for this conference.* However, such measurement checks of the high-quality procedures imply clearance levels, because, when we select the sensitivity of measurements, we also select clearance levels in practical terms.

We need the IAEA to provide quantitative guidance on clearance levels within the scope of radiological protection. Such guidance should also address the situation where a State finds it necessary to apply conditions that are outside the scope of radiological protection. Paper CN-93[51] mentions concern about public acceptance. This is outside the scope of radiological protection. Therefore, within the scope of radiological protection, which is the scope of the International Basic Safety Standards, it appears that the IAEA is in a good position to provide international guidance on clearance levels. We need the IAEA to provide guidance from the standpoint of radiological protection and trivial dose. The IAEA can independently address, in other guidance, levels of long lived radionuclides in commodities from areas or regions where interventions have taken place. This is a separate, although overlapping, issue.

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* AVEROUS, J., CHAPALAIN, E., "Building confidence in decommissioning in France", these Proceedings, contributed papers; see the CD-ROM in the back of this book.

C.M. MALONEY (Canada): In my view, it is fairly easy to assess technical risk in the field of radiological protection. Should we not, however, also be considering criteria such as stakeholder acceptance, taking into account those people who are most averse to risk?

K.D. CROWLEY (USA): In my view, different societies differ as to what is an acceptable risk. You may be able to set international standards, but the regulators in each individual country will have to consult the stakeholders in that country.

J. AVEROUS (France): I do not know of any country where, say, steel recyclers would accept steel cleared in the course of a decommissioning project. In my view, this issue needs to be addressed before we try to set clearance levels from a purely technical — radiation protection — point of view.

L. JOVA SED (IAEA): Further to what Mr. Meck just said, I would emphasize that the IAEA works not only for the 20–30 Member States that have very good radiation safety assessment infrastructures. Its guidance can be of use to all countries wishing to set clearance levels. As the guidance is non-binding, countries can set clearance levels other than those recommended by the IAEA, but many countries will take the IAEA's recommendations on board as they stand.

I. AULER (Germany): With regard to what Mr. Averous just said, during the past ten years some 20 000 tonnes of material — including about 500 tonnes of metal — from nuclear power plants have been recycled after it had been shown that the residual activity in the material was below Germany's very low clearance levels.

J.T. GREEVES (USA): Earlier, Mr. Averous said that, if a country wished to have clearance levels that were more restrictive than the internationally agreed ones, it should be allowed to. As Mr. Paperiello said still earlier, what crosses international borders is concentration, not dose. That being so, could Mr. Averous accept an approach for trade based on clearance levels in becquerels per gram, with some process for ensuring measurement quality?

J. AVEROUS (France): Provided that I was able to control what happened in my country, I could accept such an approach.

J.T. GREEVES (USA): I am glad to hear it.

C. PAPERIELLO (USA): The IAEA's Code of Conduct on the Safety and Security of Radioactive Sources recommends monitoring for the purpose of detecting orphan sources. In the USA, border monitoring for radioactive materials is obviously a major issue since 11 September 2001, and our detection devices will detect materials with activity levels equal to the clearance levels being considered within the IAEA and European Union frameworks. Without an international agreement on the clearance of materials, we will have to take a decision whether to issue an import licence every time such materials are presented at our borders by prospective importers and are not simply contaminated with naturally occurring radioactive material. That will be a big legal problem for us.

J.R. COOPER (United Kingdom): It seems to me that your purpose would be served better by numbers for international trade than by numbers for clearance.

H. EFRAIMSSON (Sweden): Don't the exemption levels in the International Basic Safety Standards fulfil that purpose?

G. LINSLEY (IAEA): It is true that we have a set of exemption levels that are common to the International Basic Safety Standards and the European Union's basic safety standards. The only issue is the quantities involved. The exemption levels were calculated on the basis of fairly small quantities in terms of mass and, if you do the calculations for larger quantities, the numbers become more restrictive. If you were moving materials across international borders in amounts exceeding, say, one tonne, you would probably have to use the more restrictive numbers.

S. THIERFELDT (Germany): It appears that Mr. Averous would accept a set of clearance levels for commodities but not an international set of clearance levels, although his caveats apply to both sets. He implied that the scenarios would not be comprehensive enough. However, the scenarios underlying the European Commission's recommendations regarding the release of slightly radioactive residues from nuclear facilities (RP 89, RP 113 and RP 122) are fairly comprehensive. Besides, there could be monitoring over a period of years, or even decades, to see whether the practice of clearance was in compliance with the assumptions, and adjustments could be made if it was found not to comply with them. Some countries would benefit from an international set of clearance levels if they did not wish to develop a set of their own. France would not have to accept the international set.

J. AVEROUS (France): For me, the question of clearance levels for international trade is a legal — not a technical — question. If materials contain activity at levels above the clearance levels, you can send them back to where they came from.

As regards adjustments, most scenarios for calculating clearance levels presuppose some dilution of metal from decommissioned nuclear facilities by metal from conventional facilities, but there will not be that degree of dilution in a given country once a major nuclear power plant decommissioning programme starts generating 10–15 times more metal for recycling. What does one do then — set new clearance levels that are 10–15 times lower? I have great misgivings about the idea of adjusting clearance levels.

S. THIERFELDT (Germany): In my view, Mr. Averous's point is not a valid argument against the setting of international clearance levels. It is addressed in European Union documents RP 89 and RP 113, which are based on a very conservative assumption of all the nuclear facilities in a given country being decommissioned at the same time.

J. AVEROUS (France): But what does one do if one has to lower one's clearance levels some day?

S. THIERFELDT (Germany): I assure you that it will not be necessary.

R. MECK (USA): In our calculations, the final results of which should be available early in 2003, we addressed the question, "What if a vast amount of steel from nuclear power plant decommissioning goes to a foundry and is not diluted?" We found no critical gap in the logic or approach.

J.R. COOPER (United Kingdom): There is clearly a polarization of views here, but perhaps enough common ground as regards international trade for the IAEA to develop some criteria.

R. MECK (USA): If I, as a member of the public, have not been told what level for trade is safe from a radiological protection point of view, I shall feel rather uncomfortable — and the IAEA has not stated what it considers to be a trivial concentration for dose.

C.M. MALONEY (Canada): That is a matter not only for the IAEA but also for us national regulators, and it is a major challenge. When a scrap metal dealer's portal monitor is triggered by radioactive material, we cannot say whether the material is safe — we can only say whether the material complies with a certain limit and whether the scrap metal dealer should, in our view, keep the material. The scrap metal dealer is left with a very uncomfortable feeling. We need to do something about this.

We also need to do something about educating people in the recycling business so that they become more tolerant with regard to radioactive material. Some of them now understand NORM and don't worry about it too much, but they still worry about radioactive caesium and cobalt.

J. AVEROUS (France): In France, in the 1980s and early 1990s, we had as clearance levels the ones generally applied in those days. However, acceptance problems arose in connection with recycling, perhaps due in part to local lack of confidence in the authorities, and the end-users of recycled material refused to accept such material if it contained even a single becquerel of artificial activity. Consequently, recyclers refused to accept material from the nuclear industry and the system became completely blocked. We therefore no longer rely on clearance levels, but keep nuclear waste separate from conventional waste, so that there is a high level of confidence that the conventional waste does not contain any artificial radionuclides.

J.T. GREEVES (USA): We are looking into the possibility of conditional clearance of metal from nuclear power plant decommissioning for reuse within the nuclear industry, since metal recyclers in the USA will simply not accept such metal.

J. AVEROUS (France): We already have conditional clearance for reuse within the nuclear industry, and it works. As regards unconditional clearance, there is some, but it is always on a case by case basis, with the involvement of the stakeholders.

J.R. COOPER (United Kingdom): Clearly, recycling within the nuclear industry is an interesting possibility.

V. MASSAUT (Belgium): In my view, recycling within the nuclear industry is not 'conditional release' — control over the material is never relinquished.

J.T. GREEVES (USA): This is probably a matter of terminology: perhaps we need to use a term other than 'conditional release' when talking about recycling within the nuclear industry. A good example of conditional release is when you release material for disposal in a landfill.

J. AVEROUS (France): We are considering — as a kind of conditional release — the release of low level scrap metal for use in making pipes for the petroleum industry. It is easy to carry out the necessary impact studies, and the petroleum industry can be required to dispose of the pipes safely in due course.

S. THIERFELDT (Germany): When France starts decommissioning nuclear facilities on the scale that Germany has been decommissioning such facilities, will recycling within the nuclear industry and conditional release for use in, say, the petroleum industry enable it to deal with the many tonnes of waste metal that will be generated?

J. AVEROUS (France): A great deal of such waste metal cannot be recycled, so we have established a dedicated very low level waste repository that charges prices more or less the same as the prices charged by repositories for chemical waste. A vast amount of waste metal from nuclear power plant decommissioning will be disposed of at that repository. We think that the system will work, even if decommissioning has to be interrupted occasionally because some becquerels of activity were detected somewhere where they were not expected — something we have been living with in France for some time.

J. GINNIVER (United Kingdom): The basis for the release of materials and of sites has been the doses which people may receive as a result of their release, and we need to make the public understand that a dose from artificial radionuclides is no worse than the same dose from natural ones. For that reason, I do not see why the criteria for the release of materials and sites contaminated with natural radionuclides should differ from those for the release of materials and sites contaminated with artificial ones. Different criteria simply reinforce the public perception that all work done with artificial radionuclides is very dangerous and that natural radionuclides are relatively harmless.

I would welcome views about the release of uranium mining and milling facilities, as the release criteria often correspond to dose levels that are higher than would be acceptable in the case of facilities contaminated with artificial radionuclides.

J. AVEROUS (France): I wish Mr. Ginniver luck if he tries to decontaminate a uranium mining and milling facility down to 10 μSv/a. In France, we have a dose constraint of 1 mSv/a for the remediation of uranium mining and milling facilities. This is quite high (although there are, of course, justifications and ALARA requirements), but it is more widely accepted by local people than a release limit of 10 μSv/a in the case of a nuclear facility with artificial radioisotopes.

M. SCHRAUBEN (Belgium): Something that must be borne in mind in this connection is the matter of costs. The amounts of NORM (and TENORM) associated with uranium mining and milling facilities and the like are enormous, and it is as a rule prohibitively expensive to decontaminate such facilities to the levels to which one decontaminates nuclear power plant sites.

C.M. MALONEY (Canada): As in France, we have a dose constraint of 1 mSv/a for the remediation of uranium mining and milling facilities. The extent of pressure to remediate to a lower level depends on the confidence of the local stakeholders in the regulator and the former facility operator. Moreover, when the local community understands something about ambient background radiation, realizing that, say, there are rock outcrops in the vicinity which are more radioactive than the mill tailings, they appreciate the regulator's problems and do not press for 10 μSv/a.

K.D. CROWLEY (USA): It is not always necessary to decontaminate uranium mining and milling facilities and the like to unrestricted release levels. Many can be put under administrative control so as to restrict access to them. That is what we are doing in the USA in the case of many sites with uranium mill tailings. Already, some 50 sites have been capped and fenced in and are now subjected to quarterly or annual inspections — and groundwater monitoring in some cases.

When the DOE’s cleanup programme has been completed, there will be over 100 DOE sites under administrative control, which will have to continue for a very long time in some cases owing to the uranium and other long lived radionuclides present.

M. SCHRAUBEN (Belgium): Putting a site with an area of, say, 100 $km^2$ under administrative control is feasible in a vast country like the USA, but hardly feasible in a small, densely populated country like Belgium.

J. GINNIVER (United Kingdom): Much of what has been said confirms my view that the criteria for dealing with artificial radionuclides and those for dealing with natural ones should be the same, and it confirms the IAEA’s view that it is the optimization of cleanup which is particularly important. If it is reasonably practicable from a social and an economic point of view to remediate a site to 10 μSv/a, you should do it. However, in the case of, say, sites with huge amounts of only slightly radioactive material, that may not be the optimum solution.

J.R. COOPER (United Kingdom): What about material? Deriving value concentrations on a 10 μSv/a basis for natural radionuclides, you may find that you are regulating most things.

R. MECK (USA): I think we need to be clear about some of the concepts that we have been using here. The comments made about the practicability and costs of cleaning up sites contaminated with natural radionuclides relate to the principle of justification — is there a net benefit in cleaning up the sites? If you decide that there is a net benefit, you optimize. That may not lead you to the per annum dose level that is considered to be a trivial dose — and what we are talking about in terms of setting criteria is based on this 10 μSv/a — and so, in a situation where you have a commodity with natural radionuclides, it once again depends; if, for example, you have a big piece of equipment from a uranium mine, you may be able to decontaminate it to a trivial dose level and therefore clear it in the sense that we have been talking about — or at least it would be acceptable from a radiological protection point of view (there may be other criteria that the government wants to put on it). However, if you have a truckload of high phosphate fertilizer, you may need to apply justification and optimization to those circumstances. If we keep these principles distinct in our minds and try not to force them to be the same, it may clarify our thinking.

D.W. REISENWEAVER (IAEA): I should be interested in hearing views about whether buildings should be treated as land or as materials. In one IAEA Member State, the people want to release a building and we are trying to decide which criteria should be applied.

W.A. BIRKHOLZ (Germany): In our Radiation Protection Ordinance there are clearance levels for buildings. The clearance levels depend, besides the radionuclides present, on what is to happen with the building after it has been released — is it going to be torn down or is it going to be used?

A particularly tricky question is whether one should regard the underground canalization of a nuclear power plant as a building or as part of the land. Much depends on whether it is to be left in situ or removed, and it is a question which we have not yet resolved. The related question of whether entombment is an acceptable alternative to immediate dismantling and safe enclosure applies especially to underground structures.

J.R. COOPER (United Kingdom): There seemed to be a general feeling that the same criteria should be applied to natural as to artificial radionuclides, but there are clearly practical problems when one comes to deriving numbers; one may find oneself having to regulate everything in the world. Perhaps one may have to fall back on the principles for exemption — the risks should be so low as not to warrant regulatory concern, and exemption is the optimum regulatory solution — rather than the criteria, which are problematic numerically. One might, as Mr. Meck implied, reach different end points for natural and artificial radionuclides if one adopted that approach.

# CLOSING SESSION
# AND PRESENTATION OF FINDINGS

## (Session 3)

**Chairperson of Session**

**W. RENNEBERG**
Germany

## Summary of Session 2.A

# DECOMMISSIONING STRATEGIES AND REGULATIONS

**Chairperson**

**H. SCHATTKE**
Germany

The discussion focused largely on the decommissioning of large nuclear facilities. Equivalent strategies and procedures need to be developed for the safe decommissioning of the many other applications in medicine, industry and research involving radioactive materials.

The twin bases for successful and safe decommissioning are sound and robust decommissioning plans and a framework for continuous regulatory oversight of the implementation of these plans.

Planning for decommissioning should start early. Ideally, decommissioning considerations should have been taken into account at the design stage. In practice, however, for existing facilities the aim should be to start planning decommissioning well before the end of operation.

Three basic decommissioning strategies are envisaged as possibilities for nuclear installations: immediate dismantling; safe enclosure prior to deferred dismantling; and entombment. All have advantages and disadvantages, but immediate dismantling is the generally preferred option. However, there are a number of factors that might lead operators to choose one of the other strategies, and each situation should be examined case by case to identify the optimal strategy.

Immediate dismantling typically has the fewest uncertainties. It also eliminates the risks associated with the facility as promptly as possible, normally costs less than delaying and allows the retention of operational staff who know the facility and its history to contribute their expertise and experience during decommissioning.

Safe enclosure may have benefits for safety in facilities for which short lived radionuclides represent an important source of the risk, it may provide 'breathing space' in cases where sufficient funding is not yet available, or it may be convenient where there are multiple facilities on the same site. However, such benefits should be considered in the context of the additional costs associated with providing long term surveillance and maintenance, the problem of ensuring that sufficient expertise and knowledge will be available for dismantling, and the additional uncertainties introduced by delay. For example, financing may be more difficult to guarantee, there may be unforeseen changes in regulatory requirements or the availability of waste disposal facilities, the condition of the facility may deteriorate despite care and maintenance programmes, and some equipment may need to be recommissioned after a long period.

Entombment is used in some Member States for certain types of facility, and these need to be considered on a case by case basis. As a general guide, entombed facilities should comply with radiological criteria for waste disposal facilities, but more specific international guidance would be welcome on the acceptability of and conditions for use of the entombment strategy. Entombment may be an option for States needing to decommission a single facility, for example, one research reactor, and in cases where there are no resources to develop or obtain the infrastructure needed for dismantling and waste disposal.

Approaches to regulating the implementation of decommissioning plans vary — for example, some regulators require operators to have specific licences for each stage; others maintain continuing regulatory oversight through existing licence conditions — but the common aim is to provide effective regulatory control to ensure safe decommissioning.

The transition from operation to decommissioning will usually be accompanied by organizational changes, particularly reductions in staff. Such reductions may be inevitable, but the operator must manage the change so as to retain the expertise needed and to guard against a degradation of safety culture due to demotivation of the remaining staff. The regulator also needs to be particularly vigilant in relation to the possible effects of such changes.

The safety situation at a facility will typically change much more often during decommissioning than during operation, and the safety case may therefore need to be updated more frequently. Although the general trend will be for the risks to reduce, there may be short term increases in risk, particularly to workers, for example during decontamination or dismantling of a normally inaccessible part of a plant. Unexpected conditions may also be encountered, and decommissioning plans and regulatory attitudes need to be sufficiently flexible to deal with such situations.

Decommissioning is hindered if suitable disposal routes are not available for the different waste types generated during decommissioning. Two issues are of particular concern. Firstly, internationally accepted criteria are needed for the ‘clearance’ of materials that do not need to be treated as radioactive waste, to avoid unnecessary cost and taking up of capacity in repositories. (Such criteria need to be internationally agreed, because such materials, once they are designated ‘non-radioactive’, can enter international trade without any controls.)

Secondly, many States do not have repositories for radioactive waste, or have insufficient capacity to cope with large volumes of decommissioning waste.

The absence of an available disposal route has been used as another argument for the safe enclosure strategy rather than immediate dismantling, the idea being that dismantling is delayed until a repository is available. Otherwise, waste needs to be conditioned to a stable form suitable for long term storage, with the possibility that it may need to be conditioned differently for disposal in the future. Thus, in addition to the factors discussed above for choosing between strategies, the cost of waste storage and the possibility of reconditioning need to be added to the disadvantages of immediate dismantling, but again, each specific situation needs to be examined on its merits.

The ultimate aim of decommissioning is to allow the removal of some or all regulatory control from a site, but internationally agreed criteria for the removal of such controls are needed. (Unlike materials, sites do not cross national borders, and so national criteria may be sufficient, but internationally agreed criteria would be preferable.) Release of the site for uncontrolled use (i.e. any use) is the generally preferred option, but this may not always be practicable, and controls on the future use of the site may need to be maintained. International guidance would also be welcome concerning the situations in which significant amounts of radioactive material can be left on a site, and the conditions that should be applied in such cases.

## Summary of Session 2.B

# PLANNING AND IMPLEMENTATION

**Chairperson**

**L. KEEN**
Canada

This session can be summarized by a statement in one of the papers given in the session: "Dismantling of nuclear facilities is basically not a technical problem but a challenge to project management and logistics once the legal and economical boundary conditions have been clarified".[1]

The session balanced generic principles and concerns raised by decommissioning projects with practical examples of lessons learned from some specific projects and raised some key issues for all involved in decommissioning — whether regulator, operator or other stakeholder.

Ideally, planning for decommissioning should start as early as possible, preferably when the facility is being designed. The planning should address the establishment of mechanisms for the funding of decommissioning and should anticipate that facilities may cease operations prematurely for technical, economic or political reasons. However, in practice that has not always been the case. It was noted that many facilities have less than adequate decommissioning plans or funding mechanisms.

When a facility or activity is shut down it is very important that a formal decision to decommission is made so that the situation is clear to all stakeholders. Examples were given where failure to take a decision to decommission has led to loss of control of large sealed sources (teletherapy sources in Gôiania, Brazil, and Turkey).

When a decision to close down a facility is being made, it is imperative that good communications with all stakeholders are established early. The impact on the work force and the local community due to the cessation of operation of a facility must be recognized and addressed early in the transition from operation to decommissioning. Factors such as uncertainty, potential job losses and diminution of career paths as research careers are replaced by construction/deconstruction jobs all lead to poor morale and an exodus of qualified

[1] RITTSCHER, D., "Decommissioning of nuclear power plants: Project planning and implementation in Greifswald and Rheinsberg", these Proceedings.

staff. One panellist did note that an extended period of safe storage (30 years) did have the benefit that many of the troublesome personnel issues associated with early decommissioning were avoided.

Early in the transition phase it is essential to establish and 'freeze' strategies concerning personnel, dismantling techniques and the regulatory requirements. Regulatory requirements of particular importance are waste categorization and clearance levels. Without such certainty, projects will prove to be more costly, take longer and may give rise to increased public concern.

Decommissioning should start as soon as possible to maximize use of the skilled work force and existing equipment and infrastructure. The German experience of decommissioning WWER reactors showed that prompt decommissioning resulted in lower cost, less waste produced and lower dose commitment. It also has demonstrated that decommissioning of these types of reactors is feasible and, indeed, is not particularly complex.

Attention to safety culture during all phases of decommissioning will assist in ensuring that safety and environmental protection objectives are met, as well as promoting desired worker retention.

It was noted that good record keeping during construction and operation will facilitate decommissioning. Certain types of records should be 'flagged' as key and should be readily available when detailed decommissioning plans are being prepared. These records include as-built drawings, history of incidents and routine surveys. Information from operator staff should be used to supplement the formal records.

Session participants indicated that sharing of practical experience is very valuable. Building on the experience of others should lead to future decommissioning projects being completed more easily at lower cost, with less waste produced and lower personnel doses.

Some issues for future consideration include the following:

— Consider the role of the State in the clearance process: should the State take responsibility for decommissioned sites that cannot be 'green fielded'?
— Consider establishing expert missions focused on decommissioning similar to those of the IAEA's Operational Safety Assessment Review Team and WATRAP.

Actions that could be taken include:

— Clarifying the status of all shutdown facilities that have not declared decommissioning;

— Ensuring that the focus of the decommissioning programme includes all significant fuel cycle activities, including mining and activities involving significant amounts of radioactive material, such as commercial medical radioisotope production, irradiators and teletherapy sources;
— Promoting peer discussion and recording of experience gained from decommissioning projects. (i.e. move from principles to application);
— Promoting stakeholder discussion on planning for decommissioning with special reference to sustainable development and the precautionary principle;
— Investigating safety and environmental protection criteria for the decommissioning of non-nuclear industrial facilities and sites, i.e. compare acceptable risks from residual chemical and biological contamination to radiological contamination.

It was suggested that documents on the following subjects would be helpful in decommissioning activities:

— Guidance on reinforcement of safety culture in decommissioning situations (starting with the decision to cease operations),
— Guidance on entombment,
— Guidance for training of staff involved in decommissioning,
— Guidance on specific regulatory challenges associated with decommissioning.

## Summary of Session 2.C

# FUNDING APPROACHES AND STRATEGIES

**Chairperson**

**J. BARCELÓ VERNET**
Spain

While there is a need to find and use decommissioning strategies and techniques that are cost effective as well as safe, decommissioning is not possible without sufficient funds. Whatever funding arrangements are adopted, their aim is to ensure, with a high degree of confidence, that sufficient funds are available when they are needed to meet all nuclear liabilities. This requires a high degree of competence and care on the part of whoever is responsible for managing the funds, backed up by some form of independent review or oversight.

Three main types of funding arrangement are being used: direct funding from government; funds managed internally within operating organizations (sometimes segregated from operating funds, sometimes not); and externally administered funds specifically established for the purpose (or, in some cases, for the broader purpose of radioactive waste management). Within the European Union, systems of both internal and external types are operating successfully at present.

Accurate and robust estimation of the cost of decommissioning is the fundamental basis for planning funding. This requires not only that initial cost estimates are careful and thorough, but that estimates are regularly and frequently reviewed to ensure that they remain the best possible estimates. Similarly, the adequacy of funds should be checked regularly and frequently against updated cost estimates.

Nevertheless, it must be recognized that even the most careful estimates will be subject to some uncertainty, particularly in relation to unforeseeable factors beyond the control of the operator or fund managers, such as changes in staff or equipment costs, regulatory requirements or government priorities and policies. These uncertainties must be taken into account in planning reliable funding arrangements. A typical approach to technical uncertainties is to add a contingency to the cost estimates, but there may be other possible approaches, such as obtaining insurance against such unforeseen changes.

Similarly, even with the most careful investment planning, there will be some uncertainty about whether the funding arrangements will turn out to be sufficient to meet the costs when they arise, particularly in relation to unexpected changes in market conditions. Some States require that financial provisions are made on the basis of undiscounted costs (i.e. assuming that the value of the funds will keep pace with inflation but the real value will not increase), while others permit discounting of cost estimates. Although discounting has a sound economic basis, the assumption of continuing economic growth over a period of several decades may be considered a further source of uncertainty.

One way of minimizing the uncertainty would be to complete decommissioning as early as possible. However, this benefit of early dismantling must be balanced against the many other factors that influence the choice of decommissioning strategy. This might be expressed as follows: decommissioning should be carried out 'as soon as reasonably practicable', taking due account of all the circumstances.

At present, an important source of uncertainty is the lack of clear and stable definitions of 'boundary conditions', particularly the disposal routes for radioactive wastes and criteria for the release of materials, buildings and sites from regulatory control. The absence of such arrangements in many States is a significant impediment to the reliable planning of funding, and inconsistencies between the arrangements in different States may create difficulties in terms of trade and commercial competition. In relation to clearance criteria, international agreement on criteria would be the best solution. (The European Commission has published advisory clearance criteria for its member States.) The provision of disposal routes, however, is primarily a function of national governments. Clear and definite programmes for the construction of repositories would be of major assistance in planning financial provisions for safe decommissioning.

Some States simply do not have the resources to fund their nuclear liabilities or to carry out decommissioning, and have to seek funding and expertise through bilateral, multilateral or international arrangements. In such cases, the IAEA can play an important role, for example by facilitating co-ordination of activities between the different national and international organizations involved, by working with States to identify the best decommissioning strategies for their national circumstances, and by promoting the international sharing of experience.

## Summary of Session 2.D

# CONSIDERATION OF SOCIAL ISSUES

**Chairperson**

**C. PAPERIELLO**
United States of America

In the technical discussions, it was noted that immediate dismantlement offered the opportunity to take advantage of skilled and knowledgeable plant staff. The technical discussions also pointed to the need for early planning for decommissioning. The same conclusions hold for social issues. Immediate dismantlement continues to maintain the local economy and employment levels and increases the time available to transition to alternative employment and to adjust to alternative economic activities.

Early public participation was seen to be very important, but local conditions determine how this was to be achieved. There was extensive discussion of particular cases, showing unique features and problems associated with each site.

A number of key issues were highlighted:

— There is no single approach to deal with social issues. There are a variety of solutions depending on the social and economic situation in the region, cultural aspects, legal aspects, etc.

— Social issues, i.e. the social and economic impacts on the region, have to be considered from the beginning of nuclear facility operation. Communication between the facility operators and the local communities and other relevant bodies should be an established function long before closure is anticipated to occur.

— There are several social and economic effects of decommissioning to be considered:

- *Individual employment impacts:* Individual impacts of employment losses can be minimized through retirement, social guarantees, retraining, etc.
- *Overall employment impacts:* Direct and indirect employment losses are significant, particularly after the release of the site. However, during the dismantling, in some cases there might be some positive employment effects, particularly because of needed external staff.

- *Economic impact:* Indirect employment losses resulting from the curtailment of local purchases by the facility, and loss of support services.
- *Skills mix:* There might be the risk of losing or not having enough qualified people, who are needed for the decommissioning process. It is therefore important to retain qualified people and to look carefully at which skills are needed during the process. Highly skilled people can more easily relocate.
- *Migratory effects in both directions:* Relocation of particularly younger people.
- *Cultural effects connected to the relocations:* There might be some changes in the quality of cultural and social life in the region due to the migration of well established and active members of the society to other regions.
- Impacts on revenues of local or regional public authorities

— From the social point of view, decommissioning by the decontamination (DECON) option is preferred.

— An effective policy on communication and stakeholder participation is necessary during the entire process. Regardless of the nature of plans for post-closure, there are ways that the public can be involved in planning, which will improve the acceptance of changes that cannot be avoided. Several possibilities for involving the public were presented:

- In the case of Vandéllos 1 in Spain, a public commission dealing in information was created, in which the companies, the administrations of the area and other representative bodies (e.g. local industry) co-operated.
- If clear lines of communication have been established, if local entities are accepted as partners in the planning cycle, if provision has been made for post-closure responsibilities, and if funding for necessary actions in the future has been secured, public acceptance problems that have been identified in the past may not occur in the future (USA).
- A working group was made up of representatives from the political area, company management and workers council of the nuclear power plant, as well as the economic committee of the district council. Its tasks were to analyse the effects of the closure on the region and to find compensatory measures to create new jobs. The aim of local government policies is to prepare for a structural change in the region during the dismantling process (building up tourism, establishing new companies). However, this is making only slow progress (Germany).

  - In some countries there may be a special problem of mistrust of company planning and public authorities in general. To eliminate this mistrust, public hearings, public information centres, etc., have to be established.

— After the decision to shut down the nuclear power plant has been made, new economic alternatives are needed for the area to survive. These have to be planned in advance — e.g. at the released site — based on training/retraining of the people and on the preparations of the companies and entrepreneurs in the area (strengthening of existing sectors or creation of new activities). However, based on the experience presented, greater effort has to be made with regard to diversification of the activities in the region before shutdown in order to avoid negative economic impacts.

## Summary of Session 2.E

# CRITERIA FOR THE REMOVAL OF CONTROLS

**Chairperson**

**J.R. COOPER**
United Kingdom

The papers in Session 2.E dealt with the clearance or release from regulatory control of materials originating from nuclear installations (e.g. scrap, building rubble) as well as of land or sites. We have heard presentations and discussion topics ranging from fundamental items such as radiological criteria to issues like values of clearance levels or specific approaches taken in various countries. Among other things, these papers pointed out the following:

— The concept of clearance is an old one; the principles which govern clearance are laid down in the BSS[1].
— The papers emphasized the importance of clearance as a means of conserving natural resources and repository capacity if the material is otherwise treated as radiological waste.
— Clearance of *materials* and clearance of *sites* certainly need to be distinguished. The reason is that materials may be moved across borders, but sites by and large do not move.
— Appropriate dose criteria for clearance of materials that have been used so far are of the order of 10 μSv/a (or a few tens of μSv/a) for individual dose and 1 man·Sv/a for collective dose (alternatively, clearance is the radiologically optimum solution). These values have been internationally accepted and have formed the basis for numerous sets of clearance levels which are used internationally and on a national basis. For sites, no international agreement of an appropriate dose value yet exists. It certainly needs to be below 300 μSv/a, which corresponds to an International

[1] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, WORLD HEALTH ORGNAIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

Commission for Radiological Protection (ICRP) recommendation for doses from a single practice, but does not necessarily need to be as low as 10 μSv/a. Some countries have used dose values up to 250 μSv/a, others prefer 100 μSv/a, a few even go to 10 μSv/a for sites. It must be taken into account that prescribing very low clearance levels for sites may result in unduly high efforts for site remediation, which would be in contradiction to the principle of ALARA (as low as reasonably achievable).

— From the USA there was an interesting approach for the clearance of sites that may show a solution for many challenges which clearance still provides: the use of a graded approach which uses different standards for different situations or types of facilities. This is also corroborated by the approaches taken, for example, in Spain and Germany, where different clearance options have been implemented (general/unconditional clearance, clearance for specific purposes), all accompanied with their own sets of clearance levels.

Obviously, the international community has accepted the fact that clearance is a necessary option and that it should be fostered internationally. It seems that the dose criterion of 10 μSv/a, or a range of that order, is now also agreed upon as far as materials like scrap, rubble, etc., are concerned. A general approach towards the clearance of sites is, however, only now emerging. It may require a flexible approach; there is no need to deprive oneself of the necessary flexibility by setting a too restrictive dose constraint for sites.

The discussion, which was stimulated by the papers from the morning session and from the statements made by the panellists, was very lively and provided many interesting outcomes. The discussion was grouped according to the following four main topics.

*(1) Release of land versus release of materials — same or different criteria?*

This issue was controversial. Some participants opted for using the same criterion for the clearance of land as for clearance of materials (10 μSv/a); others voted for more flexibility, leaving countries more freedom. After all, material can be traded across borders, land cannot. Meeting 10 μSv/a in all cases might be a waste of effort; there are many types of installations which certainly could meet 250 μSv/a, for example, quite easily; 10 μSv/a, however, could be met only with excessive additional effort which would not be ALARA.

Additionally, it was suggested that internationally accepted models are needed for calculating doses from the residual contamination of sites. Furthermore, it should be kept in mind that it is hard to communicate to the public that different criteria are used in various states for land clearance.

**Conclusion:** Countries should have flexibility to address the issue of land versus material as they see fit. It would also be useful to have internationally agreed models for assessing exposures from contaminated land.

*(2) Clearance levels for materials, transboundary implications, need for internationally accepted levels in terms of Bq/g*

It was stated by some participants that it is essential to have international clearance levels; others disagreed. It was agreed, however, that values allowing international trade in materials, at least, are needed.

There do not seem to be obstacles to defining international clearance levels as far as scenarios, calculations, etc., are concerned. It may also be an option to start with definition of international values for commodities first and consider international clearance levels later.

*(3) Acceptability to the end user*

The acceptable risk level will be different in different societies. Thus, it is not possible to leave out the stakeholders' view, which may mean that clearance levels cannot be determined purely on the basis of dose levels but need to take into account other components, like social acceptance.

It was reiterated a number of times that the scrap industry is equipped with entrance monitors and will not accept radioactivity in scrap materials. For this and for other reasons it might therefore be hard to communicate to the public that cleared material could cause a contamination alarm at a scrap yard, while at the same time it is supposed not to cause any detriment. In some countries, the approach to clearance appeared to be governed by public acceptance to a very large extent.

**Conclusion:** Acceptability is a significant issue, including educating people in matters of radioactivity.

*(4) Natural versus artificial radionuclides: different criteria*

Should the same or different criteria be used for both sectors? Some expressed the view that a dose is a dose — there is no fundamental reason to differentiate between the two areas. If a distinction is made, then it gives the impression that natural radioactivity is less dangerous than artificial radioactivity. This would favour use of the same criteria.

However, while it is true that risk is similar for both areas, public perception issues, practicability and costs are important. These considerations would lead to different criteria.

Justification and optimization seem to be the key words here. This would allow keeping the same basic principles, i.e. justification (net benefit) and optimization with ALARA, while the numerical criteria need not be equal. NORM may not need to be handled within the concept of triviality.

**Conclusion:** Views seem to tend towards having the same criteria for both areas, but this does not necessarily mean having the same numerical sets of values. An alternative is to go back to the basic principles instead of numerical values.

It was also agreed that specifying clearance levels in terms of $Bq \cdot g^{-1}$ per year, or any other measurable value, needed to be accompanied by the corresponding measurement protocol.

# PRESENTATION OF FINDINGS

**Chairperson**

**W. RENNEBERG**
Germany

The conference served an important purpose in bringing together and consolidating information on the termination of nuclear practices from around the world, and the Proceedings will therefore represent a very valuable overview of the current situation. I should add, however, that the information presented at the conference was concentrated on the decommissioning of large nuclear facilities. A concerted international effort should be made to obtain a realistic picture of the scope of the decommissioning task to be expected from the many other practices using radioactive material, for example in medical, industrial and research applications.

In this regard, I note that the IAEA is currently compiling information on the magnitude of this problem, and urge it to continue with this work. This should provide a solid basis for an international discussion of actions to begin solving the problem.

A great deal of practical decommissioning experience that has been accumulated was presented at the conference. The international community should consider ways to make this information more widely available. The IAEA could contribute to this by means of a Web-based chat room dedicated to decommissioning.

One conclusion from the discussion was that the IAEA should ensure that its safety standards on decommissioning are reviewed, improved and updated, and provide more detailed guidance on practical issues.

Turning to the main findings from Sessions 2.A–2.E, six major topics emerged: the importance of early and thorough planning; social issues; funding; waste management issues; long term retention of knowledge; and the removal of regulatory controls.

With regard to the issue of **early planning for decommissioning**, emphasis was placed during the conference on the importance of planning decommissioning thoroughly. Planning should start as early as possible, ideally at the design stage of a facility, as required by the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. A fundamental first step in this planning is to obtain a thorough understanding of the condition of the facility at the end of operations, including knowledge of all the waste streams to be expected during decommissioning.

The decommissioning plan for the facility should include a description of the intended management approach for each of these waste streams. This in turn requires that the State should have national plans in place for the safe management of these wastes.

The overall decommissioning strategy to be adopted should be identified as early as possible in the planning process. The presentations and discussions at this conference indicated a distinct shift towards immediate dismantling as a preferred strategy. This preference seems to be based on a range of considerations, notably the availability of know-how and experienced staff from the operational phase, softening of the local impact and securing of funding. Nevertheless, there will still be cases in which one of the other strategies — safe enclosure or entombment — may be an appropriate approach.

Another prerequisite for planning decommissioning, as emphasized throughout the conference, is the existence and implementation of an appropriate and stable regulatory framework and requirements. Existing national frameworks should be amended, as needed, to comply with international legal instruments and safety standards, and the IAEA should continue to provide support to national authorities.

Turning to **social issues**, the participation of the public, including community leaders, work forces and interest groups, in the decision making processes should be initiated as early as possible and should continue throughout the process. The aim is to minimize the negative social and economic effects of decommissioning.

In the discussion on **waste management issues**, it was noted that there was progress on the provision of national repositories for radioactive waste would be of great benefit to decommissioning. However, the absence of a repository should not be considered an obstacle to early dismantling. If repositories are not available, regulators should provide guidance to operators on the appropriate conditioning of waste.

The **long term retention of knowledge** is of great importance in two respects: people and records. The knowledge and experience of staff involved in the operation of the facility need, if at all possible, to be exploited during decommissioning. If the early dismantling strategy is adopted, this can be done directly by retaining the people, but if decommissioning is delayed a way needs to be found to preserve that knowledge and experience in a form that can be used later. The second aspect is to ensure that proper records of the history of the site are retained in the long term after decommissioning. Failure to do this can lead to situations involving a risk of accidents, substantial costs and the generation of further waste.

**Funding** is clearly vital to decommissioning. Provision needs to be made to ensure that sufficient funds will be available, with a high degree of confidence, when they are needed. An appropriate mechanism should be in place before a new facility is licensed to operate. However, there are significant uncertainties associated with both the estimation of future costs and the performance of funds designed to meet those costs, even when an appropriate funding system is in place. A particular concern relates to facilities that need to be decommissioned, but for which funds are not available.

With regard to the **removal of regulatory controls**, it was noted that the recycling or reuse of materials from decommissioning can greatly reduce the amount of waste that needs to be disposed of in a repository. This can preserve resources and repository capacity. Criteria for the international trade in such materials are needed, and therefore should be internationally agreed. A great deal of work has been done aimed at establishing criteria for the removal of materials from regulatory control. Work aimed at reaching international consensus on an acceptable methodology, including codes and scenarios, for establishing clearance levels should continue.

Questions remain as to whether the criteria for the release of sites should be the same as those for materials, whether natural and artificial radionuclides can be subject to the same criteria, and whether there is a market for materials released from a nuclear facility, even in the case when they have been declared to be ‘non-radioactive’. The international community should make concerted efforts to resolve these issues.

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| Opening Session | W. RENNEBERG | Germany |
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| Session 1.B | A.-C. LACOSTE | France |
| Session 1.C | V.P. KANSRA | India |
| Session 2.A | H. SCHATTKE | Germany |
| Session 2.B | L. KEEN | Canada |
| Session 2.C | J. BARCELÓ VERNET | Spain |
| Session 2.D | C. PAPERIELLO | United States of America |
| Session 2.E | J.R. COOPER | United Kingdom |
| Closing Session and Presentation of Findings | W. RENNEBERG | Germany |

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