IAEA-TECDOC-1647

Progress in Radioactive Graphite Waste Management

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PROGRESS IN RADIOACTIVE GRAPHITE WASTE MANAGEMENT

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PROGRESS IN RADIOACTIVE GRAPHITE WASTE MANAGEMENT

INTERNATIONAL ATOMIC ENERGY AGENCY

VIENNA, 2010

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PROGRESS IN RADIOACTIVE GRAPHITE
WASTE MANAGEMENT

IAEA, VIENNA, 2010
IAEA-TECDOC-1647
ISBN 978–92–0–106610–7
ISSN 1011–4289

Printed by the IAEA in Austria
July 2010

FOREWORD

With the objective of helping to stimulate progress in the development of effective solutions for the management of radioactive graphite, a conference on Solutions for Graphite Waste: A Contribution to the Accelerated Decommissioning of Graphite Moderated Nuclear Reactors was held in Manchester, United Kingdom 21–23 March 2007. It was organized by the School of Mechanical, Aerospace and Civil Engineering and the Dalton Nuclear Institute of Manchester University in cooperation with the International Atomic Energy Agency (IAEA). The conference focused on the problems surrounding the management of radioactive graphite: strategic, technical, economic and social aspects. While the emphasis of the conference was on the problems faced by the United Kingdom, the situation in other concerned countries was also presented. This publication contains a selection of the papers presented at the conference and a record of the ensuing discussions.

The IAEA has encouraged work in this subject area since 1998 and issued the results of a previous meeting on the subject of graphite waste management held at the University of Manchester in 1999 in the form of a CD-ROM (Nuclear Graphite Waste Management, IAEA-NGWM/CD 01-00120, May 2001) and published a report entitled "Characterization, Treatment and Conditioning of Radioactive Graphite from Decommissioning of Nuclear Reactors" (IAEA-TECDOC-1521) in 2006. This present report reflects the continuing interest of the IAEA in this subject.

The IAEA wishes to express its appreciation to all those who contributed to the 2007 conference and to this publication, especially B.J. Marsden and A.J. Wickham (UK) who were responsible for organizing the conference, editing the papers and capturing the content of the discussions. The IAEA is also grateful to G. Linsley (UK) for the final editing of the manuscript. The IAEA officer responsible for this report was Z. Drace of the Division of Nuclear Fuel Cycle and Waste Technology.

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1. INTRODUCTION

Radioactive graphite constitutes a major waste stream which arises during the decommissioning of certain types of nuclear installations. Worldwide, a total of around 250 000 tonnes of radioactive graphite, comprising graphite moderators and reflectors, will require management solutions in the coming years.

^{14}C is the radionuclide of greatest concern in nuclear graphite; it arises principally through the interaction of reactor neutrons with nitrogen, which is present in graphite as an impurity or in the reactor coolant or cover gas. ^{3}H is created by the reactions of neutrons with ^{6}Li impurities in graphite as well as in fission of the fuel. ^{36}Cl is generated in the neutron activation of chlorine impurities in graphite.

Problems in the radioactive waste management of graphite arise mainly because of the large volumes requiring disposal, the long half-lives of the main radionuclides involved and the specific properties of graphite — such as stored Wigner energy, graphite dust explosibility and the potential for radioactive gases to be released.

Various options for the management of radioactive graphite have been studied but a generally accepted approach for its conditioning and disposal does not yet exist. Different solutions may be appropriate in different cases.

In most of the countries with radioactive graphite to manage, little progress has been made to date in respect of the disposal of this material. Only in France has there been specific thinking about a dedicated graphite waste-disposal facility (within ANDRA): other major producers of graphite waste (UK and the countries of the former Soviet Union) are either thinking in terms of repository disposal or have no developed plans.

A conference entitled "Solutions for Graphite Waste: a Contribution to the Accelerated Decommissioning of Graphite Moderated Nuclear Reactors" was held at the University of Manchester 21–23 March 2007 in order to stimulate progress in radioactive graphite waste management, especially in the UK. It is intended that this report which contains the proceedings of the conference should contribute to progress in the management of radioactive graphite worldwide. The report contains a selection of the papers presented on various issues related to dismantling and treating irradiated graphite. In addition, the report contains summaries of the four topical discussions which were held during the conference.

2. OPENING SESSION

Chairpersons

G. LINSLEY
United Kingdom

A. J. WICKHAM
United Kingdom

Opening address on behalf of the International Atomic Energy Agency

G. Linsley
United Kingdom

On behalf of the International Atomic Energy Agency (IAEA) I would like to welcome you to this conference. The IAEA is pleased to be involved in a conference on this subject and to help in disseminating its results and conclusions. Graphite waste management is an important and, as yet, incompletely resolved problem for a number of countries - most of which are represented here today. A fresh impetus for resolving them in the United Kingdom has come from the new policy of accelerated decommissioning of civil nuclear power plants. This is perhaps the novel feature of this meeting. The main roles of the IAEA in the context of this conference are:

(a) to promote the exchange of information on subjects of importance to its Member States and where necessary to encourage research and development, and
(b) to develop and promulgate international safety standards.

In relation to the first of these roles, the IAEA has held a number of expert meetings specifically on the subject of graphite waste management and you will hear about the outcome of this work during this conference. In addition, the IAEA has organized several large international conferences in recent years on radioactive waste management and decommissioning at which the issues of graphite waste management were actively discussed. These were the conferences on 'low activity radioactive waste disposal' held in Cordoba in 2004 and on 'lessons learned from decommissioning' held in Athens in December 2006.

In the safety area, while there are no specific safety standards on the subject of graphite waste management, the generic safety standards covering Decommissioning, Pre-disposal Waste Management and Radioactive Waste Disposal are relevant and cover all of the important safety issues that must be considered in managing and disposing of graphite waste.

One particular safety standard addresses the release of materials from regulatory control — exemption and clearance. After many years of discussion on this subject at international meetings, an important consensus was reached in 2004. The resulting document (Safety Guide RS-G-1.7) contains a set of radionuclide specific clearance levels suitable for application to large volumes of material containing radionuclides. The IAEA is encouraging its Member States to adopt these values and the European Commission has indicated its intention to adopt the values in its documentation. The general adoption of these values should, amongst other things, facilitate the transboundary movement of materials containing very low levels of radionuclides.

The IAEA has an important role in providing the secretariat for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Joint Convention). This is the only international legally binding instrument in the field of radioactive waste management. Contracting Parties to the Joint Convention are required to attend review meetings held every 3 years and to report on how they are complying with the articles of the Joint Convention. At the last review meeting in November 2006, many of the Contracting Parties reported on progress in decommissioning in their countries and on the issues being faced. At the present time there are 44 Contracting Parties to the convention and the IAEA is actively encouraging its remaining Member States to join.

Introduction and overview of the conference

A. J. Wickham
Conference Organizer,
Manchester University

The industry has been talking about the decommissioning and dismantling of graphite-moderated reactors for a very long time. In a few rare instances, it has actually been done... or, at least, all or part of a reactor has been taken apart. What we have not done, except in one very creditable and exceptional case, is to do anything remotely appropriate with the graphite.

It has been an odd sequence of events. Some very senior and specialist people within the industry determined that it was most appropriate to leave irradiated graphite safely in the reactor pressure vessels for up to 135 years to allow decay of shorter-lived isotopes, so making life easier and reducing the eventual personnel doses and also to hope that technology would make some useful improvement in the intervening period.

The 135-year figure was the United Kingdom one: other nearby countries chose other figures, down to as little as 40 years. The respective nuclear regulators started to compare notes and were asking the rather obvious question: 'if these people are waiting for the same isotopes to decay, why do they come up with such different timescales?'

Meanwhile, another sector of our industry was seeking to find a final resting place for nuclear waste. This has been going on for a very long time. I could remind you that, if the political goals had been achieved, we would have in this country a working and fully-functional repository by now. Of course, we have nothing of the sort. We do not even have a test site — a rock-structure laboratory — because our central government, backing the search for a suitable site, allowed local government to thwart it. At least our French colleagues are now building their underground test laboratory, and very interesting it is to visit it, which the public can do.

In order to make progress, the UK government set up a committee, the Committee on Radioactive Waste Management (CoRWM), to spend three years determining the rather obvious conclusion that what we planned to do in the first place with our general waste was perhaps not such a bad idea after all [1]. Whilst that was going on, a new Nuclear Decommissioning Authority has been created which will, in exactly eleven days[2], swallow up the original organization charged with producing the non-existent waste repository. That, incidentally, is my own definition of what I believe that NIREX UK was intended to do: officially their task was to implement UK government policy. That policy now, one supposes, is to implement the recommendations of CoRWM. But we have lost an awful lot of time, and have jeopardized the possible future nuclear contribution to power generation in the process.

The new Nuclear Decommissioning Authority's initial ambition was to bring the 135-year safe-store and decommissioning programme down to 20 years. I do hope that it can be done. But, now that people have had time to count the potential cost, that ambition could be harder to realize. However, the public view is that we should not leave a long-term legacy of an unfinished task to people who no longer know how the reactors were constructed.

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[1] CoRWM does not explicitly consider decommissioning wastes such as graphite and, so far, has not differentiated waste streams which might deserve special attention because of unique properties or situations.
[2] from the first day of the conference

We have already in the UK left two reactors for almost 50 years — reactors which do not have a pressure vessel as a containment and one of which contains residual damaged fuel — during which we lost all of the detailed knowledge about the graphite and have consequently spent a great deal of money re-characterizing it.

Mention of pressure vessels raises another important point. A very senior decommissioning expert in the United States made a comment at a conference in Spain last year with which I find it impossible to disagree: if your decommissioning plan involves constructing a new building, then it is the wrong plan. So, counter to this advice, we have taken the graphite from our Windscale prototype AGR from a secure pressure vessel and placed it in storage boxes in a metal shed by the side of the road. I leave you to reflect on whether this is progress, but we have of course demonstrated that we can dismantle the core internals of a graphite reactor without incident, be that radioactive contamination, personnel doses, fire, dust explosion or whatever other real or imagined constraint is put in our path.

Our French colleagues, for reasons which I understand but profoundly disagree with, intend to dismantle the majority of their graphite reactors under water. This is something we can maybe debate here this week, including the issues of radioisotope leaching, potential ground contamination, and so forth.

All of these 'big picture' decisions are dominated by one major issue: there are 250 000 tonnes of radioactive graphite out there and the only disposal option which is being seriously considered is for repository disposal. And no-one has a graphite repository.

Until very recently, no-one had seriously considered any alternative, although an activity within what was then the European Economic Community in 1984 used UK Magnox-reactor graphite as a base case and concluded that there was little to choose in terms of safety and cost between a repository and sea dumping. One reason for the inertia seems to be a mortal dread of radioactivity. To this audience, such a comment might sound like naivety in the extreme. But let me give you an example. Consider ^{14}C. Over 20 years ago, it was shown that if we incinerated British graphite at the rate of one reactor core per year for 20 years, we would add less than one part in one thousand to the global atmospheric ^{14}C burden which is largely derived from the interaction of cosmic radiation in the upper atmosphere with ^{14}N, something which every person on the planet must inevitably tolerate without concern. But, if we immobilize our graphite waste containing ^{14}C in cement, seal it in drums, place the drums in a container and concrete over all that at depth in a repository, we still find ourselves concerned at the potential escape of miniscule amounts of this natural radioisotope over very long times, against this huge natural background which seems conveniently to be ignored.

We do, incidentally, have three developing technologies for separating out and capturing ^{14}C from graphite if we have to. But, striving for ALARP[3] at all costs, against a significant natural background radioactivity, might just be the factor that makes radwaste, and hence future nuclear power, appear so ridiculously expensive.

One feature of the argument as presented to the lay public is that this isotope, with a half-life of 5760 years, will be around for a very long time and therefore 'must' present a danger. Another example, is ^{36}Cl, with a half-life of 300 000 years. Ironically, this isotope arises in graphite primarily from a purification process, and is the principal reason why it is considered

[3] **A**s **L**ow **A**s **R**easonably **P**ractical, but often assumed to need to be zero emissions, especially following the OSPAR agreement.

necessary to encapsulate graphite before disposal, since ^{36}Cl can enter the human system rather easily. So what should one conclude here? That ^{36}Cl leaching out of graphite in repositories is a significant and serious hazard?

From a different viewpoint, such a long half-life means very few Becquerels — so few disintegrations per second that it cannot conceivably present a real hazard either now or in the future, unless concentrated to extremely high levels in some rather unlikely biological process.

There is a special irony in this, in that our French colleagues have shown that upon handling, and especially upon grinding or cutting, much of the ^{36}Cl from graphite has already been released into the atmosphere anyway! Uncontrolled, forgotten, and essentially harmless.

A fundamental problem for us all is that recommendations for acceptable releases of isotopes from repositories are based upon old ICRP recommendations, themselves based upon projected 'acceptable' cancer rates of one in a million and derived, largely without real data, on the basis that 'all radioactivity is dangerous' — conveniently ignoring the natural background which is fact is essential to life continuing to exist on the planet[4]. This alleged 'logic' allows us to discharge far more, say, ^{14}C, per day from an operational site such as Sellafield, than we can plan to accidentally release from a repository. By NIREX's own published data, there is a factor of 3000 difference!

I do despair, actually, that a lot of students I encounter do not even seem to realise that radioactivity is a natural phenomenon — until I start to wander around the lecture theatre with a Geiger counter to see what we can find, and then ask them to assess the consequent risk objectively alongside their smoking and driving habits.

There is another irony. Our 'nuclear' radioactivity is perceived as somehow different from natural radioactivity. There are almost no controls on the discharge of radioactivity from the countless thousands of tonnes of fossil fuel burned in the power stations of the world — remember that one large coal-fired plant such as that at Didcot utilizes many thousands of tonnes of coal in one day.

Fortunately, the absence of an accessible repository for the world's nuclear graphite has led to a number of new initiatives and some lateral thinking; from the IAEA, from the Electrical Power Research Institute in California, and now from Euratom. All of them are actively looking at alternatives. We do not have papers on them all, but I feel sure that our discussions will include most of them. I believe that this alternative and lateral-thinking view is now essential for resolving the graphite problem, and I commend all delegates to be as open-minded to the alternatives as they feel able. Nuclear decommissioning needs to be dealt with now, not later, and the technologists capable of dealing with it competently are probably mostly in this room.

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[4] The argument here relates to natural radioactive heating in the Earth keeping a molten core, which generates the magnetic field which deflects cosmic and solar radiation away from the planet's surface...

3. DISCUSSION SESSION

The following papers that were discussed during session are contained on the attached CD-ROM

Magnox Graphite Core Decommissioning and Disposal Issues
M.E. Pick

Graphite Waste Treatment and Disposal – A UK Perspective on the Current Opportunities and Issues
J. McKinney, S. Barlow

Current Status and Future Objectives for Graphite and Radium-bearing Waste Disposal Studies in France
O. Ozanam

Aspects of Graphite Disposal and the Relationship to Risk: A Socio-Technical Problem
G. B. Neighbour, M. A. McGuire

Radiation Damage in Graphite — a New Model
M.I. Heggie, I. Suarez-Martinez, G. Savini, G.L. Haffenden, J.M. Campanera

Thermodynamic Modelling of an Irradiated Reactor Graphite Thermochemical Treatment Process
S.A. Dmitriev, O.K. Karlina, V.L. Klimov, G.Yu. Pavlova,M.I. Ojovan

Current Status of the Radiological Characterization of the Irradiated Graphite from RBMK-1500 Reactor in Lithuania
V. Remeikis, D. Ancius, A. Plukis, R. Plukiene, D. Ridikas, A. Smaizys, E. Narkunas, P. Poskas

Decontamination of Nuclear Graphite by Thermal Methods
J. Fachinger

GLEEP Graphite Core Removal and Disposal
M. Grave

Review of the Characterization of Nuclear Graphites in UK Reactors Scheduled for Decommissioning
A. Jones, L. McDermott, B. Marsden and T. J. Marrow

Graphite Dust Explosibility in Decommissioning: A Demonstration of Minimal Risk
A. Wickham and L. Rahmani

4. SUMMARY OF THE DISCUSSION SESSIONS

Discussion Session 1
The Case for and Against Acceleration of
Decommissioning Graphite-Moderated Reactors

Chair: G.B. Neighbour,
United Kingdom

The premise for this discussion was the original declaration from the UK Nuclear Decommissioning Authority (NDA), when it was first established, that it proposed a dramatic decrease in the planned time for decommissioning of the UK nuclear plant compared with the original plan of up to 135 years in ‘care and maintenance’ and ‘safe shutdown’ modes, leaving the graphite within the reactor vessels. The potential need to deal with large quantities of irradiated graphite at an earlier stage than originally envisaged has led to a re-awakening of interest in all potential treatment and disposal options for this waste stream.

After the initial enthusiasm, it appears that the potential to make progress, at least within the UK, is limited by the funding available which must originate primarily from government and the companies responsible for the plant. The prevailing view that this funding is wholly inadequate dominated this discussion. Within the UK, as in other Member States, there exists no specific provision for graphite-waste disposal.

M. Wareing, (NDA), said that the question was not only ‘what should one do with the graphite’ but also ‘cash flow’. Although the meeting was clearly aware of the public opinion that waste issues must not be left as a legacy for future generations, he asked the meeting to consider how one should value the ‘soft issues’ of public opinion and the technical desirability of making progress against the determination of the industry to defer cash outflow whenever possible for what it saw as sound economic reasons. He asked the meeting to consider what would drive you towards a decision to accelerate, suggesting that the waste disposal options were not time-limited and that there was no strong technical argument which suggested that the graphite within shut-down reactors had to be dealt with urgently.

M. Heggie (University of Sussex, UK) suggested that the issue of public confidence was too important to dismiss as a ‘soft issue’. M. Wareing asked how one should value it in economic terms, to which M. Heggie responded that it could be a factor in determining whether there would be a nuclear future in the UK.

D. Bradbury (Bradtec Decon Technologies Ltd, UK) took the view that it is essential (in all countries) to demonstrate to the public that comprehensive decommissioning of nuclear plant can be achieved, adding that nuclear regulatory authorities needed to have confidence that people with the relevant expertise in design and construction of these plant would be available to ensure that there is the necessary technical knowledge for decommissioning. D. Bradbury confirmed that the principal issue in his view was not money, but a need to steer public opinion by a demonstration of competence in decommissioning, in order to secure a new nuclear build programme. M. Grave (Doosan Babcock, UK) added that the need to secure site release for future build was also an important factor.

G.B. Neighbour, from the chair, asked the meeting if ‘accelerating’ was the wrong word to use, to which D. Bradbury responded by asking whether the ‘safestore’ concept should ever have been mooted, speculating how it had come about that people would even ‘dare’ to suggest leaving the graphite for 130 years. M. Wareing responded by re-stating his opinion that you had to reduce everything to a common currency: money *versus* benefit, noting that it was a serious academic challenge to compare such different things. M. Cross (Nukem, UK) suggested that one could not put a weighting on a 'soft' factor: it would all come down to judgement. D. Bradbury put to the NDA the question 'should we decommission Magnox reactors within 25 years or should the whole issue be decided on the basis of a business case'? From this technical audience, there was overwhelming support for the first option.

B. Marsden (The University of Manchester, UK) pointed out that the window of any UK government funding would certainly close when/if more nuclear power is sanctioned, and so it is desirable to move quickly to make some progress.

M. Wareing, along with S. Barlow (UK NDA) indicated that one might usefully move the debate towards environmental factors. G. Linsley (IAEA) asked whether the argument about public confidence was worthwhile if there was nowhere to put the waste, to which D. Bradbury responded that this was precisely the reason for creating some technical innovation. He explained that in the United States, the average time from a reactor shutdown to a green field site was around seven years (except for disposing of irradiated fuel, which was in temporary special storage).

M. Grave offered a further challenge to the NDA viewpoint, commenting that the UK case for hosting the 2012 Olympic Games was not predicated on a business case. He asked whether it was more a case of 'what the government wants'. M. Cross agreed: the UK should 'follow the French' and just get on with things a little more often. G.B. Neighbour wondered whether the fragmentation of the UK industry through privatisation had made things worse.

A. Wickham (The University of Manchester) quoted the NDA Mission Statement[5] and wondered if there was a time component implied as well as the safety/environmental issues. M. Pick (Magnox South, UK) attempted to rationalise the dichotomy between personnel radiation dose issues (supporting delay in decommissioning) and the cost arguments, suggesting that there is a way through if there is real determination to achieve a result. D. Bradbury concluded that, since the conference attendees were largely technical people, they should strive to have a 'quick decommissioning' technical strategy available, should there arise a political will to employ it.

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[5] The UK NDA Mission is *"...to deliver safe, sustainable and publicly acceptable solutions to the challenge of nuclear clean-up and waste management. This means never compromising on safety, or security, taking full account of our social and environmental responsibilities, always seeking value for money for the taxpayer, and actively engaging with stakeholders."*

Discussion Session 2
Alternative Destinies for Graphite Wastes

Chair: D. Bradbury,
United Kingdom

The discussion chairman set the scene for the discussion, commenting that the ‘reference case’ for graphite disposal in most cases was in an encapsulated form in a sub-surface facility of some kind, utilising the ‘concentrate and contain’ philosophy rather than the ‘dilute and disperse’. No such facility currently exists. The assumptions behind this reference case, broadly, are that it is the simplest, the cheapest, and technically the best.

All of these presumptions could be challenged in the light of technological advances. Dismantling itself was not cheap, and there was at least one potential advance which could render this unnecessary (*in-situ* pyrolysis). ‘Concentrate and contain’ gave rise to concerns about leaching: for some isotopes such as ^{14}C, dilution and dispersal within a high natural background might actually be a safer option overall. Posing the rhetorical question ‘why do we not recycle, like the rest of the population?’ D. Bradbury indicated that all alternative propositions for graphite treatment and disposal require a demonstration of effectiveness and facility to achieve the desired outcome.

He summarized that apparent options:

(1) Repository, deep or shallow
(2) Gasification, with release of the gases, sequestration, or partial recycling
(3) Recycling the solid graphite as products to be used within the nuclear industry

C. Wheatley (Serco, UK) commented that disposal in a deep repository would always be unacceptable to the public because of a perception that it might be dangerous: a large concentration of active material and the risk of leaching. A key point therefore must be that alternative destinies must be capable of demonstrating to the public that they are inherently safe and have a predictable outcome.

B. Grambow (Subatech, France) fundamentally disagreed, saying that one should not reject burial. He added that transmutation, which was not included in D. Bradbury’s initial list of possibilities, would ‘never work’.

C. Wheatley asked the meeting to consider how ‘dangerous’ incineration or pyrolysis actually was compared with coal-fired electricity-generating plant, given the quantities of various isotopes freely emitted to atmosphere in such a process. If one can carry out this process with coal, why not with graphite? A. Wickham (The University of Manchester, UK), noted that the issue of ^{14}C release in incineration did not cause a global dose issue in comparison with cosmic-ray production in the upper atmosphere, but did potentially give rise to issues local to the plant. G. Linsley (IAEA) noted that there had been historical mistakes made in the application of the ‘dilute and disperse’ philosophy, e.g., the history of the sea dumping of radioactive waste, and that although it is often technically justifiable it will always tend to raise public concerns.

M. Pick (Magnox South, UK) pointed out that there was a much better technical understanding of the issues now, but there was a wide gulf between this technical knowledge base and the success in putting messages across to the public. The UK CoRWM (**C**ommittee **o**n **R**adioactive **W**aste **M**anagement) is generally presented as the ‘solution’ to the waste management issue, although it does not deal directly with decommissioning wastes. He mentioned also the anomalies between the permitted levels of radioisotopes in 'non-nuclear' situations in comparison with the perceived targets for waste disposal, giving as an example the spoil from the creation of a repository which would itself exceed the permitted release levels for ^{40}K.

C. Wheatley developed this point, indicating that a subset of isotopes such as ^{3}H, ^{14}C and ^{36}Cl were already released into the atmosphere from nuclear installations (routine coolant 'leakage' of around a tonne per day for a typical graphite/gas reactor), these levels being well within current permitted daily-release levels but also greatly exceeding what was likely to be permitted for a repository with current thinking. M. Grave (Doosan Babcock) agreed: people regularly asked him why the industry no longer favoured 'dilute and disperse', and wondered whether we were collectively producing 'solutions' which actually made things worse.

A. Munro (Amec NNC, UK) took up the issue of operational safety cases at operational sites, and noted the tendency to leave the nuclear island until last in decommissioning, such that its decommissioning had almost become a 'hobby', to be completed at some point in the future when available staff were otherwise 'at a loose end'. This was surely wholly unacceptable: delay was failure, and failure was not an option.

J. McKinney (NDA) posed the question of comparing all of the alternative options for graphite disposal, such that a national decision could be made. He suggested an objective comparison to the reference case, and it would then be necessary to get stakeholders to 'buy in'. C. Wheatley said that there were tools already available to help make such decisions — *e.g.* cost/benefit analysis programs with uncertainties built in: one could even factor in public opinion. M. Wareing (NDA), returning to the financial theme he had raised in a previous discussion, stated that one needed to get the 'language' right for the stakeholders which, in the UK, would include the treasury. The delivered message needed to be advice to 'spend the available money on 'A', not 'B''.

Discussion Session 3
The Extent of the Characterization of Graphite Required for Waste Disposal

Chair: J. McKinney,
United Kingdom

The chairman provided an introduction to this session by stating that the industry needed to arrive at a complete 'cradle to grave' solution for dealing with graphite waste. There needed to be an ability to 'track' the activity within it through time: in other words, it was not sufficient just to think about one stage of the process in isolation, such as incineration. The alternatives needed to be compared with the reference case (repository) in this respect.

It must be possible to take full account of all of the activity, and the environment it is in: this includes both chemical form and the surroundings or containment at each stage of the process. In defending the ability to be innovative, it needed to be remembered that alternative options usually would mean a change in the waste form.

The pre-characterization that would need to be completed on the graphite before treatment or disposal had to be sufficient to provide adequate information on what would occur at each stage of the process. It would also, inevitably, have to be done against the financial background of 'business need'.

M. Pick (Magnox South, UK) commented that we did not appear to have confidence in determining the isotopic contents — or, at least, there were significant differences between calculation and measurement, and the measurements were rather widely scattered. He wondered if this actually mattered at this stage, since only an 'order of magnitude' estimate was needed in the safety case for a repository, but proposed that we needed the data anyway if only for leaching purposes. He pointed out that Magnox (UK) currently had only one measurement on each of six reactors: they needed far more, and they also needed the money to do it which was currently not forthcoming from the UK Nuclear Decommissioning Authority. M. Grave (Doosan Babcock, UK) cautioned that one should not just go out 'blindly' making measurements: the usefulness and application of each measurement should be evaluated first.

B. Grambow (Subatech, France) agreed that the importance of particular information should be understood ahead of acquiring it. He commented on a number of relevant issues: the large variance in some data such as ^{36}Cl content: the complexities introduced by dismantling under water, as EdF CIDEN planned to do, and so forth.

A. Wickham (The University of Manchester, UK) wondered if it would be useful to divert some Magnox staff from less significant tasks to commence such measurements, given that EdF CIDEN had commissioned many measurements on the UNGG reactor graphite from CEA. However, he cautioned in simply obtaining activity data which would inevitably disagree with calculations, and thus raising concerns.

M. Cowper (Serco, UK) asked whether the UK Nuclear Decommissioning Authority felt empowered to make decisions in this area. M. Wareing (NDA), responded by stating that the NDA did not make policy: it presented options to government, to which the first response would be 'how much does it cost?' This brought a response from M. Cross (Nukem, UK) to the effect that we devote huge efforts to study of technical issues, after which the decision-making process (within the UK) is hopelessly flawed.

A final thought in this discussion was offered by D. Ball (DRG Consultants, USA) on the point that, because the graphite had been subjected to fast-neutron irradiation, its structure was significantly altered, and it should possibly no longer be considered as graphite but as a de-graphitised material whose properties may therefore differ from expectation.

Discussion Session 4
Strengths and Weaknesses in Current Programmes

Chair: A. Wickham,
United Kingdom

The chairman introduced the discussion by asking everyone present to try and identify at least one strength in the collective programmes which are going forward and also to give a view on where the perceived weaknesses are. He wondered whether our strengths were in *planning* the decommissioning and disposal process — as suggested by Mr. Eccles of Nexia Solutions (UK) in the main conference, or within the detailed alternative technologies which were described in the papers presented. If the strengths are indeed in the planning, do we collectively have the sufficient strength of technologists to make the plan happen? Are the strengths in compliance with environmental constraints and requirements, or is the industry giving itself the *impression* that this is being done whereas the reality is that we are not really getting to grips with the real issues? A particular question which he posed was whether we are striving to get activity levels in release situations down to natural levels, which is logical, or to improbably low levels based upon old ICRP recommendations which seem to have failed to recognise the existence of a natural radioactive background.

Reflecting on a previous discussion, the chairman asked the audience to consider whether focussing on costs — and more explicitly upon discounted costs after a time delay — was a strength or a weakness. The final question he asked the audience was — how should we address the weaknesses?

D. Bradbury (Bradtec Decon Technologies, UK) commented on the differences of approach in France and in the UK. France had made (or were close to making) a national decision, which allowed the technologists to work towards delivering the required solutions. In the UK, there was no firm decision on anything, and dithering about cost, which made any prospect of progress very difficult.

M. Wareing (NDA, UK) said that one needs to go through the whole process, looking at the complete decommissioning picture first, and stated that he needed the help of the technologists to achieve this. This would need to include the ‘soft’ issues such as public opinion. M. Grave (Doosan Babcock, UK) indicated a need to differentiate between national and international issues, and wondered what would be needed to get a government to ‘tick the box’. Mr. Wareing again indicated that, so far as the UK was concerned, this would be the business case.

D. Bradbury noted that he considered graphite to be a special case. C. Wheatley (Serco, UK) thought that a ‘dilute and disperse’ philosophy for ^{14}C should be a real possibility. J. McKinney (NDA, UK) commented that there did not necessarily have to be a single solution to the graphite issue. H. Eccles (Nexia Solutions, UK) thought that a different solution might apply in different locations, and could be seen as local job opportunities.

M. McGuire (The University of Hull, UK) wondered why the French had found it ‘necessary’ to make a decision (in favour of a shallow repository). Perhaps this was because of their clear desire to build new nuclear stations on existing sites. H. Eccles noted that governments do not build power stations (at least in the UK); rather it is private finance, coupled with a need for local authorisations. Local authorities needed to be convinced in favour of the nuclear technology, for which getting the correct decisions about waste disposal was a key factor.

W. Meyer (NECSA, South Africa) asked why we did not feel more strongly that the graphite could be re-utilised in its existing form, reflecting on its absorption capabilities, and possibly extending this feature in terms of absorption of isotopes.

Overall, this discussion was inconclusive, failing to draw any clear conclusion which would shape the direction of future research in this area.

5. CLOSING REVIEW OF THE CONFERENCE

G. Linsley

5. CLOSING REVIEW OF THE CONFERENCE

G. Linsley
United Kingdom

Session 1

Session 1 provided a perspective on the situation in the United Kingdom (UK) with three presentations giving information on inventories of graphite, on the radionuclides of most concern for radioactive waste management, on treatment options and on considerations for disposal. Currently in the UK, the majority of graphite is in operating or shutdown civil nuclear power plants. The reference disposal strategy is to emplace the graphite in containers in a geological repository — recognizing that the national inventory of graphite would occupy a significant fraction of the volume of such a repository.

A study was reported during the meeting which suggests that, of all the radionuclides present in irradiated reactor graphite, carbon-14 might be of most radiological concern in the long term if it is released from a repository in gaseous form. In session 4, an ongoing experimental programme was described aimed at, amongst other things, investigating these predictions.

Plans for the management of graphite waste in France have been set on a firm track by a law passed in 2006 which establishes target dates for the disposal process. The disposal strategy, which has been approved in principle by the regulator, is to dispose of the graphite and radium bearing waste in a near surface repository in a clay formation. The main driver for this option is cost saving; it is estimated to be an order of magnitude cheaper than geological disposal.

Studies are ongoing in both UK and France to improve understanding of the behaviour, the locations, and the release mechanisms of the key radionuclides in graphite and on minimising the volumes for disposal.

The progress of the Pebble Bed Modular Reactor development in South Africa was described including some studies to evaluate the effectiveness of micro-organisms at removing carbon-14 from the graphite that surrounds the reactor 'pebble' fuel.

The session was concluded with a discussion on the merits and demerits of accelerated decommissioning. A view was expressed that the strategy for decommissioning will be determined on the basis of cost — long term versus short term cost considerations. However, it was also argued that restoring public confidence is the key factor driving early decommissioning. In an era of a possible nuclear renaissance, a strategy of early decommissioning would demonstrate to the public that sites can be cleared — ready for 'new build'. Even if there is no immediate disposal route for the waste, progress can still be made — examples from overseas show that. At this time, therefore, the technical community should be positive – it should come forward with the means for achieving early decommissioning, if it is decided upon.

Session 2

This session contained a variety of topics — related to different aspects of graphite waste management. It started with a study suggesting that policy on graphite disposal should be based on minimizing subjective risk rather than objective risk and that socio-technical considerations are relevant to finding disposal solutions. It continued with a presentation which sought to explain the processes by which the graphite structure is damaged by radiation using dislocation theory - thereby explaining the processes leading to Wigner energy storage and release.

A topical issue in the light of the new impetus for accelerated decommissioning is the consideration of alternatives to the reference case of geological disposal. In this context, a German study showed the extent of decontamination of graphite that can be achieved by thermal methods. Up to 80% of tritium and carbon-14 can be removed by a process using heat, steam and pressure. The study also showed that carbon-14 is removed to a much greater extent than carbon-12 indicating that the carbon-14 in the graphite is not part of the crystal lattice but is adsorbed somewhere else in the structure. The thermal process is still being optimised with the aim of producing a clean graphite that can be recycled for other use. In discussion, it was noted that such an approach must produce an overall benefit - taking into account the possibility that it could produce a second waste stream that itself would require management.

The session was completed with a general discussion on the subject of alternatives to geological disposal for graphite waste. Options for consideration included: deep or shallow disposal, gasification — release or sequestration, and recycle and reuse. The German paper had already shown the possibilities of recycling. On the 'dilute and disperse' option, it was noted that it had gone out of favour in the last decades — possibly because of mistakes in the past. On the other hand, presentations at the meeting have shown that released carbon-14 would not be re-concentrated and would cause a negligible addition to what is already there naturally. In fact, all of the options are probably technically feasible and could provide for the safe management of graphite. What is really needed is a decision on which option to follow.

Session 3

In this session, two decommissioning projects involving graphite were described. They were the GLEEP research reactor graphite core removal and disposal and the Windscale Piles graphite waste management. The presentation on the Windscale work raised some concerns about the decision to package and store the graphite without pre-annealing and doubts were raised about the safety of storage and disposal without annealing.

Session 3 (and Session 2) included several presentations on different aspects of characterization. They included:

- a description of the procedures for characterizing the graphite in an RBMK reactor in Lithuania;
- characterization of radionuclide profiles inside the WAGR concrete shield;
- the characterization of UK nuclear graphite in relation to its origin, history and manufacturing process; and
- available techniques for examining the microstructure of irradiated graphite.

These presentations were followed by a discussion on the extent of the characterization of graphite needed for the purposes of disposal. How many samples are needed? How do you know when you have enough?

It is often said that you cannot do enough characterization — but if it costs money and time there must be some optimisation of the process. The amount of characterization must depend, to some extent, on the waste management option chosen. It may sometimes be sufficient to accept conservative upper estimates of inventory and concentration and for that only a few samples and some robust modelling may be sufficient. If a good understanding of the distribution of activity within the graphite cannot be obtained by modelling then more sampling may be needed — but the extent of this still depends on what is required for the particular management option chosen.

Session 4

The concept of an integrated approach to irradiated graphite waste disposal was presented and discussed. It followed an earlier presentation on a new proposal to the European Commission's Seventh Framework Programme called 'Carbowaste[6]'. Both are concerned with the idea of involving multiple international partners in setting out the logic or thought processes for progressing from graphite arisings to disposal or release — addressing all management options and considerations along the way.

The session included two presentations on graphite dust; one showing that it does not represent a significant explosion risk and the other on studies in relation to the Pebble Bed reactor in South Africa.

Concluding comments

I have appreciated the frank and open discussions during the meeting although I have sometimes felt that they might have benefited from the presence of a regulator to advise on the limitations and restrictions on what was being proposed, but on the other hand, perhaps the presence of a regulator would have inhibited or stifled the discussion.

I know that the IAEA will continue to be interested in encouraging progress in this area and to cooperate in organizing and disseminating the results of appropriate international meetings.

[6] The CARBOWASTE Project has now been approved and was initiated under the EU (Euratom) Seventh Framework Programme in Spring 2008, with 19 European and International participating organisations.

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No. 21, July 2006

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