Safety Reports Series

No.26

Safe Enclosure of Nuclear Facilities During Deferred Dismantling

International Atomic Energy Agency, Vienna, 2002

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish standards of safety for protection against ionizing radiation and to provide for the application of these standards to peaceful nuclear activities.

The regulatory related publications by means of which the IAEA establishes safety standards and measures are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (that is, of relevance in two or more of the four areas), and the categories within it are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides.**

Safety Fundamentals (blue lettering) present basic objectives, concepts and principles of safety and protection in the development and application of nuclear energy for peaceful purposes.

Safety Requirements (red lettering) establish the requirements that must be met to ensure safety. These requirements, which are expressed as 'shall' statements, are governed by the objectives and principles presented in the Safety Fundamentals.

Safety Guides (green lettering) recommend actions, conditions or procedures for meeting safety requirements. Recommendations in Safety Guides are expressed as 'should' statements, with the implication that it is necessary to take the measures recommended or equivalent alternative measures to comply with the requirements.

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA.

Information on the IAEA's safety standards programme (including editions in languages other than English) is available at the IAEA Internet site

www.iaea.org/ns/coordinet

or on request to the Safety Co-ordination Section, IAEA, P.O. Box 100, A-1400 Vienna, Austria.

OTHER SAFETY RELATED PUBLICATIONS

Under the terms of Articles III and VIII.C of its Statute, the IAEA makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety and protection in nuclear activities are issued in other series, in particular the **IAEA Safety Reports Series**, as informational publications. Safety Reports may describe good practices and give practical examples and detailed methods that can be used to meet safety requirements. They do not establish requirements or make recommendations.

Other IAEA series that include safety related publications are the **Technical Reports Series,** the **Radiological Assessment Reports Series,** the **INSAG Series, the TECDOC Series**, the **Provisional Safety Standards Series**, the **Training Course Series,** the **IAEA Services Series** and the **Computer Manual Series**, and **Practical Radiation Safety Manuals** and **Practical Radiation Technical Manuals**. The IAEA also issues reports on radiological accidents and other special publications.

SAFE ENCLOSURE OF NUCLEAR FACILITIES DURING DEFERRED DISMANTLING

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BANGLADESH
BELARUS
BELGIUM
BENIN
BOLIVIA
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BULGARIA
BURKINA FASO
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHILE
CHINA
COLOMBIA
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ESTONIA
ETHIOPIA
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
LATVIA
LEBANON
LIBERIA
LIBYAN ARAB JAMAHIRIYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITIUS
MEXICO
MONACO
MONGOLIA
MOROCCO
MYANMAR
NAMIBIA
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
PAKISTAN
PANAMA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
SAUDI ARABIA
SENEGAL
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA
VIET NAM
YEMEN
YUGOSLAVIA, FEDERAL REPUBLIC OF
ZAMBIA
ZIMBABWE

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''.

Printed by the IAEA in Austria
November 2002
STI/PUB/1142

SAFETY REPORTS SERIES No. 26

SAFE ENCLOSURE OF NUCLEAR FACILITIES DURING DEFERRED DISMANTLING

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2002

IAEA Library Cataloguing in Publication Data

Safe enclosure of nuclear facilities during deferred dismantling. — Vienna : International Atomic Energy Agency, 2002.
p. ; 24 cm. — (Safety reports series, ISSN 1020–6450 ; no. 26)
STI/PUB/1142
ISBN 92–0–118402–6
Includes bibliographical references.

1. Nuclear facilities—Decommissioning. 2. Nuclear engineering—Safety measures. I. International Atomic Energy Agency. II. Series.

IAEAL 02–00304

FOREWORD

A growing number of nuclear facilities around the world are being shut down for various reasons. There are many options being considered by Member States for the decommissioning of these facilities. One of these decommissioning options involves placing the facility into a long term storage period after shutdown. This option will defer the final dismantling of the nuclear facility for a period of time that may range from a few years to over 50 years. During this time, protection of the general public and the environment must be ensured.

Three IAEA Safety Guides outline the safety aspects to be considered during the decommissioning of various nuclear facilities: Decommissioning of Nuclear Power Plants and Research Reactors (Safety Standards Series No. WS-G-2.1), Decommissioning of Medical, Industrial and Research Facilities (Safety Standards Series No. WS-G-2.2), and Decommissioning of Nuclear Fuel Cycle Facilities (Safety Standards Series No. WS-G-2.4). Each of these Safety Guides briefly discusses the deferred dismantling option for the respective facilities. This Safety Report provides information to support these Safety Guides.

Considerable experience has been gained with nuclear facilities in long term storage and a number of safety problems and concerns have appeared when facilities are in this condition. This Safety Report provides information regarding the safety concerns that may arise and suggests solutions for anticipating them. Use of the information in this Safety Report will help ensure that a nuclear installation which has been or will be placed into a safe, long term storage mode is maintained in a safe state until the final decommissioning activities are performed. It can also assist Member States in the preparation of decommissioning plans for both active and inactive facilities where it is desirable to place them into a long term storage condition.

The assistance of all contributors to the drafting and review of this Safety Report is gratefully acknowledged. The technical officer responsible for its preparation was D. Reisenweaver of the Division of Radiation and Waste Safety.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Nuclear installations may be permanently shut down for a number of reasons, including:

(a) Obsolescence of the technology or process used in the facility,
(b) Continued operation of the process no longer being profitable,
(c) Changes to the licensing requirements,
(d) Redundancy of the facility or completion of the process,
(e) Involvement of the facility in an operating incident or accident,
(f) Legal or political factors.

When a decision is made to terminate permanently the intended operation of a nuclear installation, other decisions need to be made with regard to the decommissioning. One of the important decisions to be made concerns the selection of the decommissioning strategy.

Decommissioning strategies can incorporate actions ranging from immediate dismantling and removal of all radioactive materials from the site, allowing removal from regulatory control, to an entombment option which involves encapsulation of the most contaminated or activated components on the site and subsequent restriction of access. In all cases, the installation must be decommissioned in a safe manner and meet all regulatory requirements.

A large number of nuclear installations around the world are currently being considered for decommissioning. Even where the decommissioning strategy is for immediate dismantling to begin within a short period after shutdown, it may be necessary to defer a part of the dismantling for a few years.[1] It may be decided to

[1] The IAEA has defined three decommissioning strategies: immediate dismantling, safe enclosure and entombment. Immediate dismantling begins shortly after permanent shutdown of a facility (normally within 2–5 years), and decontamination and dismantling begin as soon as possible after this, leading to release of the facility or site from regulatory control. Safe enclosure is a strategy in which a facility or site is placed into a safe condition and in which decontamination and dismantling are delayed for up to 50–60 years (known as the safe enclosure period). During this time, a surveillance and maintenance programme is implemented for the facility. Entombment is a strategy in which the remaining radioactive material is encapsulated on-site, effectively establishing a waste disposal site.

defer the dismantling for a longer period of time for political or for other reasons, a period which may range from a few years to over 50 years. This deferral or long term storage must be performed safely and, therefore, adequate planning is needed to implement the safety requirements during the safe enclosure period [1–3].

There can be many variations of the safe enclosure strategy and Member States' needs may dictate which approach is the most acceptable. Safe enclosure includes options that can range from allowing the facility to be available for entry at all times, to isolating it and providing for entry on an infrequent basis, or some combination of these strategies.

1.2. OBJECTIVE

The objective of this Safety Report is to provide information to Member States to help ensure that a nuclear installation that will be or has been placed in a safe enclosure mode is maintained in a safe state until the final dismantling is performed and the facility or site released from regulatory control. This period of time may be referred to as the deferred dismantling, safe enclosure or long term storage period. During this safe enclosure period, control of the radioactive material and any other hazardous material must be maintained and the safety of the general public and the environment ensured.

1.3. SCOPE

This Safety Report applies to the safe enclosure of large nuclear facilities such as nuclear power plants, research reactors, large research facilities, large manufacturing facilities and some fuel cycle facilities. Safe enclosure is not normally applicable to smaller industrial and medical installations owing to the small amount of radioactive material present and the nature of that material. This Safety Report would not normally be applicable to facilities that contain long lived radionuclides, as there is little benefit in placing them into safe enclosure. For these facilities, immediate dismantling is normally the preferred option.

This publication describes the activities and concerns that are considered from the time when the initial decision is taken to defer dismantling activities, to the point when final dismantling commences or resumes. It is an expansion of the guidance provided in three IAEA Safety Guides [4–6].

This Safety Report discusses methods that can be used to meet safety requirements, describes good practices and gives practical examples. The IAEA has published a Technical Report that provides technical details relating to the safe enclosure strategy [7].

1.4. STRUCTURE

The main text of this Safety Report is organized as follows. Section 2 identifies general aspects that are important for safe enclosure and deferred final dismantling. These issues include: the purpose of safe enclosure, responsibilities, regulatory framework, safety, environmental and radiological protection considerations, and spent fuel management.

Section 3 describes the two main safe enclosure options, active and passive, as well as the considerations that are included in the decision making process. A tabular comparison of the features of each option is provided. Section 3 also discusses the transition from an active state to a more passive condition.

Section 4 discusses the planning needed to place a facility into safe enclosure and includes details on the safety assessment, the site preparation plan, and the surveillance and maintenance plan.

Section 5 addresses the management aspects of safe enclosure, including staffing and training, organization and administrative control, radiological protection, on-site and off-site monitoring, waste management, emergency planning, physical security and safeguards, and quality assurance.

Section 6 identifies critical tasks that are performed during the planning and deferral periods, such as characterization of the installation, development of the waste management plan, control of the area, and surveillance and maintenance.

Section 7 describes activities that are performed during the safe enclosure period to prepare the facility and organization for eventual dismantling.

Annex I provides a list of plans and reports that support decommissioning activities. Annex II provides a discussion of specific experiences gained with facilities that have been placed into a safe enclosure status.

2. GENERAL ASPECTS OF SAFE ENCLOSURE

Section 2 addresses a number of issues that are important for ensuring the safety of nuclear installations during safe enclosure. Some of these issues are similar to those that might be encountered during the operational phase, while others will be particular to the safe enclosure strategy.

2.1. PURPOSES OF SAFE ENCLOSURE

The objectives of the safe enclosure strategy are to place the nuclear installation into a condition of safe long term storage and at the same time reduce maintenance needs. The strategy allows time for certain conditions to be met or activities to be performed prior to the final dismantling of the facility. The reasons for placing a nuclear installation into safe enclosure may include the following:

(a) Allowing time for a reduction of radiation dose rates around the facility, thereby facilitating the control of doses to workers engaged in dismantling operations;
(b) Unavailability of a suitable disposal or storage site for waste generated during the dismantling process;
(c) A desire to develop improved dismantling technologies in order to reduce radiation exposure of the workers;
(d) Lack of appropriate decommissioning funds;
(e) A desire to wait for other on-site nuclear facilities to be permanently shut down so that the final decommissioning efforts for all facilities can be performed more effectively;
(f) Lack of available options for the removal of spent fuel from the plant.

The time needed for preparation for safe enclosure will depend on the particular design of the original plant, the radioactive inventory and its distribution, the physical condition of the facility, and the safe enclosure option selected. Also to be considered in terms of both the general acceptability of the option and the length of the safe enclosure period are the nature of the location of the nuclear facility, the local climatic conditions and the possible adjoining non-related activities. The proximity of the facility to lakes, rivers or the sea, or the occurrence of local seismic activity may pose threats to the structural integrity of the facility and may also affect the safe enclosure conditions.

During the safe enclosure period, the licence for the facility is normally converted from an operating licence to a safe enclosure licence. This safe enclosure licence would permit storage of radioactive material at the facility and allow maintenance and surveillance activities to be performed, but would preclude further operation of the facility.

Safe enclosure does not represent a decrease in the overall safety of the facility. Prior to the implementation of the safe enclosure period, steps are taken to reduce the potential hazards posed by the facility. This may include the removal of fuel from a reactor or the removal of residual radioactive material in the case of a processing plant, actions which will greatly reduce the radioactive source term. Other activities, such as rendering the facility more visually acceptable, may be included. In preparing the safe enclosure, no steps are taken that will prejudice the final disposition at any stage leading up to the planned date for final dismantling.

Figure 1 describes the various stages in the lifetime of a nuclear facility. It relates the decommissioning activities that are associated with each stage.

Facilty stage	Design, construction and startup phase	Operating phase	Shutdown/ transition	Safe enclosure preparation	Safe enclosure period	Final phase
Decommissioning activities	Initial decommissioning plan	Update decommissioning plan Finalize safe enclosure plan, prepare site preparation plan and surveillance and maintenance plan, prepare shutdown plan	Source term reduction, defuelling and waste conditioning	Site preparation and initial dismantling	Surveillance and maintenance Update final decomissioning plan	Final dismantling, final survey and licence termination

FIG. 1. Stages in the lifetime of a nuclear facility.

2.2. RESPONSIBILITIES

References [4–6] provide guidance on the responsibilities of the regulatory body and the operator for planning and implementing the decommissioning strategy.

The regulatory body implements the legal framework by developing appropriate rules, criteria and guidelines. It is within this framework of regulations that the requirements for the safe enclosure of a facility are specified. Safe enclosure requirements may be included within a Member States' provisions for the decommissioning of nuclear installations.

The regulatory control of safe enclosure can be accomplished by a single overall licence, by separate licences for each phase, or by direct control being exercised by the regulatory body. Effective co-operation and exchange of information between the regulatory body and the operator help ensure that all aspects of the deferral conditions are properly defined and implemented. The regulatory body needs to be informed of the selected safe enclosure option, general approaches, final condition of the safe enclosure and upcoming major activities. This awareness normally helps eliminate misunderstandings and allows changes to be approved in a timely manner.

In some cases, the overall decommissioning process is divided into phases, each with a separate licence issued by the regulatory body. In this case, the decommissioning plan, which is approved by the regulatory body, shows the overall planning, where each phase is identified and discussed. Operations are performed under regulatory control and, before proceeding to the next phase, the operator presents a document to demonstrate that all the specified activities have been completed as authorized.

In the absence of specific regulatory requirements, safe enclosure and deferred dismantling activities are normally undertaken on a case by case basis under existing regulations for operational facilities. In such cases, more frequent consultation between the operator and the regulatory body may be beneficial.

As decommissioning activities have become more frequent, there is a trend in many Member States to develop national regulations or specific guidance. These regulations focus on the control of hazards specific to decommissioning, including safe enclosure. In most cases, the licensing requirements normally in place during the operation of the facility can be reduced during the preparations for the safe enclosure period. This licence change normally allows possession of radioactive material, but does not allow operation of the facility as originally intended.

If the safe enclosure option is chosen by the licensee instead of immediate final dismantling, the regulatory body reviews the activities that will be performed during this long term storage period to ensure that avoidable safety problems which could complicate the eventual final dismantling phase will not develop.

The guidance provided by the regulatory body with regard to the radiological criteria for the authorized reuse or the release of the facility areas, equipment and materials from regulatory control is very important. This guidance allows the operator to reduce the risk and potential exposures to workers during the safe enclosure period. It also allows the operator to remove material from regulatory control, which may be financially beneficial to the overall project.

The holder of the licence or authorization from the regulatory body (the licensee) is ultimately responsible for all activities at the facility, including activities performed during the safe enclosure period [3]. When a nuclear facility is taken out of service, the licensee may transfer the implementation of safe enclosure activities to an organization other than the one operating the facility. This new operator ensures that the facility is maintained in a safe condition during the entire safe enclosure period. The licensee, however, maintains its responsibility for the development and safe implementation of the appropriate documentation in support of the safe enclosure period. These documents may include those elements of the decommissioning plan listed in Annex I.

Ensuring that appropriate funds are available to enable the activities to be performed during the safe enclosure period is an important responsibility of the licensee. Organizations operating more than one nuclear facility at a single site normally produce an overall decommissioning strategy for the entire site, to be reviewed and optimized periodically, which shows the availability and the allocation of financial resources over a suitable period of time. Ensuring that the funds allocated for the eventual dismantling are available when needed is equally important. The funding mechanism that was in place during the operation of the facility or during the initial phases of decommissioning guarantees that these funds will be available when needed.

Since a long period of time may elapse between the shutdown of facility operations and the actual commencement of dismantling activities, a system has to be instituted to ensure that the necessary knowledge of the facility and equipment is not lost. Good plant experience and knowledge can facilitate safe and effective decommissioning. Therefore, in the first few years of preparing the facility for safe enclosure, the use of operating personnel formerly employed at the facility can be advantageous. Arrangements made to maintain the knowledge base, assemble and train staff, and transfer experience from ‘old’ to new workers are essential. Knowledge of the operating staff is collected and retained in facility records prior to their leaving the site.

The licensee establishes an organization that can effectively implement the regulatory requirements to ensure that the facility is maintained in a safe condition during the safe enclosure period. This organization may be part of the existing organization or a separate entity that performs the surveillance and maintenance activities during the period. In either case, the licensee is still responsible for ensuring that all regulatory requirements are met.

2.3. CONSIDERATIONS RELATING TO SAFETY DURING PREPARATION AND IMPLEMENTATION OF SAFE ENCLOSURE

During all phases of the preparation and implementation of safe enclosure, the workers, the public and the environment must be properly protected [3]. A thorough safety assessment of the potential hazards faced during the safe enclosure process (including an accident analysis) is performed as a basis for defining protective measures. In some cases, such measures may be different from those in place during the operation of the facility.

The transition of a facility to the safe enclosure mode often involves the removal, at an early stage after shutdown, of significant quantities of radioactive materials, including fuel and operational waste. Even after this step, the residual activity may be significant.

Access controls are implemented to prevent unauthorized persons from entering the safe enclosure area, whether knowingly or not. Other significant safety issues arise from:

(a) Potential failure of barriers used to confine radioactive materials;
(b) Unidentified areas of significant contamination;
(c) New or unrecognized waste streams;
(d) Deterioration of residual chemicals associated with the process operations and which may remain in the piping or systems;
(e) Spread of contamination during maintenance and surveillance activities;
(f) Unidentified areas that have high dose rates and which may require a remote handling capability for conducting maintenance or surveillance;
(g) Deterioration of buildings, structures, systems and components which may have an impact on safe worker access or on final dismantling;
(h) Potential impacts of non-radiological component failure on overall safety;
(i) Potential safeguards and criticality considerations for systems that may contain fissile material such as that present in reprocessing plants;
(j) Maintenance of existing on-site spent fuel storage and the effect of this storage on safety.

While safe enclosure is ongoing, the safety of workers is also a major concern: any safe enclosure activities need to include a programme on the industrial safety of workers. This programme takes account of the training requirements of the workers, the engineering features necessary for reducing potential risk and the existence of a good safety culture.

2.4. CONSIDERATIONS RELATING TO A RELEASE OF RADIOACTIVE MATERIAL TO THE ENVIRONMENT

Discharges to the environment from a facility in safe enclosure are maintained below permitted limits during the entire period. They may consist of normal discharges, such as airborne effluents from the ventilation system and liquids from groundwater collection systems, or unplanned releases resulting from accidents.

Normal discharges are released in such a manner that they may be estimated or measured if necessary. Abnormal discharges due to a change of condition within the facility would be considered a failure and addressed by the safety assessment on a consequence and risk basis. The potential for airborne discharges of radioactive material is considered during the planning and assessment processes.

Fire in the facility could lead to the release of radioactive material to the atmosphere. Ingress of water from the air or the ground leading to corrosion or leaching is also a possible mechanism for the dispersion of radionuclides to the environment. Any process, including degradation or external threat, that increases the likelihood of water ingress is analysed. Certain processes that may be needed to allow for the requisite inspection and maintenance of the facility (roof replacements, access to areas) could also lead to water ingress.

Systems and barriers that inhibit discharges to the environment are maintained during the safe enclosure period. The number and types of systems and barriers will depend on the type of facility, its design, the radionuclides present, the safe enclosure mode selected and the length of the deferral period.

Programmes for monitoring both radiological and non-radiological impacts are maintained during the safe enclosure period. The monitoring particulars may change during the safe enclosure preparation period as well as during the safe enclosure period itself.

The safe enclosure plan may have to address the potential for soil contamination under or near the installation, along with any groundwater contamination that may have occurred during the operational period of the installation. Contaminated soils may have to be removed or treated during the safe enclosure preparation.

2.5. CONSIDERATIONS RELATING TO RADIOLOGICAL PROTECTION

The facility in a safe enclosure status is prepared, maintained and finally dismantled in a manner that maintains the dose to workers involved in these stages as low as reasonably achievable (ALARA). This can be accomplished by limiting entry into controlled areas to those persons who are needed to maintain safety and perform test, inspection, surveillance and maintenance activities. An optimization assessment may need to be done at the planning stage in order to demonstrate that the activities to be carried out during the safe enclosure period are necessary and will be performed in the most effective manner. All the operations are carried out under authorized radiological control conditions and are reviewed periodically during the safe enclosure period. Where it is planned that workers make periodic visits to the safe enclosure facility for surveillance purposes, the doses they may accrue, together with those they may have received elsewhere, are taken into account in managing the control of their exposures.

The areas, systems and components that still contain significant amounts of residual radioactive material at the beginning of the safe enclosure period are identified for the benefit of maintenance workers. This is important for ensuring that these workers keep their exposures ALARA and that they understand the radiological conditions before performing any maintenance functions.

2.6. SPENT FUEL AND OPERATIONAL WASTE MANAGEMENT

The spent fuel and operational waste management may be considered in the context of the safe enclosure preparation process, but normally it is considered as being part of the operational phase of the facility.

The storage of spent fuel and operational waste may have to be continued on a site for some time after operations have ceased. It is assumed that such storage, although carried out with minimum maintenance, is not considered part of safe enclosure. The temporary installation used to store spent fuel on-site after the operational phase may need a separate licence.

The dismantling activities and site preparations may be seriously affected when spent fuel remains on the site. There may me a significant number of systems located throughout the facility that would need to be maintained in order to ensure the safety of the fuel and waste while in storage. If the spent fuel and operational waste are expected to remain in the facility during the safe enclosure period, the licensee takes this into account when developing the safety assessment and shows how this affects decommissioning activities.

3. SELECTION OF A SAFE ENCLOSURE OPTION

3.1. GENERAL

Safe enclosure is a decommissioning strategy that provides two basic options: active and passive.[2] The common feature of these options is that final dismantling is

[2] The active option means that the facility will be available for entry at any time and staff is on-site at least during the normal work day. The passive option means that the facility is not normally accessible and that entry is only made periodically (once or twice a year) to assess conditions.

deferred for a significant time period and that the safety of workers and the public is maintained during this period. The selected strategy should be one that optimizes radiation protection, taking into account the radiation exposures that may be received by all parties during both the enclosure period and the final decommissioning stages. When evaluating safe enclosure options, there are many aspects to consider, including the time period of the deferral, the extent of dismantling before the safe enclosure period begins, the need for additional radiation protection features to reduce risk, the amount of decontamination that may be needed, the environmental monitoring needed, the scope of the inspection programme and the number of assigned staff.

Safe enclosure strategies have to be considered on a plant-by-plant basis. The design of the enclosure barriers, the duration of the enclosure period and the application of a passive or active regime may vary from plant to plant.

Safe enclosure may not be the alternative selected for every nuclear installation. In the case of fuel cycle facilities that are contaminated with plutonium and other alpha emitters, safe enclosure may not be the most advisable option. Deferring the dismantling of such facilities (i.e. reprocessing plants) does not significantly reduce the radionuclide inventory, the quantities of radioactive waste produced during eventual dismantling, or the radiological exposure to site personnel, except in the case of new technologies being developed during the deferral period that could reduce such exposure or technically justify the safe enclosure of the facility. This strategy is not normally preferred because of the relatively long half-lives of the isotopes involved and the potential for isotopic in-growth (as with americium), which may result in an actual increase in the total dose to the workers over the safe enclosure period and during the subsequent dismantling activities. In these situations, immediate dismantling is the preferred strategy.

Experiences at nuclear power plants with a history of fuel cladding failures have shown that, several years after shutdown, beta–gamma emitting isotopes had decayed to a level that no longer permitted their use as tracer isotopes for alpha emitting isotopes or for other nuclides that are difficult to detect (for instance ^{63}Ni, ^{3}H). This lack of an indicator makes work planning and monitoring much more difficult and time consuming.

The following are considered when determining which safe enclosure option will be chosen:

(a) Size, configuration and condition of the nuclear installation, including radiological containment barriers specific to the plant;
(b) The outcome of a safety assessment justifying that the selection of the safe enclosure option for the particular installation under consideration is the optimal solution;

(c) The policy of the regulatory body on decommissioning and safe enclosure strategies;
(d) Equipment that will be maintained or installed to ensure a safe environment during the period;
(e) Systems and components which will need to be reactivated at the end of the safe enclosure period in order to support eventual dismantling;
(f) Types, levels, quantity and location of radioactive material;
(g) Availability and condition of appropriate services (e.g. water, ventilation, fire protection), if needed for the option chosen;
(h) Presence of available staff;
(i) Possible use of the facility or area for other purposes;
(j) Proximity to other activities or facilities;
(k) Adequacy and availability of financial resources;
(l) Past or current environmental releases (current soil and groundwater contamination).

Each of the two options, passive and active, has advantages and disadvantages. Each option has a large degree of latitude and it is also possible to have a combination of these options that are based on specific areas, systems or time after shutdown. The safe enclosure plan will focus on engineered passive safety features rather than on safety features that require active surveillance and maintenance.

3.2. ACTIVE OPTION FOR SAFE ENCLOSURE

The active option for safe enclosure of the facility is characterized by allowing entry at all times, having dedicated personnel to survey the facility and environmental conditions throughout the entire storage period, and keeping the equipment and systems operational during the safe enclosure period. Consideration is given to the preservation of ongoing maintenance of those systems and equipment necessary for final dismantling. In some cases, lower total radiation exposures and lower overall costs may result from not having to maintain the systems or equipment necessary for final dismantling during the safe enclosure period and by replacing them when final dismantling efforts are made. Such an approach is applicable only when the results of the safety assessment indicate that these systems do not need to be in operation during the safe enclosure period.

The active option for safe enclosure may necessitate significant maintenance activities, depending on the number of active systems to be maintained over the safe enclosure period, and consequently, in some cases, on a significant, on-site, full-time staff. Smaller staffs may be supported by visits by staff from other sites to undertake infrequent specialist tasks.

The permanent presence of personnel allows immediate identification of the deteriorating conditions affecting the structural and radiological containment barriers, and the performance of decontamination, limited dismantling and other decommissioning activities in between surveillance and maintenance activities. These activities are established as part of the overall surveillance programme by the operator/licensee and approved by the regulatory body.

The active option may be more readily accepted by both the regulatory body and the public. Nevertheless, this is not sufficient grounds for selecting this option in all cases. In fact, from a financial or project lifetime cost perspective, the passive option may be the option of choice. It is expensive to maintain a trained active staff for fifty to sixty years as compared with a passive option that may have no staff assigned to the facility. The choice of the active option does not obviate the need for a full safety assessment and the periodic updating of the safety documents.

3.3. PASSIVE OPTION FOR SAFE ENCLOSURE

The essential feature of the passive option is the fact that the site is not staffed for the majority of the safe enclosure period but only during periods of inspection and maintenance.

This is achieved by placing the facility, area or system into a condition that needs the minimum of attention during the long term storage period. Normally, the facility or area is secured to limit human access. The facility or area is only entered on an infrequent basis (once or twice a year) for routine maintenance and surveillance activities. Individuals enter the facility at other times only when absolutely necessary.

All connections to the outside of the facility or area are either severed or controlled. This means that the ventilation systems are replaced with static flow or ‘breather’ filters. The facility or area is placed into a dormant state by removing as many potential hazards as possible. This would include:

(a) Removal of all combustible and incidental materials;
(b) Drainage of liquid systems;
(c) Reduction in electricity demands to the maximum extent possible;
(d) Removal or fixation of radioactive contamination in accessible areas;
(e) Removal, fixation or marking of other hazardous substances such as asbestos, lead and mercury;
(f) Reduction in the overall areal dimensions of the facility by demolition of redundant sections or portions of the facility.

Certain systems, such as fire protection or groundwater infiltration systems, may have to be maintained, but at a lower level of complexity than if the area were maintained for normal occupancy. It may be possible to minimize fire protection features on the basis of the low probability of fires occurring, by removal of ignition sources and by ensuring the absence of combustible material and the limited consequences of a fire occuring. Fire is one issue that would be addressed in the safety assessment.

Additional measures may need to be taken such that the consequences of degradation, external events or intrusion will meet the conditions of the safety assessment. As an outcome of the safety assessment, additional protection to prevent water ingress, protection against groundwater infiltration, protection against extreme weather, or additional physical security measures may be needed. It may be necessary to renovate existing structures, make provisions for high integrity waterproof and weatherproof containment, provide for passive drainage of water, construct new systems and barriers, or provide remote security and condition monitoring.

The passive safe enclosure implies a low surveillance frequency. Each entry for inspection and maintenance would be planned in advance, whenever possible. Exceptions would be made for inspections that followed abnormal events such as fire, severe storms, floods or seismic activity.

Whenever entering the safe enclosure facility, it is necessary to verify that safe conditions exist prior to entry. Conditions to consider include:

(i) Verification of environmental conditions in the work areas prior to entry,
(ii) Possible deterioration in structural integrity since the last entry,
(iii) Possible changes in radiological conditions since the last entry.

It is normally a condition of the surveillance and maintenance plan that the inspections aimed at confirming the safety of the plant during safe enclosure are carried out in a safe manner. When access to the facility or area is necessary, systems (such as ventilation, electricity) would be restored for the entry period, if still available. Otherwise, portable systems may be needed. The safe enclosure option relies on the use of remote systems to monitor security and safety at the facility.

A comparison of the attributes of the two options is provided in Table I.

3.4. COMBINATIONS OF SAFE ENCLOSURE OPTIONS

In many cases, the final plan for safe enclosure of a facility includes elements of both the active and passive options. For example, portions of the facility may be placed in a passive state but active ventilation systems may be used to control environmental conditions within the facility. Decisions taken with regard to those

TABLE I. COMPARISON OF SAFE ENCLOSURE OPTIONS

Concept	Active option	Passive option
Characteristics	Facility secured with barriers. Available for routine entrance or inspections.	Facility secured with hardened barriers. Not needing routine entrance, only periodic inspections.
Physical security	Security systems controlled by permanent on-site staff.	Security systems with remote alarms.
Systems needed to maintain safe enclosure	In active operation.	In passive status.
Monitoring	Performed by on-site staff.	Infrequent or remote.
Maintenance	Planned and performed by on-site staff.	Infrequent. Only actions needed to maintain safety.
Dismantling activities	Possible but limited	Avoided.
Spent fuel	Facility defuelled. May exist in a separate on-site storage installation.	Fuel removed from site. May exist in a separate building under a separate licence.
Radioactive waste	Removed from site as much as possible with the remainder conditioned and stored.	Removed from site as much as possible with the remainder conditioned and stored in separately licensed facility.

aspects of the safe enclosure plan that are active or passive are based on the results of the safety assessment, cost estimates over the safe enclosure period, and specific plant conditions that will exist over the period.

3.5. CHANGES IN THE SAFE ENCLOSURE OPTION

Uncertainties over deferral times, regulatory body requirements, public acceptability or funding restrictions are such that, although technically feasible and safe, the passive option may not be adopted as the first option. An active regime could be adopted initially which, following feedback of information on the behaviour of the plant under safe enclosure, allows a gradual and progressive evolution into the passive option. It is envisaged that a formal review of plant safety would be undertaken and reported by the licensee periodically (every 5–10 years). Such a review would provide a discussion forum for reconsidering the safe enclosure option.

If a passive option is initially chosen, changing to an active option may be necessary if it is decided to perform limited dismantling, decontamination or waste conditioning and shipping. Unless the activities had been foreseen during the initial licensing phase, it would then be necessary to change the safe enclosure licence as approved by the regulatory body. The intended deferral period is reviewed at the same time, taking into account the state of the plant and the availability of waste disposal facilities.

4. PLANNING FOR SAFE ENCLOSURE

4.1. GENERAL

Experience has shown that if properly planned and implemented, the safe enclosure of a nuclear installation can be accomplished without incurring undue risk of it having a radiological impact on the workers, the public or the environment. The planning starts when the decommissioning option is chosen. As the initial activities of planning for the overall decommissioning project are being performed, consideration is given to the activities that are needed to place the facility into a safe enclosure condition.

Once a decommissioning option is selected, a Decommissioning Plan is developed containing the information listed in Annex I. For the purpose of safe enclosure, the decommissioning safety assessment, the site preparation plan, and the surveillance and maintenance plan provide the guidance necessary to place the facility in the safe enclosure mode and maintain the facility during the safe enclosure period. Other documents listed in Annex I may be included in the Decommissioning Plan or reference made to other documents that can be used to support the decommissioning. During the safe enclosure period, the various plans are reviewed and updated as necessary. The extent of each plan and the degree of detail necessary may differ depending on the complexity and hazard potential of a particular facility or area, and on the requirements of the regulatory body.

The following situations may cause the plans to be modified:

(a) Abnormal events;
(b) Significant changes to systems or structures which could affect the safety assessment, the eventual decommissioning or the surveillance and maintenance processes;

(c) Changes in the conditions of areas surrounding the safe enclosure;
(d) Changes in regulations or government policy;
(e) Changes in the cost estimates and financial provisions;
(f) Changes in the availability of waste disposal options.

4.2. SAFETY ASSESSMENT

A new safety assessment is performed when a facility moves from an operational status to one of safe enclosure. A site specific safety assessment is developed at an early stage in the planning process in order that any necessary safety requirements concerning engineering features, inspection and maintenance can be included in the discussions of options and strategies.

The safe enclosure status represents a significant change in the role of the plant. Therefore, the safety requirements used for the design and operation of the plant may not be relevant for safe enclosure. The safety assessment may provide a new set of safety requirements which, in most of the cases, result in less stringent requirements than during facility operations.

It is possible that, for some plants, the safety assessment may be completed by simply updating the existing safety assessment.

As indicated previously, the active safe enclosure option may have been initially selected, but over time this may change to being one of passive safe enclosure. The safety assessment may need to address the changes in facility conditions and hazards resulting from this phased approach. The closer a project moves towards the passive safe enclosure option, the fewer the hazards and risks to be assessed.

The precise approach employed in preparing a safety assessment may vary in form between Member States. In particular, in some States items such as the surveillance and maintenance scheduling may form a crucial part of plant protection and therefore part of the safety assessment. In other States, it may be that the maintenance schedule is a ‘stand alone’ item under the decommissioning plan or is part of the safety assessment. These differences of presentation should not alter the essential features of the safety assessment.

4.2.1. Background safety assessment

The safety assessment addresses potential risks and hazards, and protective measures to cope with these risks, and contains a justification that these measures are sufficient under normal incident or identified potential accident situations during the safe enclosure period.

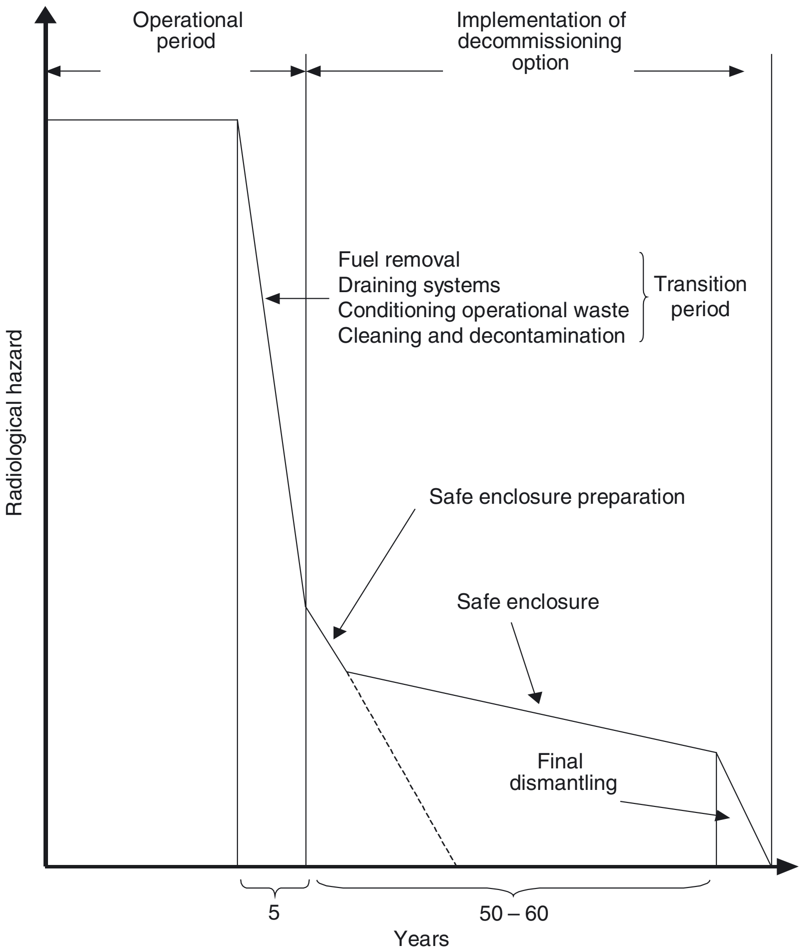


FIG. 2. Change in the potential radiological hazard presented by the facility at different phase of decommissioning (the hatched line shows the immediate dismantling option).

4.2.1.1. Potential risks and hazards

The potential risks and hazards at a facility which is in a safe enclosure mode are mainly determined from consideration of the source term and the potential for releases to the environment. Source term reduction before safe enclosure is highly advisable and may include removal of fuel elements and other fissile materials, contaminated liquids and operational wastes. Source term reduction has a strong impact on the potential risk presented by the facility (Fig. 2.).

The scope of the safety analysis is determined by:

(a) Identification of the hazards (radiological and non-radiological) by taking into account the nature of the safe enclosure, the possible time period under consideration, and the extent and time periods during which active control is maintained. Consideration is given to typical internal or external initiating events but it may also be necessary to include events specific to safe enclosure such as ageing and corrosion, ensuring that significant breakdown of confinement barriers caused by degradation mechanisms is considered.
(b) Establishment of the reference incidents or potential accident scenarios that cover all the hazard situations described above.

4.2.1.2. Description of the protective measures

Factors considered in the determination of the protective measures include:

(a) Adopted safe enclosure option (passive, active or a combination of both);
(b) Design features and systems of the safe enclosure (mainly existing confinement barriers) that prevent, protect against or mitigate the potential consequences of the incidents or accident situations being considered;
(c) Items whose failure could result in a release exceeding the safety criteria (these items may include features such as the confinement structures, weight bearing structures, filters and the ventilation system).

Confinement of radioactive materials within systems or components may be achieved by the system or component itself: confinement of the core structure, for instance, could be implemented in the main reactor vessel. The confinement of radioactive materials in many cases may be achieved by utilizing existing buildings, after having first sealed their penetrations.

4.2.1.3. Safety assessment

Once the incidents and accident situations that may occur during decommissioning are identified and the protective features of the facility determined, an assessment is performed to demonstrate that the overall safety criteria are met. The IAEA is currently preparing a document that provides guidance on undertaking a safety assessment.

4.2.2. Industrial safety

Some of the hazards that may be encountered during the safe enclosure period may not be encountered during normal operations. Examples include the deterioration of the facility’s structural components and the possible occurrence of chemical reactions within tanks or piping systems in fuel processing or enrichment facilities. These can lead to personnel injury during surveillance activities, accidents during the safe enclosure period or the possible spread of radioactive contamination. Although the procedures for coping with most of these non-radiological hazards are normally managed by regulations from other regulatory organizations within a Member State's government, a consolidated safety culture will help ensure that the hazards are identified and their potential consequences mitigated.

Conventional industrial safety should be reviewed as part of the safety assessment. The industrial safety assessment considers the work needed to install modifications necessary for the safe enclosure preparations and to minimize deterioration of facilities and systems during the safe enclosure period. When considering worker safety, in general it may be found that for a facility in the safe enclosure mode, conventional risk outweighs radiological risk. For example, there may be exposure to chemicals and hazardous materials such as mercury, lead and asbestos. Chemicals and chemical reactions can have an effect on the possible spread of radioactive contamination and need to be addressed in the safety assessment.

4.2.3. Review of the safety assessment

Major changes to the facility from internal degradation or from the effects of external events may call for a review of the safety assessment and a presentation of the reviewed assessment to the regulatory body. Safety assessments and related reviews are normally performed:

(a) Prior to the safe enclosure period and are undertaken over the entire safe enclosure period,
(b) Periodically in formal reviews,
(c) Following internal or external events that may have affected the considerations used in the safety assessment.

4.3. SITE PREPARATION PLAN

The site preparation plan describes the activities that will be performed to prepare the facility for safe enclosure. This plan is prepared during the initial decommissioning process, once the safe enclosure option has been chosen.

This site preparation plan identifies existing systems that will be maintained during the safe enclosure period, systems that will be necessary to support the eventual dismantling and systems that are no longer needed for future activities. It describes in detail the activities that will be performed to prepare the facility for safe enclosure. When developing the plans to prepare the facility for safe enclosure, consideration is given to the results of the safety analysis, the surveillance and maintenance plan, and the cost estimates for maintaining the facility over the entire safe enclosure period.

Particular attention is paid to the evaluation of the specialized tools and equipment used during operation and shutdown. These specialized tools are unique and during the final dismantling they may be needed to operate or to disassemble selected pieces of equipment. The plan discusses the removal of any residual material (contaminated, hazardous or clean) that may arise prior to placing the facility into a safe enclosure state and will also include the disposition of this material either as waste or, if it can be released, as scrap or surplus material. This may include reference to specific procedures or a separate terminal cleanout or residual removal plan.

The site preparation plan identifies systems, structures or structural components that will necessitate construction or upgrading in order to accommodate the safe enclosure period. The plan contains a schedule and details of personnel needs and approximate costs of implementing the activities. It also indicates where modifications to operating rules, operating instructions and the maintenance schedule are necessary.

4.4. SURVEILLANCE AND MAINTENANCE PLAN

The surveillance and maintenance plan identifies the specific tasks that will be performed during the safe enclosure period to ensure that the facility or area is maintained in a safe condition. This plan is prepared during the initial decommissioning planning phase.

The surveillance and maintenance plan utilizes existing procedures whenever possible. The frequency of maintenance may change but the basic techniques used for maintaining the equipment are normally the same as those used during the operations phase. New procedures are developed as necessary for additional maintenance and surveillance items such as inspection for groundwater leakage in lower facility areas and inspection of the condition of roofs.

The surveillance and maintenance plan identifies equipment and systems that will need maintenance and stipulates the required frequency of the maintenance activities. Those surveillance and maintenance activities specific to systems or structures are developed in detail in procedures that contain checklists and forms for the recording of results and corrective actions as necessary. Supplies and equipment that will be needed to perform any maintenance activities are identified. The volumes of waste by category that will be generated during each maintenance cycle are estimated and a waste handling and disposal strategy identified for each waste stream. The funds and human resources needed to perform the necessary maintenance are estimated and the frequency of general surveillance of the facility stated. The plan identifies what records will be maintained and what their storage particulars will be.

The surveillance and maintenance plan includes actions that will be taken in the case of accident or abnormal situations arising during the maintenance activities. These actions may be linked to an overall site emergency plan.

The surveillance and maintenance plan includes a radiological monitoring plan for the facility and site. The monitoring arrangements are designed to detect any unexpected release of radioactive effluents. The plan will provide for the monitoring of the plant to confirm its integrity. In the case of the passive option, many of these parameters will be monitored remotely. Examples of elements to be monitored to confirm the integrity of the plant or building are:

(a) Temperature,
(b) Humidity,
(c) Corrosion;
(d) Atmospheric pollutant level,
(e) Facility security,
(f) Seismicity,
(g) Drainage,
(h) Ventilation,
(i) Concrete status,
(j) Material coatings status.

The frequency of routine inspections and surveys will vary from facility to facility and throughout the safe enclosure period. It may be found by experience gained during the initial period of deferral that the frequency of inspections can be reduced as the licensee, the regulatory body and the public gain confidence in the safety of the safe enclosure.

A typical initial plan for inspections is (for the passive option):

(i) Site security: weekly or monthly.
(ii) Building inspections: initially every 6 months, then later every subsequent year.
(iii) Major structural survey: every 5 years.
(iv) Leak rate tests (where applicable): every 2 years.

When developing a surveillance and maintenance plan, there is a need to combine the knowledge gained with existing procedures with the changed use of the system and/or structure during the safe enclosure period. The team preparing this plan will consist of both current surveillance and maintenance personnel who know the procedures and equipment and personnel with decommissioning or safe enclosure experience.

5. MANAGEMENT OF SAFE ENCLOSURE

5.1. GENERAL

The licensee retains its responsibility for managing the safe enclosure and the associated site in accordance with the relevant national or international conditions relating to the ownership of a nuclear site or radiological installation. This will apply whether the site is remote or adjacent to other facilities and in either the passive or active safe enclosure mode. The licensee will carry out all the duties specified in the decommissioning plan and in the safety assessment and safe enclosure plan and maintain sufficient resources and organization for performing such tasks while still holding the licence.

5.2. STAFFING AND TRAINING

A team of maintenance, radiation protection and conventional safety personnel are required to manage and perform required activities during the safe enclosure period. Although new competencies may be required during the safe enclosure period, the retention of some former employees who are familiar with the facility may be useful during the initial safe enclosure preparation phase. The licensee will have, or have access to, competent staff to provide adequate cover of the following areas:

(a) Radiological protection,
(b) Maintenance,
(c) Quality assurance and quality control,
(d) Waste management,
(e) Physical security,
(f) Engineering,
(g) General safety,
(h) Records maintenance,
(i) Emergency response,
(j) Scheduling and cost control,
(k) Licensing.

In some cases, outside contractors or personnel from similar facilities may be used to perform all or some aspects of the surveillance and maintenance. Adequate levels of control, supervision and training specific to the facility are provided by the operator, consistent with the site licence, to ensure adequate levels of safety are maintained.

Personnel should be familiar with the facility, the safety requirements of the licence, and the technical specifications, operating rules and applicable procedures, including the radiological protection requirements. Care is taken to use sound working practices and to maintain good working conditions. The basic requirements for a training programme and for refresher training in decommissioning activities, including safe enclosure, are normally described in the decommissioning plan and would be consistent with the licensee's quality assurance programme.

It will be more difficult to retain personnel having historical knowledge of the facility and its operations once the passive safe enclosure option has been implemented. The technical support staff for the safe enclosure period may have to be drawn from other locations within the licensee's organization or the licensee will have to contract for the required services or skills.

5.3. ORGANIZATION AND ADMINISTRATIVE CONTROL

The organizational structure that will be employed during the safe enclosure period is described in both the decommissioning plan and the safe enclosure plan. There should be a clear delineation of responsibilities. This is particularly important when contractors or outside organizations are involved. The use of contractors or other organizations will not relieve the licensee of its responsibilities. The organizational structure ensures that the quality assurance function is independent of those persons directly responsible for performing the maintenance activities.

If the passive safe enclosure option is selected and if no personnel are assigned to the facility location, the organizational responsibilities and administrative controls become less distinct. When there are no assigned staff at the facility, the licensee assigns overall responsibility to a single organization or individual whose responsibility it will be to assemble the resources required for when periodic entries into the site need to be made. In this case, it will be almost impossible to retain the historical knowledge that would be required to assist in the periodic entries and inspections unless it has been well documented. It is essential to document the historical knowledge of personnel associated with the facility prior to shutdown and during the site preparation phase. Much of this information is included in initial versions of the decommissioning plan and associated documents.

Additional information concerning organization and management of decommissioning projects is provided in Ref. [8].

5.4. RADIOLOGICAL PROTECTION

The radiological protection organization normally functions independently in matters affecting the health and radiological safety of the workers and the public. This may be difficult to achieve with the small staff required during the safe enclosure period. If it is not feasible to maintain this function, an independent organization or person should periodically perform a separate review of the radiological protection programme. Many of these procedures may be the same as those used during operation and maintenance of the facility or during the operation and maintenance of other facilities operated by the licensee.

A radiological monitoring programme is performed as detailed in the decommissioning plan, the safety assessment and the safe enclosure plan. The extent of the monitoring programme will take into account the risk from the safe enclosure and may change between the safe enclosure preparation period and the deferral period. It is likely that the risk will be significantly less than that asosciated with facility operation. During final dismantling, the level of monitoring may need to be increased. Monitoring programmes inherited from the operational period may need to be modified for applicability during the safe enclosure period.

The degree of on-site monitoring will vary depending on which safe enclosure option has been chosen. The monitoring programme inside the facility will be less if the passive option is selected. On-site monitoring may include personnel monitoring and routine area monitoring for airborne radioactive material, radiation and surface contamination.

Off-site routine discharges of radionuclides via airborne and liquid pathways are controlled, monitored and recorded during the safe enclosure period. Relevant recommendations are provided in Ref. [9].

5.5. WASTE MANAGEMENT

A waste management plan, which is part of the decommissioning plan, is implemented during the safe enclosure period. The plan that was developed during the initial decommissioning planning process may need review and revision.

It is normally assumed that the operational waste from the plant has been retrieved and packaged prior to the start of the safe enclosure period. It is preferable that this packaged waste be sent to an authorized disposal facility. However, if such a facility is not available, the waste may have to be stored within the safe enclosure facility or another suitable interim storage facility, having first gained the approval of the regulatory body.

The waste streams encountered during the safe enclosure period will be similar to those encountered during the operation of the facility. The decay of short lived radionuclides results in changes to the isotope ratios and may require updated analysis of the waste stream characterizations. This is especially significant for facilities with high levels of alpha emitter contamination. The amounts of waste generated during the safe enclosure period will normally be very small when compared with the volumes of operational waste. If limited decontamination or dismantling activities occur during the safe enclosure period, then the amounts of waste may increase to near operational levels. The waste may include items such as expendable clothing, worn out parts, used high efficiency particulate air (HEPA) filters and other consumables.

Processing waste during the safe enclosure period in order to achieve large waste volume reduction may be neither economic nor feasible owing to the low volumes of waste anticipated. Reductions in waste volumes can also be achieved through training, administrative controls, decontamination programmes, contamination control, sorting of waste material and effective processing. The radiation exposure of workers and the public may vary depending on the waste handling and minimization strategies employed. An integrated approach is needed to balance waste minimization with the associated potential radiological exposure and to ensure that the optimization principle is satisfied.

The accumulation of waste, either radioactive or non-radioactive, during the safe enclosure period is not recommended. If such waste were combustible and if it were allowed to accumulate, then it may become a fire hazard. Also, if the storage period were lengthy, the waste containers would need to be inspected periodically and any deteriorating containers repackaged, thereby unnecessarily exposing the workers to radiation. Staging areas for waste awaiting shipment are designed to prevent potential accident conditions arising (such as fire) and prevent them from affecting the rest of the facility, and to protect the containers in the event of adverse environmental conditions arising that could accelerate package deterioration.

5.6. EMERGENCY PLANNING

An emergency plan and related procedures to deal with postulated events predicted in the safety assessment are prepared for the safe enclosure period. These procedures may be developed from the original operating emergency procedures, with appropriate changes made to reflect reduced source terms. The hazards arising during the storage period will normally be less than those arising during operations and the radiological consequences may be restricted to within the site boundary.

Personnel are trained in the emergency procedures and sufficient equipment is made available to evaluate the incident properly and to mitigate its effects. It is important that agreements with outside organizations (such as police department, fire department, ambulance services and medical facilities) for providing emergency assistance, if needed, are in place and are periodically exercised.

5.7. PHYSICAL SECURITY AND SAFEGUARDS

Appropriate physical security and surveillance of the facility are maintained during the safe enclosure period. These activities will have been defined in the surveillance and maintenance plan or in a physical security plan. If the facility contains materials subject to safeguards, the operator has an obligation to adhere to the relevant international agreements and to take into consideration IAEA safeguards principles [10–12]. In most cases, if there is no material that is subject to safeguards, a watchman or remote monitoring can provide the necessary security. It may even be possible for the security monitoring to utilize an alarm system which alerts the local police authorities. In this case, local authorities are provided with training and instruction on how to respond to the alarms and how to notify the facility owner.

5.8. QUALITY ASSURANCE

The quality assurance programme is updated and implemented before safe enclosure begins. This plan will be an abbreviated form of the normal operations or decommissioning quality assurance programme. Safe enclosure activities are performed in accordance with approved work procedures.

6. CRITICAL TASKS OF SAFE ENCLOSURE

A number of critical tasks will be performed prior to and during the safe enclosure period. These tasks will vary according to the type of facility involved and the amount of radioactive material remaining in the facility. Each of these tasks is properly considered during the planning process and each is incorporated, as applicable, in the decommissioning plan and in other complementary documents.

6.1. CHARACTERIZATION OF THE INSTALLATION

The characterization survey is performed immediately after the facility operations are terminated. The information collected is important for the safe enclosure phase and for eventual dismantling. The survey is expected to identify both the radiological and non-radiological hazards that may be encountered in preparing the site for safe enclosure or during the surveillance and maintenance activities performed during the safe enclosure period. The survey includes the provision of data needed to perform the final decommissioning planning for the facility. The characterization survey will cover the entire facility and not just those locations to be accessed during surveillance and maintenance activities. If an emergency were to occur, access to any portion of the facility may be needed; characterization data are therefore indispensable for the purpose of entry.

The initial site characterization may be limited to obtaining the information necessary for the safe enclosure safety assessment, establishing a baseline for future monitoring, providing information for the maintenance and surveillance plan, and supporting planning for future dismantling. If the safe enclosure period is relatively short and the information is needed for planning final dismantling, the survey may be very detailed and include all areas of the facility and the interior of every system, along with environmental characterization of contaminated soils or groundwater. On the other hand, if the safe enclosure period is for an extended period the survey might only provide an overall status of the facility, not detailed information. If the facility is to be put in safe enclosure for a very long period (namely, for more than 20 years), it may be more prudent to perform the detailed survey later on in the safe enclosure period in order to obtain a more realistic appraisal. If this is the case, a plan is prepared to identify what data need to be obtained and how they will be obtained. These characterization data may be collected as a part of the surveillance and maintenance programme and addressed in the surveillance and maintenance plan.

Routine survey information collected during the safe enclosure period can be compared with the characterization data to identify changing conditions and thereby provide more current and complete information for the eventual dismantling activities. This information is collected when the radiation protection technicians perform their required periodic surveys. The characterization data files are updated as new data are generated during the safe enclosure period to provide the decommissioning team with the most current data possible.

The radiological characterization of the facility may be achieved by a combination of measurement, estimation and calculation techniques. To validate calculations, for instance for activation calculations, physical measurements or radiochemical analysis may be necessary. During the lifetime of the working facility, material samples may have been retrieved for a number of reasons. Analysis of such material may be useful for the estimation of the inventory and in assessing the condition of the radioactive material.

6.2. WASTE MANAGEMENT PLAN

A physical inventory of materials, components and structures to be removed during both the site preparation and the safe enclosure period is described in the waste management plan. The radiological/non-radiological characterization applied to this inventory gives the characteristics of the waste, its activity and the quantities of materials (radiological and hazardous waste). All of this is needed for the waste management plan that usually forms part of the decommissioning plan.

The waste management strategy is integrated with the decommissioning strategy and the existing disposal routes are used as much as reasonably possible. The waste management plan establishes:

(a) Waste classification;
(b) Quantities of materials;
(c) Methods for conditioning and packaging;
(d) Criteria for identification and storage inside and outside the site;
(e) Waste stream routes;
(f) Materials to be released with or without restrictions (recycle, reuse or unrestricted release).

Significant amounts of residual radioactive material may be present at the time of final facility shutdown. Most of this material is removed as part of the prepartions for safe enclosure of the facility.

6.2.1. Waste management plan for preparation of the safe enclosure

If not already performed as part of the shutdown procedures, the following waste management tasks are normally undertaken during the preparation of the facility for safe enclosure:

(a) Drainage of systems to remove liquids;
(b) Removal of operational waste, or the processing of such wastes into a form suitable for final disposal or storage within the safe enclosure;
(c) Ensuring that areas have hazards properly identified;
(d) Removal of discrete sources (startup, check, irradiation);
(e) Performance of terminal cleanout of processing plant material;
(f) Removal and shipment of new and spent nuclear fuel;
(g) Removal of loose material and rubbish, especially combustible material;
(h) Retrieval and processing of any deteriorating or unsafe material;
(i) Retrieval and processing of other hazardous substances that may or may not be radioactively contaminated, such as mercury, asbestos or process chemicals;
(j) Preparation and possible decontamination of the areas where human access is routinely required for inspection and maintenance.

6.2.2. Waste management plan for operation of the safe enclosure

During the safe enclosure period, waste is produced but in smaller quantities than during the operating or safe enclosure preparation period. In the case of the active option, some production of waste, connected with the staffing of the facility, will arise. This will be reduced if the safe enclosure is made into an area free of loose radioactive contamination during its preparation. Other wastes may derive from components or equipment replaced during the deferral period. The passive option may be expected to produce less waste than the active option.

Both deferral options may produce contaminated water as a result of routine human entry or failure of the containment, thereby allowing ingress of water into active areas. This may call for a controlled discharge to the environment (or treatment before discharge) in accordance with procedures approved by the regulatory body.

6.3. UPGRADE OR SHUTDOWN OF INSTALLATIONS OR SYSTEMS

During the safe enclosure period, certain systems may be shut down as parts of these may no longer be needed, depending on which safe enclosure option is chosen. These systems are identified during the planning stages and a systematic approach used to initiate their deactivation. Steps taken during these activities are documented to maintain updated knowledge of the facility and to pass this information on to the workers responsible for eventual dismantling. The impact on future safety will also be considered when modifying systems or deactivating their functions. These modifications are considered during revisions to the safety assessment.

As regards those systems that are needed for the safe enclosure option selected, it may be appropriate for the inactive portions of these systems to be physically isolated from the operational or needed (active) portions of the systems. Radioactive contamination and the contents of systems may migrate to where they would not be expected. In some cases, failures in the inactive portions of the systems may cause an overall system failure. Systems are normally isolated by means other than the use of isolation valves.

Special attention is given to the facility's electrical and instrumentation systems. At most older nuclear facilities, electrical systems will have been modified many times during the operational phase of the facility, but the drawings may have been updated only very infrequently. As a result of this, electrical hazards can be a major concern during the decommissioning process. As much of the electrical system as possible is shut down and dismantled during the safe enclosure preparation period. A separate electrical system or an update of the existing system to support the safe enclosure needs to be supplemented by good drawings to support the eventual dismantling effort.

Other systems may have to be upgraded to meet current safety requirements or adapted for safe enclosure conditions. Such modifications of systems would normally be performed before the safe enclosure period begins. Any modification of current systems or the addition of new systems is documented for present and future reference. The surveillance and maintenance needs of any new or modified systems will be included in the surveillance and maintenance plan and schedule for the safe enclosure.

6.4. CONTROL OF AREAS

Areas that contain radioactive material are controlled and marked with appropriate warning signs in accordance with the regulatory body's requirements. The purpose of this control is to restrict inadvertent entry, which could cause a loss of control of material and the exposure of individuals. Control measures within the safe enclosure facility have to accommodate other design features of the facility. For example, active or natural ventilation in parts of the structures may render it necessary that barriers to human access also be constructed in such a manner as to allow air circulation.

If passive safe enclosure is chosen as the option, the entry points may be welded, locked or kept at a high security standard during the periods between surveillance inspections. This ensures adequate control of the area. For active safe enclosure, all entries other than one main entry point may be secured. The main entry point is either staffed when the facility is open or locked during non-working hours. Daily access is assumed for active safe enclosure.

Security fencing may be provided to restrict access to the site around the safe enclosure, and to the land area of the originally licensed nuclear site. A reduction in the area enclosed by the outer security fence may be allowed with the agreement of the regulatory body. However, the results of safety analysis and the need for land for future dismantling actions are considered. Both the outer fence and entry points may be equipped with remotely monitored security detection devices.

6.5. INFORMATION MANAGEMENT

The collection and retention of records are very important during the safe enclosure period. These records document any changes to the facility, systems or areas that occur during the period. It is recognized that workers will begin to leave soon after the plant is permanently shut down and that personal knowledge of the facility will be lost. There is thus no alternative to proper record keeping. The licensee retains responsibility for the collection and storage of all necessary records. Typical records maintained during the safe enclosure period provide:

(a) Sufficient information on the design, the construction, the operational phase and the radioactive inventory such that the safety of the safe enclosure can be

properly assessed and that final dismantling can be performed at any time during the deferral period;
(b) Indication of spills or other releases, such as any ground or soil contamination;
(c) Radiological characterization data to include the current location of radioactive and non-radioactive hazardous materials;
(d) Identification of any material that has been removed;
(e) Identification of the destination of the material that has been removed from the facility;
(f) Operating instructions and/or procedures that may be needed during the final dismantling effort;
(g) Maintenance work instructions that support the disassembly of major components;
(h) Indication of maintenance and surveillance activities performed;
(i) Records of financial assurance mechanisms.

In addition, documentation may be needed for possible future litigation, to show compliance with statutory requirements and to demonstrate that the site has been managed in a safe and proper manner.

Information is maintained in accordance with selection criteria developed by the regulatory body in order to limit the number of records maintained. Record management systems are used to facilitate the retrieval of information when necessary.

The types of storage media and computer software used are also very important. More than one form of storage media is normally maintained in order to help ensure retrievability. It must be recognized that current technologies may have become obsolete by the time eventual dismantling is undertaken. Copies of computer software are retained or backwards compatibility verified to ensure that the data can be interpreted in the future.

Records are stored in an environmentally controlled area during the safe enclosure period and conditions that reduce deterioration of the storage media maintained. It is to be noted that even common environmental factors may cause deterioration of the information; for instance, exposure of blueprints to fluorescent light for long periods of time will cause fading of the documents. Duplicate archives of essential information need to be maintained at a separate location, at a distance from the originals.

Consideration will also be given to the organization of the retained records. Experience has shown that even when records have been maintained, the organization of those records may make very difficult the task of finding what is needed and understanding the records. The difficulty in record retrieval has at times forced decommissioning teams to obtain new field data, thus wasting time and money, and causing unnecessary additional radiation exposures.

6.6. SURVEILLANCE AND MAINTENANCE

In the concept of safe enclosure, the design lifetimes of the structures, equipment and components are considered. When these times are exceeded, deterioration and failure of the structures, systems or equipment can occur, with a possible impact on the safety of the facility. The surveillance and maintenance plan is used to specify a strategy of either increased maintenance or one involving replacement of parts or components to extend the design lifetime of the facility or system.

An initial list of all equipment requiring surveillance or maintenance is developed to ensure that all components are included in the maintenance schedule derived from the surveillance and maintenance plan, the safety assessment or the decommissioning plan. This list will be very specific and will provide the following information about each component:

(a) Nomenclature,
(b) Serial number,
(c) Manufacturer,
(d) Location,
(e) Maintenance frequency,
(f) Replacement frequency and cost,
(g) Results of last maintenance.

An overall schedule includes all required surveillance and maintenance activities. This schedule will include the replacement of key components and structures, namely, building roofs and ventilation motors. The replacement of these items can be very costly and is factored into the overall cost estimate for the safe enclosure period.

The following activities are performed during this period as provided for in the safety assessment and decommissioning plan, and documented in detail in the surveillance and maintenance plan:

(i) Surveillance, monitoring and inspection appropriate for the level of hazard;
(ii) Maintenance of the facility and the barrier/containment structure;
(iii) Physical security (as required);
(iv) Maintenance of a financial mechanism to guarantee that funds are available when needed for the eventual final dismantling.

The surveillance and maintenance plan assesses the need and availability of spare parts needed during the safe enclosure period and identifies a strategy for maintenance or replacement of the equipment required during the safe enclosure period. Experience has shown the difficulty of obtaining replacement parts for essential equipment that is 50–60 years old. The manufacturer may no longer exist or may no longer make replacement parts for that component, or may no longer have the drawings for that component and thus cannot readily produce it.

A record is maintained of each task performed during the safe enclosure period. Accurate and complete information relating to the locations, configurations, quantities and types of radioactive material remaining in the facility is essential and is maintained. For eventual final dismantling, these records are used to demonstrate that the radioactive material present when facility operations were suspended has been properly accounted for and that its ultimate destination and use have been identified and confirmed. This documentation also takes account of material that may have been released from regulatory control.

On completion of the safe enclosure and deferred dismantling period, appropriate records are retained and held for purposes such as confirmation of completion of preventive maintenance and surveillance activities.

6.7. ACTIVITIES DURING SAFE ENCLOSURE

A number of safety related activities other than the surveillance and maintenance tasks may be performed during the safe enclosure period, if the active option or an option other than complete passive safe enclosure is chosen. These activities normally reduce the risk associated with the facility and help ensure the safety of the general public and the environment.

Non-essential systems can be identified and marked, even those that do not contain any radioactive material. These are systems that will not be needed during the eventual dismantling activities or for maintaining the facility in a safe configuration. Each system is normally marked with a distinctive colour to allow ease of identification and tracking. These non-essential systems can be removed from the facility as time allows. The removal of these systems can be used as ‘filler’ work for workers during the active safe enclosure period, provided that licence conditions during the safe enclosure period permit these activities. If an entire system cannot be removed in a single operation, the remaining components will be left in a safe condition.

Provided that licence conditions allow, other activities that may be performed during this period and which will support the eventual final dismantling activities may include:

(a) Decontamination of systems or areas,
(b) Undertaking additional radiological surveys to collect more complete data to support the characterization effort,

(c) Undertaking radiological surveys to remove components from regulatory control and to reduce the inventory of spare parts,
(d) Removal of non-radiological hazards such as those presented by asbestos or chemicals,
(e) Removal and isolation of superfluous safe enclosure or final dismantling equipment and material,
(f) Demolition of portions of the facility.

For passive safe enclosure, the majority of the above activities are carried out during preparations for safe enclosure.

7. PREPARATION FOR FINAL DISMANTLING

No matter which safe enclosure option is selected, a number of actions or tasks have to be performed in preparation for the final dismantling. These can be undertaken towards the end of the safe enclosure period or as the first set of tasks in the final dismantling phase.

A number of systems or areas may need upgrading or reactivating, or alternatives may have to be developed for the final dismantling effort. In many instances, the systems or areas will not have been used during the safe enclosure period and these systems or areas will therefore have to be evaluated to determine how best to proceed. Completely new systems or areas may need to be constructed. The use of temporary systems or areas needs to be considered as a part of the evaluation. Also as a part of the evaluation, consideration need to be given to developing special tools (such as long handled tools) that can be used for the final dismantling. In the case of a long period of safe enclosure, it may be assumed that any existing equipment will either be obsolete or unserviceable when needed and will therefore have to be replaced.

Systems, equipment and items that may need modification or construction in order to support the dismantling activities may include:

(a) The ventilation system (to handle the increase in the generation of airborne radioactive material);
(b) Personal monitoring facilities;
(c) Protective clothing change rooms or areas (to accommodate a large number of workers and clothing changes);
(d) Waste handling facilities (to handle the increased waste volumes and possibly new waste streams);

(e) Lay down areas (to allow for the temporary storage of waste boxes and large components);
(f) Machine shop (to support the needs of the final dismantling crew);
(g) Laundry facilities (to process protective clothing sets and for cleaning respirators);
(h) Radiological analytical capabilities (to analyse the large number of samples taken during the final dismantling effort and the final survey);
(i) Security and access control;
(j) Drainage systems and/or facilities capable of accumulating and treating liquid wastes;
(k) Shipment and reception facilities (to marshal properly the flow of equipment and materials onto and off the site);
(l) Lighting systems;
(m) Fire protection and alarm systems;
(n) Power supply systems (either upgraded, new or an external temporary system);
(o) Final dismantling support infrastructure (such as compressed air, water and electricity);
(p) Lifting equipment;
(q) Worker support infrastructure (such as toilets, showers, change rooms, eating facilities, transport and medical support).

Work procedures and work instructions for the final dismantling will also be developed. New procedures and work instructions will normally be necessary. Some existing procedures might be practicable but will still need to be reviewed for applicability. The procedures may need to be modified to account for changes that may have occurred during the safe enclosure period. This review of procedures may involve revision of the safe enclosure surveillance and maintenance plan, if performed prior to the commencement of the final dismantling effort.

Annex I

PLANS AND REPORTS ASSOCIATED WITH DECOMMISSIONING

I–1. DECOMMISSIONING PLAN

The decommissioning plan includes the following components:

(a) Characterization survey plan,
(b) Characterization survey report,
(c) Safety assessment,
(d) Cost estimate,
(e) Environmental impact assessment,
(f) Financial assurance plan,
(g) Radiation protection programme,
(h) Environmental protection plan,
(i) Quality assurance plan,
(j) Waste management plan,
(k) Emergency plan,
(l) Physical security plan,
(m) Safe enclosure plan,
(n) Site preparation plan,
(o) Surveillance and maintenance plan,
(p) Final survey plan.

I–2. FINAL DECOMMISSIONING REPORT

The final decommissioning report includes a final survey report and shutdown plan (this plan is normally prepared as part of the operating phase and is not considered part of the decommissioning plan or the decommissioning process).

Annex II

CASE STUDIES

This annex presents facilities that have been placed into a safe enclosure configuration.

II–1. FRANCE: CHINON A2 NUCLEAR POWER PLANT

II–1–1. Main plant features

The Chinon A2 nuclear power plant's main features are as follows:

Reactor type:	Natural uranium–graphite–gas cooled (CO_2) reactor.
Thermal power:	800 MW(th).
Start of commercial operation:	1965.
Hours of operation:	131 825.
Total electric power generation:	23.6×10^9 kW·h.
Shutdown date:	14 June 1985.
Licence date for safe enclosure mode:	7 February 1991.

II–1–2. Plant description

The core of the reactor is housed in a spherical steel vessel (diameter: 18.3 m, thickness: 100 mm). This vessel is installed inside a cylindrical concrete structure which works to provide biological protection. The heat is extracted from the core by four carbon dioxide loops. Each loop is fitted with a motor driven pump and a steam generator and is housed in a separate building. The plant is shown in Fig. II–1.

II–1–3. Safe enclosure implementation (passive option)

The reactor was defuelled between September 1985 and May 1986 and the fuel shipped to the reprocessing plant. The reactor internals have not been removed. The reactor vessel still contains the graphite structure (3619 columns, each column made of 7 barrels). All the control rods used during operation are stored inside the vessel.

FIG. II–1. The Chinon A2 nuclear power plant.

The thermal isolation material has been removed and sent to a low level waste repository. The reactor loops have been cut into sections (maximum length 1.4 m) and these sections have been used as containers for metallic waste and stored in the heat exchanger buildings (404 containers are stored, representing a mass of 1300 t and an estimated activity of nearly 10^{13} Bq).

The main components (reactor vessel, heat exchangers) have been isolated by welding steel plates onto the nozzles (with biological protection if necessary). Control rod and refuelling penetrations of the reactor vessel have been closed by bolted plates fitted with joints.

The facility, which is in the safe enclosure mode, is limited to the reactor vessel and its biological shielding, which is a cylindrical concrete structure containing the reactor vessel. It is 25 m in diameter and 22 m in height.

The four heat exchanger buildings have external dimensions of 15 m × 22 m × 57 m (height). A decision has been taken to confine radiological material to the components themselves, namely, the reactor vessel, the heat exchangers and each individual waste container. Five confinement chambers have been created, one for the reactor vessel and one for each of the four heat exchangers. The order of magnitude of the source term is 10^{16} Bq for the reactor vessel and 10^{13} Bq for the four exchangers. The

TABLE II–1. FREQUENCY OF PERIODIC TESTS

Test	Item assessed	Test interval
Radiological:		
	Rain and groundwater	4 weeks
	Gaseous releases	4 weeks
	Room contamination	6 months
	Reactor vessel activity	5 years
	Liquid releases	4 weeks
Vessel atmosphere:		
	Temperature	4 weeks
	Humidity	4 weeks
Confinement integrity:		
	Overall integrity and leaktightness	5 years
	HEPA filter	5 years
Alarm system		6 months
Building	Visual appearance	6 months

internal pressure control of each confinement chamber is achieved by an exhaust line fitted with a check valve (to limit moisture ingress) and an HEPA filter (five separated circuits).

The cylindrical concrete structure of the reactor and the four heat exchanger buildings provide radiological protection and protect against intrusion. All penetrations have been closed, either with concrete blocks or with a metallic casing fitted with a door when access is needed.

Periodic tests are performed as indicated in Table II–1.

II–2. GERMANY: LINGEN NUCLEAR POWER PLANT

II–2–1. Main features of the Lingen plant

The main features of the Lingen plant are as follows:

Plant: Kernkraftwerk Lingen (KWL)
Schüttorfer Str. 100
D49808 Lingen, Lower Saxony
Germany.

Owner:	Kernkraftwerk Lingen GmbH.
Parent company:	RWE (formerly Vereinigte Elektrizitätswerke Westfalen (VEW)).
Reactor type:	BWR, with oil/gas fired superheater (Fig. II–2).
Reactor power:	520 MW(th).
Generator power:	264 MW(e) gross, 10 × 109 MW·h.

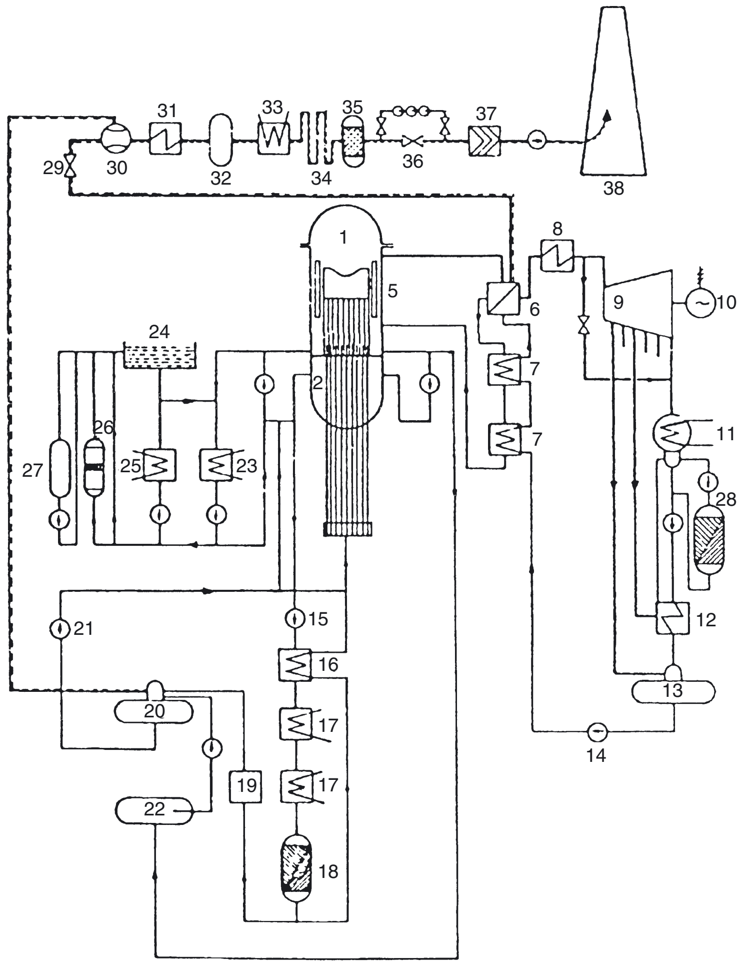
II–2–2. Plant history

The Lingen plant's history is summarized as follows:

Start of construction:	October 1964.
First criticality:	January 1968.
Demonstration run:	September 1968.
Commercial run:	October 1968.
Plant shut down for investigation and repair (steam converters):	January 1977.
Application for decommissioning licence:	June 1983.
Last fuel shipment for reprocessing:	August 1983.
Licence for decommissioning granted:	September 1985.
Operation of safe enclosure (operation licence valid for 25 years):	March 1988.
Application for a modification of the licence in order to rebuild some operational systems to enable conditioning of operational waste for delivery to the final repository at Morsleben:	August 1996.
Licence granted:	November 1997.
Closure of Morsleben and adoption of the concept for the new waste disposal option:	September 1998.

II–2–3. Plant operation

KWL was operated for nearly ten years with an average availability of 60% and achieved a total output of 11 TW·h. During this time there were several problems with the steam converters, and therefore new ones were ordered and delivered. In January 1977, the operation was halted to allow inspection of the steam converters and again a failure was found. This was the reason why the licensing procedure to replace the converters was initiated. All the necessary papers had been prepared, even for the backfitting of the plant.



Key

1 Pressure vessel
2 Reactor vessel
3 Control rod drives
4 Circulating pump
6 Water separator
7 Primary condensate cooler
8 Superheater
9 Turbine
10 Generator
11 Condenser
12 Feed water heater
13 Feed water tank
14 Feed water pump
15 Primary water clean up pump
16 Regenerative heat exchanger
17 Recuperative heat exchanger
18 Ion exchanger
19 Throttling section
20 Primary water tank
21 Primary water pump
22 Buffer tank
23 Off-load cooler
24 Fuel pond
25 Fuel pond cooler
26 Filter for fuel pond water
27 Flushing water tank
28 Ion exchanger for the secondary condensate
29 Pressure regulator
30 Jet pump
31 Heater
32 Recombiner
33 Cooler
34 Delay line
35 Grit filter
36 Delay system
37 Mechanical filter
38 Stack

FIG. II–2. Schematic diagram of the Lingen nuclear power plant.

In 1979, during preparation and planning of the backfitting activity, VEW, the parent company of KWL, decided that the risk of investing € 50–100 million without a guarantee of getting a new operating licence was too high, so it was decided to shut down the plant permanently.

II–2–4. Preparation for safe enclosure

It is known that the licensing procedure, including the preparation of the necessary documents, takes a long time. KWL requested a modification be made to the operational licence in order to adapt the plant and the operation to permanent shutdown. These operations included:

(a) Cutting and sealing of a number of pipes leaving the controlled area (secondary feedwater, secondary steam, auxiliary steam pipes);
(b) Disconnecting all cooling water pipes to and from the reactor building (two years after the shutdown of the plant there was no need of cooling water, even for the spent fuel elements in the storage pool);
(c) Reducing the main grid;
(d) Reducing the instrumentation;
(e) Reducing shift personnel;
(f) Reducing the permitted rates of release of radioactive material by air and water.

The authority granted the licence in August 1981 and the work was carried out in 1981 and 1982.

II–2–5. Decommissioning plan

Planning for the final shutdown continued and the safe enclosure option was chosen. One of the reasons for choosing this option was the lack of a final repository for radioactive waste. Another reason was the fact that a new nuclear power plant, Kernkraftwerk Emsland (KKE, a PWR with an output of 1300 MW(e)), was under construction nearby and the personnel of KWL had the opportunity to work there. The application for safe enclosure was filed with the regulatory authorities in May 1983. In August 1983, the shipment of the spent fuel elements to a reprocessing plant was completed.

II–2–6. Safe enclosure plan

It was planned to reduce the controlled area to an optimal size (by decontaminating and demolishing the flush water tank and the surrounding building) and to put the remaining nuclear part of the plant (reactor building, waste treatment building and connecting building) into safe enclosure for about 25 years (Figs II–3, II–4). This means that the plant is to be demolished nearly 30 years after shutdown. The main radiation in the plant is emitted by ^{60}Co and radioactivity levels range from 10 mSv/h in the region of the steam converters up to 200 mSv/h near the primary circulation pipes. This activity will decay to less than 2% of these values over a period of 30 years.

The steps taken to bring the plant to a safe enclosure primarily consisted of:

(a) Cutting all pipes leaving the controlled area, except for one exhaust air pipe.
(b) Closing all openings, using materials that match, in terms of quality, those of the surrounding walls, but leaving one door for access.
(c) Removing all liquids and draining all pipes and vessels.
(d) Installing a small air circulation and conditioning system to keep the relative humidity of the air around 50% in order to prevent corrosion inside the controlled area.
(e) Installing a small exhaust air system to effect a controlled release of air. This air is filtered and samples are taken continuously and measured periodically; a detailed description of the process is has been published.[1]
(f) Cleaning floors and staircases to avoid contamination during inspections.
(g) Avoiding all ignition sources inside the controlled area (such as electricity, moving (rotating) parts). The lighting is switched on only for inspections and repairs.
(h) Installing an instrument board outside the controlled area to provide specific information, for example, through alarms connected to the air conditioning and exhaust systems, an alarm signalling the absence of integrity of the entrance door and excess water levels in the sumps of the buildings.
(i) Storing operational waste in the plant without undertaking conditioning, except for combustible waste, which was transported to a nuclear incineration facility, and evaporator concentrates, which were fixed by bituminization.

Whereas the ventilators for the air conditioning and exhaust systems were installed outside the controlled area, the filters lay inside the area.

---

[1] HARBECKE, W., Konsequenzen der Aufhebung der Unterdruckhaltung im Containment des Kernkraftwerkes Lingen, Rep. EUR 13131, Office for Official Publications of the European Communities, Luxembourg (1991).

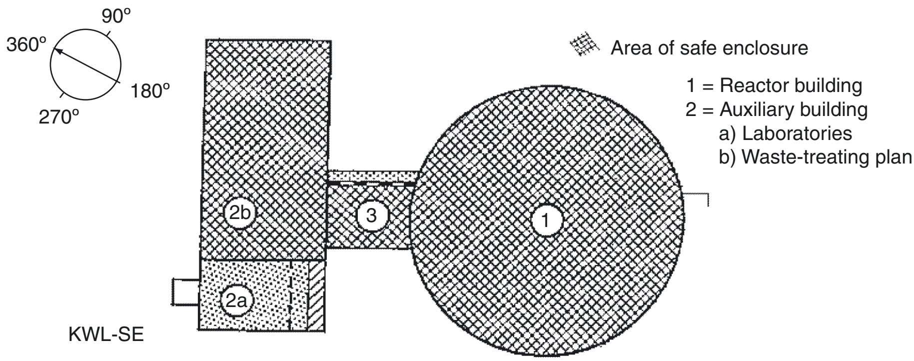


FIG. II–3. Layout of the Lingen site.

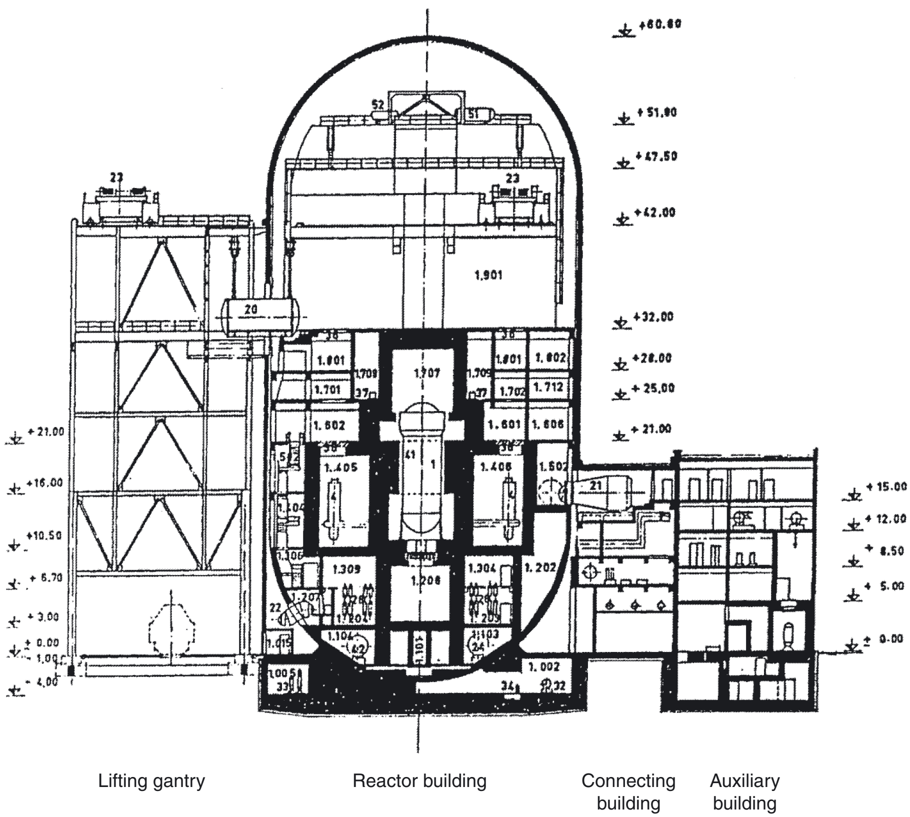


FIG. II-4. Cross-section A–A of the Lingen plant.

TABLE II–2. TOTAL ACTIVITY LEVELS AT THE LINGEN PLANT

Item		Activity level (Bq)
Contaminated operational waste:		
Resins		1.8×10^{14}
Filtration powder		2.2×10^{12}
Concentrates (fixed)		1.3×10^{12}
Other contaminated material		2.5×10^{10}
Contamination of system surfaces:		
Systems in the auxiliary building		1.4×10^{10}
Systems in the reactor building		2.1×10^{13}
Contamination of building surfaces and structures:		
Auxiliary building		1.7×10^{8}
Reactor building		1.7×10^{9}
Activity inventory of the reactor pressure vessel:		
Vessel		2.2×10^{15}
Interiors		6.0×10^{15}
Core:		
Control rods		5.0×10^{14}
Poison blades		3.0×10^{14}
Fuel element casings		3.0×10^{14}
Activity inventory of the biological shield:		
Concrete, liner, bars		5.1×10^{11}
	Total:	$\sim 9.5 \times 10^{15}$

II–2–7. Plant data for planning purposes

A number of investigations were conducted to obtain the data necessary for planning the decommissioning. Data were collected to establish the radioactive inventory of:

(a) The reactor pressure vessel (calculated data),
(b) The biological shield (measured and calculated as part of a Euratom research programme),

(c) The contaminated pipes (calculated on the basis of representative measurements and dose rates).

The total amount of activity is given in Table II–2 (1987 figures).

II–2–8. Surveillance and maintenance plan

As mentioned, the circulated air in the controlled area is continuously sampled and the filters analysed twice a month. The interior of the controlled area is maintained with a dry atmosphere. No work except small repair activities is performed; therefore no sudden increase in airborne radioactive material within the controlled area is expected. The measured activities are below 5×10^{-5} Bq/m^3 (^{60}Co), 8×10^{-5} Bq/m^3 (^{137}Cs) and 100 Bq/m^3(^{14}C). All other isotopes are below the detection limits. The low values mean that activity was not detected beyond the high efficiency particulate air filters; therefore the radioactive releases are calculated and are in the range of 100 Bq/a (for beta/gamma). As another nuclear power plant (KKE) in the vicinity is operational and is subject to a complete survey programme, and as long as the effluents are as low as expected, then KWL only needs to conduct a periodic survey along the site boundary. Inside the controlled area there is instrumentation for humidity and temperature measurement (nine measuring points for each) and sump level alarms. There is a water level indicator and an alarm for each of the two condensed water collection tanks associated with the air drying system.

Inspections are conducted on a monthly, quarterly and yearly basis, as defined in the operational handbook. Only essential maintenance activities are conducted inside the controlled area, e.g. maintaining lighting on floors and staircases.

II–2–9. Status of the safe enclosure at Lingen

KWL had planned to send the waste to the Morsleben repository (Endlager für Radioaktiver Abfälle Morsleben — ERAM). A licence was requested to rebuild some operational systems (such as the water treatment system, the ventilation system, the entrance to the controlled area) for the conditioning of the waste. A licence to this effect was granted in November 1997. However, by the end of September 1998, ERAM was closed by the Government before the installation of the new systems could be completed. As the installation of the infrastructure was close to completion and as personnel with the proper training became available, it was decided to proceed as far as possible with the work. Currently, the waste management plan is tailored to minimize the volume of waste produced by decontamination to free release limits or by burning or melting. In-circuit system decontamination is to be performed to reduce radiation levels pending data collection for the detailed preparation of the demolition plan. In January 1998, the safe enclosure status of KWL changed from passive to active.

II–2–10. Lessons learned

The lessons learned are as follows:

(a) The plant is in a very good state of conservation, even considering that in some areas the relative humidity exceeded 60% for some time. Nearly all of the components (even the electrical systems) in the controlled area work well after almost ten years of safe enclosure. There is no indication of corrosion having occurred.
(b) The efficiency of the originally installed drying devices (which functioned by cooling the air) was not good during the summer. They were replaced by a dehumidification system.
(c) The specific activity of airborne material is very low, even with all the nuclear systems inside the controlled area open to the atmosphere.
(d) The effluent releases are very low.
(e) It seems that the use of beta–gamma activity as a tracer for alpha activity is becoming difficult because of the different half-lives of the nuclides.
(f) Even after the relatively short duration of safe enclosure, it is difficult to find personnel that are familiar with the plant.

II–3. ITALY: NUCLEAR FACILITIES AND THEIR CURRENT STATUS

At present, there are four research reactors and some repositories for fuel and radioactive wastes still in operation in Italy (Table II–3). The other plants have permanently ceased operation and are awaiting an authorization according to Article 55 of D.L. 230/95. Only activities that are related to plant safety and waste treatment are being performed.

II–3–1. Main features of the Latina plant

The main features of the Latina plant are as follows:

Reactor type:	Natural uranium–graphite–gas cooled (CO_2) reactor.
Thermal power:	705 MW(th).
Start of commercial operation:	May 1963.
Gross energy produced:	26 TW·h.
Shutdown date:	December 1987.

TABLE II–3. FACILITIES IN ITALY

Facility	Operational status	Waste status	Fuel status
Reactor AGN 201 'Costanza', Palermo University	In operation	No waste	
ITREC plant, C.R. Trisaia, ENEA	Out of operation	Conditioning being performed	
TRIGA RC-1 Reactor, C.R. Casaccia, ENEA	In operation	Waste stored at NUCLECO	
Reactor RSV TAPIRO, C.R. Casaccia, ENEA	In operation	Waste stored at NUCLECO	
Plutonium plant, C.R. Casaccia, ENEA	Out of operation	Waste on plant site	
Reactor RTS 1, CISAM	Undergoing deactivition	Unconditioned	No fuel on plant site
Reactor RB3, Montecuccolino Laboratories, ENEA	Undergoing deactivation	No waste on plant site	No fuel on plant site
FN plant, Bosco Marengo	Out of operation	Partially conditioned	Fuel on plant site
EUREX plant, C.R. Saluggia, ENEA	Out of operation	Partially conditioned	Fuel on plant site
TRIGA MARK II reactor, L.E.N.A., Pavia University	In operation	Unconditioned	
L54 CESNEF, Milan Politecnico	Out of operation	Unconditioned	No fuel on plant site
ESSOR reactor, C.C.R. Ispra	Cold shutdown	Partially conditioned	Fuel on plant site
Avogadro deposit, FIAT AVIO	In operation		
Latina nuclear power plant	Safe enclosure	Waste on-site	No fuel on plant site
Garigliano nuclear power plant	Safe enclosure	Waste on-site	No fuel on plant site

II–3–2. Outline of the safe enclosure at Latina

The following list provides an outline of the safe enclosure at Latina:

Type:	Active.
Duration:	100 years after shutdown.
Systems necessary:	
	Electrical,
	Fire protection,
	Security,
	Biological shield conditioning,
	Monitoring of the internals of the reactor and biological shield,
	Radiation monitoring.
Staff necessary:	15–20 persons.

II–3–3. Particulars of the safe enclosure at Latina

Four main safe enclosure activity areas have been identified: the reactor building, components and structures, waste management and conventional cleaning.

II–3–3–1. Reactor building

Details of the reactor building are as follows:

(a) The reactor was defuelled between 1988 and 1991, and the fuel shipped to the reprocessing plant.
(b) The steel pressure vessel (22 m diameter) will be separated from the other components by removing the cooling ducts (6 circuits, each with a diameter of 1.7 m and some 80 m in length); the access to the reactor for fuel management (197 standpipes) will be sealed.
(c) The steam generators will be removed (6 steam generators weighing 900 t each).
(d) The biological shield will be sealed and the interior kept in a dry atmosphere (below 60% relative humidity).
(e) Major maintenance activities will be performed on the reactor building (and probably the overall height will be reduced).

II–3–3–2. Components and structures

Details of the components and structures are as follows:

(a) The fuel cycle equipment components were decontaminated to reduce the radiological risk to workers, and then dismantled and stored in the reactor building.
(b) The waste treatment plant will be decontaminated and dismantled before safe enclosure starts.
(c) It is expected that the majority of equipment in the reactor building will be released from regulatory control.
(d) The fuel storage pool was decontaminated, except for a small portion that will probably be modified to transform it into a decontamination facility. When decontamination is complete, the pool will be used to store water for the fire protection system.
(e) The conventional structures will be removed on the basis of a cost–benefit criterion that takes into account possible reuse.

II–3–3–3. Waste management

Waste management activities are as follows:

(a) Some rooms in the reactor building, for instance, the blower house and blower annex, will be modified for use as a temporary store in order to reduce to a minimum the number of plant areas where radioactive material is located.
(b) Operational waste (some 80 t of magnesium alloy from the fuel element sheet and 20–30 m^3 of sludges from the pool and waste treatment plant) will be conditioned or supercompacted.
(c) The option of melting metallic waste derived from the dismantling of boilers, ducts and the waste treatment plant is under consideration.

II–3–3–4. Conventional cleaning

Conventional cleaning details are as follows:

(a) All dangerous materials present on the plant site will be removed,
(b) Some 250 t of asbestos was removed and an additional 80 t is to be removed to achieve complete cleaning,
(c) Oils contaminated with polychlorinated biphenyls were removed,
(d) Other minor materials are removed on a routine basis.

Table II–4 provides the inventory of radionuclides within the graphite at the Latina plant.

TABLE II–4. GRAPHITE ACTIVITY INVENTORY AS OF 31 DECEMBER 2001

Isotope	Inventory (Bq/g)
Ag-108	3.5×10^2
C-14	2.5×10^4
Ca-41	1.3×10^2
Cl-36	2.7×10^2
Co-60	2.6×10^3
Cs-134	7.0×10^1
Eu-152	4.8×10^2
Eu-154	2.3×10^3
Eu-155	5.1×10^2
Fe-55	2.6×10^2
H-3	2.5×10^5
Ni-63	1.7×10^2

II–3–4. Main features of the Garigliano plant

The main features of the Garigliano plant are as follows:

Reactor type:	Boiling water reactor.
Thermal power:	507 MW(th).
Start of commercial operation:	June 1964.
Gross energy produced:	14 TW·h.
Shutdown date:	August 1978.

II–3–5. Outline of the safe enclosure at Garigliano

The following provides an outline of the safe enclosure at Garigliano:

Type:	Active.
Duration:	100 years after shutdown.
Systems necessary:	
	Electrical,
	Fire protection,
	Security,
	Natural ventilation of the secondary containment,

	Monitoring of the internals of the reactor and biological shield,
	Radiation monitoring.
Staff necessary:	15–20 persons.

II–3–6. Particulars of the safe enclosure at Garigliano

II–3–6–1. Reactor building

Details of the safe enclosure activities at the reactor building are as follows:

(a) The reactor was defuelled between 1985 and 1987 and the fuel shipped to the Saluggia deposit.
(b) All circuits were drained.
(c) The internal volume of the secondary containment was divided into two separate regions: Region 1, which has a surface contamination <4 Bq/cm^2; and Region 2, which contains the main primary circuit components such as the vessel, the secondary steam generators and the cleanup system. Air in natural circulation flows from Region 1 to Region 2; passive dryers are used to maintain humidity below 50%.
(d) Gross decontamination was performed on the vessel, reactor channel and pool walls using high pressure water jets.
(e) The fuel pool was modified and is used to store contaminated components.

II–3–6–2. Turbine building

The turbine building details are as follows:

(a) The turbine building has been modified to store conditioned wastes.
(b) Components have not been removed (overall activity at shutdown: 85 GBq).

II–3–6–3. Waste

Details of the waste are as follows:

(a) High activity material outside the secondary containment (close to 4 t and 2.6 PBq at shutdown) was cemented in six containers ready for shipping.
(b) Sludges, concentrates and resins (about 250 t and 74 TBq at shutdown) were conditioned; some 1300 drums were produced.
(c) Other low activity radioactive materials are stored in underground trenches (about 1100 m^3 and 7.4 GBq in 1996), in 800 overpack containers and in a few caissons.

II–3–6–4. Other materials

Other materials are dealt with as follows:

(a) Asbestos in the turbine building was encapsulated, but no action has been taken with asbestos in the reactor building.
(b) Other minor materials are removed on a routine basis.

II–3–6–5. Waste treatment plant

Waste treatment plant details are as follows:

(a) All major components below ground level will be decontaminated and removed (total contamination approximately 75 GBq in 1996).
(b) It is planned to free release 50% of the material; the remainder will be stored in the turbine building.

II–3–6–6. Civil structures

Civil structures will be dealt with as follows:

(a) The stack will be decontaminated and dismantled.
(b) Other civil structures will be removed on a cost–benefit basis.

II–3–7. Licensing aspects common to the Latina and Garigliano plants

Work already performed has been authorized, on the basis of a case-by-case philosophy, in the framework of prior legislation (D.P.R. 185 of 13/02/64).

A new licence has been requested in order to complete the actions for placing the facility into a safe enclosure state, pursuant to the amended legislation (D.L. 230 of 17/03/95). At the end of this phase, a new licence will be requested in order to maintain the facility during the safe enclosure period. The documentation presented in the request for the safe enclosure licence consisted of:

(a) A master plan for decommissioning operations.
(b) A report which includes:
    (i) A general description of the site,
    (ii) A description of the present operating systems,
    (iii) A radiological characterization of the plant,
    (iv) The radioactive inventory.

(c) An outline of the plant in the final state that includes:
  (i) A general description of the plant at the end of operations,
  (ii) Releases to the environment during the safe enclosure,
  (iii) Estimates of the radiation doses to the workers during the safe enclosure period,
  (iv) Safety analysis of the safe enclosure period.

All of the following aspects will be considered in more detail when the licence to maintain the facility during the safe enclosure will be requested:

(a) A proposal of technical prescriptions for placing the plant into a safe enclosure state.
(b) A site preparation plan that includes:
  (i) A description of system modifications and new ancillary systems;
  (ii) A description of temporary waste storage facilities;
  (iii) An evaluation of releases during the operations;
  (iv) An evaluation of radiation doses to workers;
  (v) A safety analysis;
  (vi) A description of the management of the material produced;
  (vii) Criteria for the radiological protection of workers, the population and the environment.

Similar documents will be produced at the time of the application for a licence to maintain the facility during the safe enclosure period.

II–4. SPAIN: VANDELLOS 1 NUCLEAR POWER PLANT

II–4–1. Main features of Vandellos 1

The main features of Vandellos 1 are as follows:

Reactor type:	Natural uranium–graphite–gas cooled (CO_2) reactor.
Thermal power:	1670 MW(th).
Start of commercial operation:	May 1972.
Days of effective full power:	4750.9.
Shutdown date:	19 October 1989.

II–4–2. Outline of the safe enclosure at Vandellos 1

The following provides an outline of the safe enclosure at Vandellos 1:

Type:	Active.
Duration:	30 years.
Systems necessary:	
	Radiological monitoring, Monitoring of the internals of the reactor vessel, Fire detection, Electrical, Physical security.
Staff necessary:	15–20 persons (licensed operators and radiation protection, maintenance, waste management, physical security personnel).

II–4–3. Particulars of the safe enclosure at Vandellos 1

The defuelled reactor vessel (prestressed concrete) is to be isolated by sealing all penetrations. The moderator (graphite) and other metallic internal structures and com-ponents (e.g. steam generators) will remain confined to allow radioactive decay to occur.

The rest of the plant will be dismantled and the buildings demolished. The site will be released from regulatory control, except that part surrounding the current reactor building, which will also be dismantled. A new building of a smaller size is to be built to protect the reactor vessel from the maritime climate.

Table II–5 lists the general planning activities by plant lifetime phase. Table II–6 presents the proposed surveillance maintenance schedule to be employed during the safe enclosure period.

II–4–4. Documentation for the decommissioning plan

The decommissioning plan contents are as follows:

(a) Safety report:
- (i) Operational history of the facility,
- (ii) Radiological status of the facility,
- (iii) Decommissioning option and project description,
- (iv) Final state description,
- (v) Safety analysis,
- (vi) Radiological impact assessment.

TABLE II–5. PLANNING ACTIVITIES FOR VANDELLOS 1

Project	Phase	Period	Main activities	Tasks
Dismantling and decommissioning	Phase 1: Basic design and licensing	February 1992 to May 1994	Basic decommissioning engineering and planning	Engineering and planning
			Drawing up of licensing documentation (dismantling and decommissioning plan)	
	Phase 2: Design	June 1994 to December 1997	Elaborate engineering of the safe enclosure	
	Phase 3: Execution	January 1998 to 2002	Preparation of the site	Work at the site
			Implementation of the initial dismantling	
			Preparation of the safe enclosure	
	Safe enclosure	30 years		Surveillance and mainteance

(b) Environmental radiation monitoring plan.
(c) Technical specifications.
(d) Dose calculation programme.
(e) Organization and responsibilities.
(f) Project schedule.
(g) Quality assurance programme.
(h) Radioactive waste management.
(i) Radiation protection programme.
(j) Emergency plan.
(k) Physical security plan.
(l) Environmental impact assessment.

TABLE II–6. PROPOSED SURVEILLANCE AND MAINTENANCE AT VANDELLOS 1

Item	Parameter/action	Number of measurement/sampling points	Frequency
Enclosure barrier (concrete vessel):			
	Temperature	5	6 months
	Deformations	10	6 months
	Stress on reinforcement bars	14	6 months
	Verticality	4	6 months
	Geometrical measures	10	6 months
	Carbonation		5 years
	Chloride penetration		5 years
	Corrosion on reinforcement bars		5 years
	External visual inspection		5 years
Internal structures:			
	Remote (television) inspection of certain bolted unions	6	5 years
	Corrosion of typical unions	6	5 years
	Monitoring of corrosion rate	6	5 years
Safe enclosure atmosphere:			
	Temperature	9	Continuous
	Differential pressure	3	Continuous
	Humidity	3	3 months
	Sample analysis[a]	3	3 months
Containment	Leak rate		5 years

[a] ^{14}C, ^{3}H. Activity α, β–γ. Spectrometric and chemical analyses.

II–5. UNITED STATES OF AMERICA: HUMBOLDT BAY NUCLEAR POWER PLANT, UNIT 3

II–5–1. Main features of Humboldt Bay Unit 3

The main features of Humboldt Bay Unit 3 are as follows:

Reactor type	General Electric boiling water reactor, single cycle, natural circulation.
Thermal power:	240 MW(th).
Rated gross electric power:	65 MW(th).
Start of commercial operation:	August 1963.
Days of effective full power:	2727.54.
Shutdown date:	2 July 1976.
Licence date (ownership, not operation):	July 1985.
Decommissioned status:	SAFSTOR (safe enclosure).
Commencement of SAFSTOR period:	1988.

II–5–2. Outline of the safe enclosure at Humboldt Bay Unit 3

Details of the safe enclosure at Humboldt Bay Unit 3 are as follows:

Type:	Active.
Duration:	30 years.
Systems necessary:	Spent fuel storage and monitoring, Radiological monitoring, Waste collection and processing, Fire protection, Electrical, Physical security.
Staff necessary:	15–20 persons (the site is shared with operational non-nuclear facilities and therefore personnel with non-nuclear responsibilities are also used to support the safe enclosure activities).

II–5–3. Particulars of the safe enclosure at Humboldt Bay Unit 3

All fuel was removed from the reactor vessel and stored in the existing spent fuel storage pool along with expended fuel assemblies remaining from previous fuel cycles. There are currently 390 spent fuel assemblies stored in the spent fuel pool.

Non-operating systems were drained and secured to prevent deterioration and to minimize the potential for a release of contained radioactive material. Connections between non-operating systems and systems needed during the safe enclosure were either physically removed or had blanks installed.

Radioactive wastes remaining on the site prior to the start of the safe enclosure period, along with wastes generated during the preparations for safe enclosure, were processed and shipped off the site for disposal. Plant facilities were decontaminated to levels that would minimize the potential for spread of contamination outside the facility, permit periodic access during the safe enclosure period and minimize the requirements for periodic surveys and monitoring.

General area radiation levels in the vicinity of equipment operated or maintained during the safe enclosure period were reduced to levels as low as reasonably achievable. Plant facilities were modified to support the long term storage of spent fuel and minimize the generation of radioactive wastes and the maintenance and surveillance activities needed during the safe enclosure period.

Baseline conditions were established to provide a framework for the monitoring and surveillance programme during the safe enclosure period. Table II–7 illustrates the project schedule.

II–5–4. Safe enclosure experience and lessons learned

II–5–4–1. Loss of experienced personnel

Personnel who were present during the operational phase of the nuclear unit or even during the decommissioning planning phase will have left the organization, for example, through retirement, transfer or resignation. They take with them much valuable knowledge of the physical plant as well as background information about why certain things were done or about the assumptions made in developing plans. This is an even greater concern for older facilities, which may have operated during a period when the requirements to maintain basis documents or other background information did not exist as they do currently.

II–5–4–2. Loss of information and/or historical 'memory'

Along with the loss of experienced personnel, records or experiences that may have been maintained informally will be lost as personnel with knowledge of these records become unavailable. These documents cover the following:

(a) Licensing basis,
(b) Basis for design modifications,
(c) Basis and background for decisions,
(d) Regulatory background for decisions.

In cases where agreements with regulators on the applicability of licensing requirements to shut facilities down may have led to existing licence conditions, then these agreements have to be documented and retained. These basis documents will be needed to develop the final transition plan out of a safe enclosure period and into a

TABLE II–7. SAFSTOR PROJECT SCHEDULE

Phase	Period	Significant activities
Preliminary	June 1983–July 1985	Decision to decommission the unit Submission of the decommissioning plan Submission of preliminary dismantling plan Submission of physical security plan Environmental impact reviews Reactor defuelled Non-operating systems drained and secured Engineering and safety analyses completed
Safe enclosure implementation	July 1985–July 1988	Implementation of approved safe enclosure plan Modification or lay-up of systems which could not be modified under operating licence
Safe enclosure period	July 1988–2015	Ongoing monitoring and surveillance Ongoing decontamination and waste management Limited dismantling on a ‘need to perform’ basis Planning, licensing and preparation for fuel removal Planning for future dismantling
Removal of spent fuel	2003–2004	Licensing of spent fuel storage casks and independent spent fuel storage installation
Dismantling	2004–2009	Final dismantling and site decontamination

final dismantling period. The loss of personnel and background information is an issue for the regulatory authority as well, since it will also experience turnover of its personnel.

II–5–4–3. Alpha contamination

In the case of plant contaminated with significant levels of alpha emitting isotopes, serious consideration needs to be given to the choice of either immediate dismantling or very short, safe enclosure. During and shortly after the operating phase of a plant life cycle, the beta–gamma emitting isotopes remain in sufficient quantities to serve as indicators of the levels of alpha contamination. This information is necessary for the planning and monitoring of maintenance and, ultimately, dismantling activities. During extended safe enclosure periods, the beta–gamma tracers will decay to levels that will not permit them to be used to locate and estimate alpha contamination. Owing to the difficulty of measuring and monitoring alpha contamination on a real time basis, this could make work much more difficult to plan and monitor and may lead to worker exposure problems.

II–5–4–4. Changing regulations and/or interpretations

During an extended safe enclosure period, regulatory changes intended for operating nuclear facilities may impact facilities that have been shut down as well. A plant that has been shut down will likely not have the staff necessary to track such changes nor implement them nor seek clarification from the regulators on their applicability. Changes in regulatory personnel will complicate this situation if agreements regarding applicability or intent are not documented. This is a problem when periodic facility inspections are performed by inspectors who normally inspect operational facilities and who use current standards.

II–5–4–5. Equipment degradation and/or obsolescence

During an extended safe enclosure period, equipment may degrade faster owing to reduced maintenance or changes in environmental conditions. It will be difficult to locate repair parts or even replacement equipment. New equipment, when installed, may not be compatible with the systems remaining. This is especially true of instrumentation and monitoring systems.

II–5–4–6. Budget and personnel

Once a plant is shut down and no longer contributing to a company or organization's objectives, it may be difficult to obtain the funding necessary for maintenance over an extended safe enclosure period. This will be especially true of facility upgrades or equipment replacement. In the case of public utilities that may undergo cost reasonableness reviews, there may be a problem dealing with regulatory agencies as well. Access to accumulated funds for final dismantling may not be available to a plant in a delayed dismantling status. The number of people needed to support a plant over a safe enclosure period can easily be underestimated, especially if an active safe enclosure option is selected.

II–5–4–7. Regulatory commitments

During the regulatory approval process for Humboldt Bay Unit 3, many licensing requirements from the plant operating phase were retained. This was due either to a belief that these would not be onerous to satisfy since the staff was already maintaining licensing requirements, or that trying to eliminate existing requirements could delay the licensing review. It has become necessary to eliminate this unnecessary work. The licensing aspects of eliminating these commitments now are more difficult owing to the loss of personnel from both the facility and the regulator's organization.

II–5–4–8. Environmental considerations

The permit considerations or requirements for necessary reviews by environmental agencies can easily exceed those of nuclear regulatory agencies. These reviews and the associated hearing processes must be included in the overall schedule and in the decision as to whether to seek immediate or deferred dismantling.

II–5–4–9. Final dismantling

The development of a licence for safe enclosure needs to take into consideration the transition from safe enclosure to final dismantling. Reactivation of equipment, training and qualification of personnel, and the capacities of waste storage and processing systems are examples of licence requirements that may change when a plant's status is changed from safe enclosure to dismantling.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, The Principles of Radioactive Waste Management, Safety Series No. 111-F, IAEA, Vienna (1995).

[2] 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 ORGANIZATION, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna (1996).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste, Including Decommissioning, Safety Standards Series No. WS-R-2, IAEA, Vienna (2000).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Nuclear Power Plants and Research Reactors, Safety Standards Series No. WS-G-2.1, IAEA, Vienna (1999).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Medical, Industrial and Research Facilities, Safety Standards Series No. WS-G-2.2, IAEA, Vienna (1999).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Nuclear Fuel Cycle Facilities, Safety Standards Series No. WS-G-2.4, IAEA, Vienna (2001).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Safe Enclosure of Shut Down Nuclear Installations, Technical Reports Series No. 375, IAEA, Vienna (1995).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Organization and Management for Decommissioning of Large Nuclear Facilities, Technical Reports Series No. 399, IAEA, Vienna (2000).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulatory Control of Radioactive Discharges to the Environment, Safety Standards Series No. WS-G-2.3, IAEA, Vienna (2000).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, The Physical Protection of Nuclear Material, INFCIRC/225/Rev. 2, IAEA, Vienna (1989).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, The Agency’s Safeguards System (1965, as Provisionally Extended in 1966 and 1968), INFCIRC/66/Rev.2, IAEA, Vienna (1968).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/153 (Corrected), IAEA, Vienna (1972).

CONTRIBUTORS TO DRAFTING AND REVIEW

Eidam, G.	Bechtel Jacobs, United States of America
Harbecke, W.	Private consultant, Germany
Kaercher, M.	Électricité de France/SEPTEN, France
Laraia, M.	International Atomic Energy Agency
Linsley, G.	International Atomic Energy Agency
Morcillo, R.	IDV, Spain
Nelson, T.	Pacific Gas and Electric, United States of America
Newman, R.	BNFL Magnox Generation, United Kingdom
Reisenweaver, D.	International Atomic Energy Agency
Sturvi, M.	Società Generale Impianti Nucleari, Italy

Consultants Meetings

2–6 November 1998, Vienna, Austria
1–5 November 1999, Vienna, Austria
7–11 May 2001, Vienna, Austria

Technical Committee Meeting

15–19 May 2000, Vienna, Austria