

**Revision 3 (04/04/02)**

# **THE DECOMMISSIONING AND DISMANTLING OF NUCLEAR FACILITIES IN OECD/NEA MEMBER STATES - Status, approaches, issues**

## **FOREWORD.**

As nuclear facilities around the world continue to age, many countries will be faced increasingly with the task of taking them out of service (decommissioning) and dismantling them. Appropriate provisions will have to be made in terms of policy, financing, and management. Depending on the path chosen, decommissioning and dismantling (D&D) of nuclear facilities may take a few years or several decades, especially for the larger ones. This range of possible timescales entails specific issues for decision-making, and also has a wider impact by way of such issues as the sustainability of nuclear power and preservation of the well being of local communities.

The NEA Radioactive Waste Management Committee (RWMC) has long recognised that D&D and waste management are intimately related and, since 1982, has been involved in various projects concerned with technical matters such as dismantling of plants and decontamination of materials. As these technologies have become mature, however, the broader aspects of managing D&D have come to the fore. These involve safety, societal and regulatory matters together with issues of costs and funding, all of which require informed dialogue between institutional and non-institutional parties. The RWMC has traditionally provided the neutral ground for such wider debates, and this has been carried forward in the field of D&D. The broader NEA Strategic Plan includes decommissioning as one of the cross-sectorial areas of its programme of work

This report is intended to provide, in non-specialist terminology, a concise overview of the status of D&D of nuclear facilities and of the associated issues in the NEA Member countries. The report draws upon a database of fact sheets produced to a standard format by individual Member countries and that can be accessed on line from the NEA website. In the context of this report, the term “nuclear facility” includes all facilities associated with the production of nuclear power, from mining of uranium, through fabrication of nuclear fuel, nuclear power plant operation, fuel reprocessing and waste management, including related R&D facilities, and research and demonstration reactors.

This report was drafted by the RWMC Working Party on Decommissioning and Dismantling (WPDD) and it includes the contribution of other NEA groups.

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## 1. SUMMARY OF CONSENSUS ON KEY POINTS.

There is agreement on the following key points amongst those involved in decommissioning and dismantling (D&D) of nuclear facilities. These include operators, regulators, policy-makers and those representing local communities likely to be affected by shutdown of major facilities.

- **The purpose of D&D is to allow removal of some or all of the regulatory controls that apply to a nuclear site.**

The purpose of D&D is to allow removal of some or all of the regulatory controls that apply to a nuclear site whilst securing the long-term safety of the public and the environment, and continuing to protect the health and safety of decommissioning workers in the process. Underlying this are other practical objectives including release of valuable assets such as site and buildings for unrestricted alternative use, recycling and reuse of materials and the restoration of environmental amenity.

- **There is no unique or preferred approach to D&D of nuclear facilities.**

It is widely accepted that the route to removal of regulatory controls depends on various factors and may involve various stages and interim uses. National policies differ on detailed objectives to be achieved en route. Individual countries are influenced variously by such matters as national policy on the future use of nuclear power, the continued availability of trained staff, societal issues associated with the effects of facility shutdown and D&D on neighbouring communities, and by the broader financial issues of how best to use available funds and when to deploy them.

- **Techniques for D&D are already available, and valuable experience is being fed back to plant design and decommissioning plans.**

Techniques for decontaminating and dismantling nuclear facilities are already available. The design of facilities and selection of materials that facilitate these techniques are now standard practice. It is important for the future to ensure that the accumulating experience of applying these techniques to large plants is shared throughout the D&D community and that lessons continue to be fed back into new facility designs and into D&D plans.

- **Many nuclear facilities have already been successfully decommissioned and dismantled.**

The available techniques have been applied successfully to the D&D of many early facilities for development and demonstration of nuclear power, and some sites have already been returned to a condition suitable for unrestricted reuse. This has provided a substantial body of experience on a wide range of complex applications that is now

being used on larger commercial facilities. The challenges for the future are to further improve strategies and processes for securing safety, environmental protection and economy and to develop satisfactory ways of dealing with other socio-economic aspects.

- **Current institutional arrangements for D&D are sufficient for today's needs.**

The bodies currently in place for establishing policy, legislation and standards, for operating nuclear facilities and managing radioactive waste, and for regulating these activities, are adequate for dealing with D&D. Depending upon individual national circumstances, however, it may be convenient to modify practical arrangements by creating new bodies, such as dedicated liabilities management organisations, to assume responsibility for D&D from operators no longer in business, and to maintain and further develop the related expertise.

- **Current systems for protection of the safety of workers, the public and the environment are satisfactory for implementation and regulation of D&D.**

The effects of D&D on health and safety of both workers and the public, and on the environment are well understood. The protection systems already in place will deal with them satisfactorily but there is a need now to review these issues in order to ensure continuing safety of workers, the public and the environment over the entire period of the D&D process, and to ensure continuity and transparency of the regulatory process.

- **Systems are in place for funding of D&D, but evaluation of costs requires further attention.**

It is recognised that provisions for funding D&D need to be made during the operating lifetime of a facility, and these are now widely established in OECD/NEA Member Countries. The challenge for the future is to ensure that D&D costs are calculated correctly and that fund management systems are in place for guaranteeing that sufficient funds will be available when required. Such fund management systems are likely to vary from country to country, depending upon the D&D strategies adopted, and may or may not involve liabilities management organisations of the kind described above. The overall costs of D&D are dominated by the costs of waste management so it is important not only that waste quantities are minimised but also that the costs of waste treatment, storage and disposal are separately identified and assigned.

- **Most D&D wastes are similar to normal operational wastes but some present new challenges that will need to be addressed.**

Management and disposal of radioactive waste is a key element in satisfactory completion of D&D of nuclear facilities and is the major contributor to its overall

costs. Much of the waste produced during D&D of nuclear facilities is similar to that produced during their operational lifetime, so a major part of this new challenge is already shared with current activities. The new element, characteristic of D&D specifically, is the large quantity of waste containing only small concentrations of radionuclides. This requires serious attention to development and application of principles by which valuable materials may be released from regulatory control for re-use or recycling, and the need for disposal as radioactive waste minimised. The management of specific wastes containing materials such as graphite, beryllium, sodium, asbestos, etc. will also need further attention.

- **Local communities are increasingly demanding involvement in planning for D&D.**

It is widely accepted that openness and transparency are essential for the winning of public approval for D&D plans. The local public is increasingly demanding to be involved in such planning and this may accelerate introduction of concepts such as “step-wise decision-making”. The challenge for the future, therefore, will be satisfactory development of systems for consulting the public, and local communities in particular, and the creation of sources of information in which the public can have full confidence.

## 2. INTRODUCTION.

The term “decommissioning”, when applied in its broadest sense to nuclear facilities, covers all of the administrative and technical actions associated with cessation of operation and withdrawal from service. It starts when a facility is shut down and extends to eventual removal of the facility from its site (termed “dismantling” in this report). These actions may involve some or all of the activities associated with dismantling of plant and equipment, decontamination of structures and components, remediation of contaminated ground and disposal of the resulting wastes. The purpose of these activities is to allow removal of some or all of the regulatory controls that apply to the nuclear facility while securing the long-term safety of the public and the environment, and continuing to protect the health and safety of decommissioning workers in the process.

It is generally presumed that the eventual end-point of these activities is return of the site to a condition in which it can be released for unrestricted use. Within Member countries, however, there is a wide range of opinions and policies on the route and timescale to arrive at this eventual end-point. These opinions and policies are influenced by national positions, or lack of them, on such matters as the future use of nuclear power, societal issues associated with impact on neighbouring communities, possible alternative uses for the facility, technical and regulatory issues, arrangements for waste management, and on economic issues associated with costs and cash flow.

This report summarises the status of D&D in OECD/NEA Member Countries, the approaches currently adopted, and the general challenges to be faced. It describes the liabilities remaining from early nuclear developments and arising from current nuclear power programmes and the work that must be done before D&D activities peak after about 2015. The purpose of D&D and the various national policies and objectives are described, together with discussion of emerging societal issues and of how to involve local communities. It identifies the bodies responsible for setting policies and standards for D&D, for implementing these policies and for regulating the associated activities. It also describes features of the regulation of safety of D&D and discusses arrangements for ensuring that sufficient funds are available to complete it. The report then describes the strategies and techniques available for carrying out D&D safely, together with a discussion of the issues arising from the safe management of the resulting waste and of the further developments required. It concludes with reference to arrangements for providing the public with information about plans for D&D and suggests further reading for those interested in detail.

### 3. THE STATUS AND CHALLENGES OF D&D.

#### *Status of Nuclear Facilities in OECD/NEA Member Countries.*

OECD/NEA Member countries include those involved in the earliest developments of nuclear technology in the 1940s and 1950s. These countries have a wide range of plant and equipment that has now served its purpose and needs to be decommissioned and dismantled. This range includes R&D facilities for chemical processing, uranium and plutonium production, isotope separation, nuclear fuel fabrication, etc. as well as research reactors, critical assemblies, materials research reactors and various designs of experimental and demonstration reactors, including fast breeder reactors, and high temperature reactors with special fuels. The list also includes processing facilities associated with mining of uranium, and facilities for the treatment and storage of a wide range of radioactive wastes. In addition, some countries have facilities associated specifically with nuclear weapons production and with naval nuclear propulsion systems.

Even though individual facilities may be relatively small, this inventory of historic facilities presents a range of complex nuclear technical challenges compounded, in some cases, by the presence of non-radioactive, hazardous substances such as asbestos and PCBs, which are of substantial concern for health, safety and environmental reasons. The difficulties of dealing with these older facilities are exacerbated by the fact that some original documentation may be difficult to retrieve, and the original designers and staff have retired in most cases. Nevertheless, substantial progress on D&D of these facilities has already been made and valuable technical experience has been gained on a wide range of technologies.

A new range of challenges opens up as the more modern nuclear power programmes mature and large commercial nuclear power plants approach the end of their useful life by reason of age, economics or change of policy on the use of nuclear power. The scale of such challenges may be judged from the fact that over 500 nuclear power plants have now been constructed and operated worldwide, and OECD/NEA Member Countries account for a large proportion of these. They include Gas Cooled Reactors (GCRs), Boiling Water Reactors (BWRs), Pressurised Water Reactors (PWRs), Pressurised Heavy Water Reactors (PHWRs) and various types of demonstration plants such as High Temperature Reactors (HTRs) and liquid metal cooled Fast Breeder Reactors (FBRs). Only about 80 of these power plants have been retired from service, including the early demonstration plants. For the most part, these are smaller units (<200 MWe) and are either being maintained in a safe condition under surveillance, after removal of fuel, or are being decommissioned. Some commercial nuclear power plants have been decommissioned, dismantled and, in some cases, their sites returned to unrestricted reuse of the site. In addition to power plants, there are associated nuclear fuel

fabrication and irradiated fuel reprocessing facilities, at least parts of which have been, or soon will be, retired from service.

In Germany, for example, 17 nuclear power plants and prototype reactors, 32 research reactors and critical assemblies as well as 6 fuel cycle facilities have been permanently shut down. Two of the power reactors, 21 of the research reactors and critical assemblies and one of the fuel cycle facilities have now been decommissioned, and the sites of the two power reactors restored and released from regulatory control. The other power reactors are currently in safe enclosure or are being dismantled, and their sites will be returned to a condition suitable for unrestricted reuse.

In Belgium, about half of the cells in a major fuel reprocessing plant have been emptied and decontaminated and the other half are currently in the process of being brought to the same state. A small prototype PWR is in the process of being dismantled and decontaminated, and laboratories used previously for nuclear R&D have been decontaminated, released from radiological control and are now being used for conventional research. Early facilities for radioactive waste processing and storage are currently undergoing D&D and some are already returned to unrestricted reuse.

Programmes in France and the UK, although more extensive in scale, are broadly similar in principle to that in Belgium. In the context of scale, however, the US is most notable. Since 1960, more than 70 test, demonstration and power reactors have been retired, most of them relatively small. The first decommissioning of a commercial nuclear plant was in 1989, and 14 nuclear plants greater than 100 MW have been shutdown and decommissioned since then. Additionally, during the course of nuclear weapons R&D and production, the Federal Government built and used more than 20,000 facilities. More than 10,000 of these facilities are now surplus to requirements and over 3,000 of them are scheduled for decommissioning. To date, more than 500 have been decommissioned.

By contrast, other countries with relative young nuclear programmes, like Finland, the Czech Republic and Hungary for example, have no decommissioning programmes underway and none foreseen for some years (except maybe for research facilities).

### *The Modern Challenges.*

The current situation is thus that much has already been done to deal with the early facilities but much remains to be done. The work on earlier facilities has provided a substantial body of knowledge and experience over a wide range of complex technical issues but the requirement now is to apply the available techniques to D&D of the larger commercial facilities. In addition to technical issues, however, plans and procedures will

need to address other major issues associated with impacts on society and the environment, regulatory arrangements and with long-term funding.

In OECD/NEA Member Countries, the average age of nuclear power plants is about 15 years so, given an average operating life span of at least 30 years, the rate of retiral from service will peak some time after 2015, although the statistical distribution is rather wide. This is reflected throughout OECD/NEA Member countries by the fact that some countries have already retired some commercial nuclear power plants from service, and have even decommissioned and dismantled them in some cases, whilst in other countries it will be some years before any plants are retired.

#### **4. PURPOSE AND OBJECTIVES OF D&D.**

##### *Purpose of D&D.*

The generally accepted purpose of D&D is to allow removal of some or all of the regulatory controls that apply to a nuclear site, whilst securing the long-term safety of the public and the environment, and continuing to protect the health and safety of decommissioning workers in the process. Underlying this, of course, are other practical objectives including release of valuable assets such as buildings for alternative use, recycling and reuse of materials and the restoration of environmental amenity. In all cases, the basic objective is to achieve an end-point that is sensible in technical, social and financial terms and that properly protects workers, the public and the environment.

Stringent regulatory controls protect the public, the environment and workers from the hazards associated with nuclear facilities. These hazards arise from the radioactive inventory of the facility and from the nature of the operations carried out. When a facility is shut down for reasons of age, redundancy or breakdown, the hazards associated with operational activities are generally eliminated or substantially reduced, but those associated with the radioactive inventory remain and tight regulation is still required. The regulatory arrangements are often complex, costly and require highly qualified personnel, so there is a strong incentive to remove the necessity for them by removing these radioactive hazards.

##### *Policies and Objectives to be achieved en route.*

In OECD/NEA Member countries it is generally presumed that the eventual end-point of D&D is return of the site to a condition that will allow its release for safe, unrestricted use. Opinions and policies differ, however, on the detailed objectives to be achieved en route and, therefore, they differ on details of the activities and timescales for arrival at that end-point. Individual Member Countries are influenced by various factors. For example, national policy on the future use of nuclear power may influence choice of future use of the site. Concerns about the continued availability of staff trained in nuclear technology may influence matters of timing of D&D. Societal issues associated with the effects of facility shutdown and D&D on neighbouring communities may also influence both use of the site and the timing of D&D, as will broader financial issues of how best to use available funds and when to deploy them.

In those Member Countries that have decided to phase out use of nuclear power, the objective is normally to achieve the safe, unrestricted use of a nuclear site as soon as possible. Some countries in this category are concerned about degradation of the facility after shutdown, about possible loss of relevant documentation and about loss of knowledge and competent personnel when nuclear power programmes are finished. They

may also be concerned about the possible demise of the responsible operator or loss of the necessary funds for D&D during any period of deferral. They foresee D&D being completed within 10-20 years. Sweden, Germany, Denmark, and Italy are typical examples of this group. Other members of the category are influenced more by the benefits of deferring D&D in order to take advantage of the natural decay of radionuclides, which simplifies some of the D&D activities, thus reducing and deferring the costs. The Netherlands is such an example. Deferral is also the preferred option of those Member Countries that see advantage in waiting until appropriate waste disposal facilities are available. In cases of deferred D&D, the facility is maintained in a safe state under careful supervision and in some cases of extended deferral may be sealed for safe storage.

Member Countries that are committed to continued use of nuclear power, such as Japan and France, also share the objective of completing D&D as soon as possible. In these cases, the objective is to make way for new nuclear facilities. This is one example of maximising the use of existing assets and of saving the resources that would be necessary for finding and seeking permission for development of new nuclear licensed sites. Also, in such cases, the requirements for site remediation need only be consistent with the requirements for a licensed nuclear site and need not meet the standards for unrestricted use.

Other Member Countries, such as the US, Canada, Belgium, UK, and Switzerland, have more flexible policies. These allow detailed decisions for particular facilities to be made on a case-by-case basis. In the US, for example, such decisions might include deferring D&D so that available Government funds can be used for dealing with higher priority issues such as soil or groundwater remediation, although this is unlikely in situations where a fund has been accumulated specifically for D&D.

In most countries, the range of options, for interim purposes at least, also includes re-use of facilities for alternative, conventional industrial use. As well as maximising the use of assets, this policy offers benefits where there is a societal need for continued employment for example. In these cases, the requirements for site remediation will be more stringent than for reuse as a nuclear site but may not be as stringent as for unrestricted use.

In some cases it may be impracticable to return some sites to a condition suitable for unrestricted use. This possibility is foreseen, in Canada for example, in regard to uranium mining and milling facilities. In the US, a similar view may apply in the case of highly contaminated land where the consequences of remediation, in terms of effects on workers, are not justified by the benefits. In such cases, the objective of D&D will be to return the site to such a condition that the long-term safety of the public, the environment and of any workers may be secured by long-term stewardship and on-going institutional

control. These cases will thus become more like some radioactive waste disposal sites, with analogous safety features.

It may be seen, therefore, that there are various routes to a satisfactory end-point for D&D, depending upon the circumstances in individual Member Countries.

## 5. SOCIAL AND ENVIRONMENTAL IMPACTS.

### *Emerging Societal Issues.*

Up to now most D&D projects have dealt with smaller nuclear facilities located within larger complexes of facilities that continue in operation. As an increasing number of larger, commercial nuclear power plants, on dedicated sites, reach the end of their useful life, however, a new range of social and environmental issues associated with site closure now have to be addressed. Fortunately, this is not a feature unique to the nuclear industry and so the generic issues, at least, are well understood and preparations are being made in most OECD/NEA Member countries.

The social and environmental issues that are of most interest to communities in the locality of decommissioning sites can vary considerably. Nevertheless, there are several issues that are common to a variety of nuclear facilities. Among the issues of common concern are health impacts of releases, both during and subsequent to the decommissioning activity. In addition to such routine releases, the risks from possible accidents, both during and after decommissioning, are also of great interest to the community. Environmental impacts of interest include effects on water quality and on wildlife, such as fish in water bodies that might receive runoff from the decommissioned site.

### *Role of Local Communities.*

Of wider, national significance is the likelihood that communities where nuclear facilities are located may be willing to accept that wastes and other remnants of a former facility may remain in storage in the community after the facility ceases to operate, but they are likely to be concerned about the possibility of storage becoming disposal and may be reluctant to accept wastes from other locations. This could result eventually in creation of a network of relatively small radioactive waste management facilities for storage and management of locally produced wastes only. The long-term safety, environmental and social implications of this for national policy need to be carefully considered, particularly in those Countries that have decided to phase out nuclear power and that are most likely to lose the necessary technical skills for safe maintenance of such facilities.

In most OECD/NEA Member Countries there are well-developed mechanisms for involving stakeholders and local authorities in the planning of activities that affect such social and environmental issues. Generally they require detailed environmental impact assessment, addressing a wide range of factors including impact on amenities, landscape, noise, transport provisions and general nuisance as well as the more specific issues of

waste management and impact on the environment as such. Most importantly, these mechanisms make specific provision for information and involvement of the public.

There are other social impacts of facility shutdown, however, that are not so well covered by established mechanisms, and that need to be carefully considered at local level. These impacts are likely to be felt most strongly in small or isolated communities whose livelihoods have depended on the facility during its construction and operation. They include possible loss of employment, reduced opportunities for education and training, reduction in property values, etc. Local authorities may feel that they have little direct influence over major developments on the facility, which are generally dealt with at national level, but these authorities will usually have played a key part in development of the local infrastructure, health and social services etc, that have supported the facility during its construction and operation. Against this background, they will be well placed to advise on the planning and timing of D&D, particularly as regards the social implications of early or deferred implementation and of alternative uses for the site, such as conventional industry, tourist attraction or site for new source of energy production. They will see it as their role to protect the interests of the local community and will be best placed to ensure that the community is accurately informed in order to prevent rumours, perverse manipulation of public opinion and loss of morale. In some countries, such as the UK for example, the regulatory authorities have a statutory obligation to consider the effects of their regulatory proposals on certain local communities, particularly in rural areas.

#### *Step-wise Decision Making.*

The way in which local communities and the public in general are engaged in dialogue about D&D of facilities in their locality is likely to become an increasingly important issue as the scale of the activity grows. This is already an important issue for radioactive waste management and the development of repositories, and it is clear, by way of public protests, that the public are increasingly demanding to influence decisions. Although the two situations are not directly comparable, it is possible that lessons learnt in regard to waste disposal may apply also to some aspects of D&D. Consideration is increasingly being given to concepts such as “stepwise decision-making” and “adaptive staging” in which the public, and especially the local public, is meaningfully involved in the planning of developments. The key feature of these concepts is a plan in which development is by steps or stages that are reversible, within the limits of practicability. The public are involved at each step and also in review of the results of having taken a previous step. This is designed to provide reassurance that decisions are not irrevocable and can be reversed if experience shows them to have adverse or unwanted effects. In the context of D&D, of course, such reversal will be most relevant to decisions concerning deferral of D&D, or reuse of the site, since decontamination and dismantling of a decommissioned facility will obviously not be reversed when carried out.

A major issue, however, is how to identify the “public” for these purposes and the kind of forum appropriate for taking and reviewing decisions. There is still little

experience of this in practice, but arrangements in Sweden and Finland, for example, may offer a valuable lead.

## 6. ROLES AND RESPONSIBILITIES.

The main roles associated with D&D of nuclear facilities involve:

- Setting national policies for shutdown of nuclear facilities and for management of the resulting wastes,
- Establishing legislation for nuclear safety, radiation protection and environmental protection, together with the related regulatory requirements for control of D&D and waste management,
- Implementing D&D and waste management activities, and
- Implementing the related regulatory arrangements.

These roles are specifically recognised in the International Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which includes decommissioning of nuclear facilities within its scope. It follows that OECD/NEA Member countries also recognise them, even though the designation of bodies for the various roles may differ from country to country.

### *Policy and Legislation.*

In general, the setting of national policies and the establishment of legislation and regulatory requirements are carried out at national level by Government Departments or Ministries. Typically, these include Ministries for Trade and Industry, for the Environment, for Health, and for the Economy. The systems for developing legislation and regulatory arrangements may vary in detail depending upon constitutional arrangements within Member Countries and some countries, such as Italy for example, make provision for the involvement of specific stakeholder groups. Nevertheless, it is generally true that in matters concerning nuclear power, the primary body for these issues is central Government.

OECD/NEA Member Countries in the European Union are also bound by the terms of the EURATOM Treaty which, in respect of ionising radiation, requires the European Community to “establish uniform safety standards to protect the health of workers and of the general public”. In this regard, it also requires national governments to implement various Directives and Standards. Thus, the European Commission is a key player but, with some detailed exceptions, the European Directives, Standards, Guidelines and Recommendations are implemented by way of national legislation and regulations. An important example is the “Council Directive of 13 May, 1996 laying down Basic Safety Standards for the Health Protection of the General Public and Workers against the dangers of Ionising Radiation”, (96/29/EURATOM). Amongst other things, this permits recycling, reuse or disposal of radioactive substances to be carried out without the controls imposed by the Directive, provided that the substances comply with requirements on maximum concentrations of individual radionuclides in the substance. These so-called “clearance levels” have to be established by national authorities

following basic dose criteria given in the Directive, and have to take into account other technical guidance given by a group of experts established under the terms of the Euratom Treaty.

### *Implementation of D&D activities*

In most OECD/NEA Member Countries responsibility for D&D activities lies with the body that operated the nuclear facility during its operational phase. A key issue is the funding of D&D, and this is addressed separately in Section 8, below. As regards implementation of the practical activities of decontamination and dismantling, various options are adopted or are being considered in OECD/NEA Member Countries. These options include undertaking of D&D by the operator of the facility, or by specialist contactors employed by the operator, or some combination of the two. It is also recognised explicitly in some countries such as Canada and Finland that, where an operator is unable to fulfil his role for whatever reason, the responsibility for completing the task will fall to the regulator or to the State. In fact, for those Member Countries that are also signatories of the International Joint Convention, this is already an obligation, at least in so far as the safe management of spent fuel and waste is concerned.

Some countries, however, have already recognised the possibility that an operating body may cease to exist before D&D is completed and that responsibility may need to be transferred to some other stable body for the long term. In Spain, for example, responsibility for implementing D&D is transferred to a national agency, ENRESA, when the nuclear facility is shut down. ENRESA is a body established with specific responsibility in Spain for D&D activities and for radioactive waste management and disposal. It is thus an early example of a body well-placed to maintain and develop the expertise necessary for D&D of nuclear facilities, and for managing the resulting waste, regardless of whether nuclear facility operators continue in business or not. In Belgium, the body the responsible for waste management and disposal, ONDRAF/NIRAS, will assume responsibility also for D&D operations in the event of operator failure.

In regard to waste management and disposal specifically a key issue is assignment of responsibility as between Government and some other organisation or organisations. Some countries, such as Germany for example, recognise the advantages of Government responsibility in terms of powers and longevity. Others choose to rely on existing organisations, but some have designated the task to organisations created specifically for the purpose. As noted above, Spain and Belgium have created the organisations ENRESA and ONDRAF/NIRAS respectively. Analogous organisations have been created in other countries such as France (ANDRA), Netherlands (COVRA), UK (NIREX) and the Czech Republic (RAWRA). The powers and duties of these waste management organisations vary from country to country but some, such as ONDRAF/NIRAS and ANDRA for example, have substantial powers in regard to specifying waste acceptance criteria and approving waste management plans and programmes, including the associated funding arrangements.

## *Regulation*

Arrangements for regulation of D&D activities in OECD/NEA Member Countries, depend upon individual, national constitutional arrangements. Perhaps the most significant feature is whether a country has a central or federal system of government. In the latter case, regulatory powers may be shared between national government and the governments of the component states of the federation. In addition, different regulatory bodies may be responsible for different aspects of the activities associated with D&D, ranging from spatial or physical planning, through health and safety of workers to waste disposal and nature protection.

In some countries, such as Hungary and Korea, the ultimate regulatory authority remains with relevant Government Departments, who are advised by Inspectorates charged to carry out site inspection, review of licences, monitoring, etc. In other countries, such as Sweden and Spain, regulatory bodies are charged with enforcing the laws on nuclear safety, radiation protection and environmental protection independently of Government Departments, and they report directly to Government. In most countries, however, the regulatory bodies operate independently within a well-defined remit but answer to one or more relevant Government Departments, or to their equivalents in Federal States. Detailed arrangements vary widely across OECD/NEA Member Countries but they are usually some combination of the above examples.

**The OECD/NEA has reviewed the regulatory arrangements in Member Countries and is publishing the results by Autumn 2002**

## 7. REGULATION OF SAFETY IN D&D.

### *Current Situation.*

Most OECD/NEA Member Countries regulate D&D of nuclear facilities by way of arrangements similar to those that apply during the operational phase. These arrangements generally include a requirement to maintain satisfactory decommissioning plans as a condition of the operating licence. International consideration is being given, however, to the question of whether current arrangements will be adequate for ensuring safety throughout the transition from operational to decommissioned status, and over the long time-scales associated with some proposals for deferred D&D. This transition may involve regulatory issues such as the phased release of some parts of a nuclear facility from regulatory control before the decommissioning process for the entire installation or the entire site is complete. These possibilities are already recognised in international regulatory guidance. The requirements for further regulatory guidance and for regulatory oversight both during and after decommissioning are being reviewed. For both phases, the need to have effective arrangements for consulting and communicating with the public and local communities is recognised.

### *Key Features of D&D Safety Management.*

The first step of D&D of a nuclear facility usually entails removing spent or unused fuel, in the case of nuclear power plants, and any other stocks of radioactive material associated specifically with previous operations, in the general case. Thus, the potential for major accidents involving radiation exposure of workers or uncontrolled radioactive releases to the environment during subsequent D&D activity is greatly reduced. Nevertheless, the nature of D&D operations may, temporarily, involve higher radiation exposure of workers than during normal plant operation and increased potential for minor accidents or unexpected situations. It may also result in increased exposure to conventional industrial hazards and in the increased possibility of accidental releases of some radioactive or conventional toxic or hazardous substances. This means that D&D operations must be undertaken with the utmost care, and only after thorough planning and preparation.

There are many issues to be considered for the safe management of D&D of a nuclear facility. They include the nature of the facility, e.g. power plant, fuel cycle plant, etc, its age, the condition of buildings and equipment, the radionuclides involved and their concentrations and quantities, and many other factors. They also include the major considerations of D&D strategy, including the choices as between immediate D&D and extended safe storage, for example. Hence, safety management systems for D&D cannot be generalised and need to be addressed on a case-by-case basis. The common aim, however, is to achieve an appropriate balance between health and safety, environment

and economic factors that is consistent with legal requirements and with national policies and objectives in regard to timing, re-use of facilities, etc, as described in Section 4.

It is widely accepted that the safety case for operation of a nuclear facility may not be appropriate for its D&D and that a separate safety case should be established. In this regard, a key feature is analysis of potential accidents during D&D operations and of their consequences. It is likely that the nature of releases and other consequences of fires, loss of plant support systems, earthquakes, aircraft crashes, etc. will be different as between the operational phase of a nuclear plant and during D&D. It is also likely that these consequences will be time-dependent and differ as between early and deferred D&D. In addition, because D&D of a nuclear facility is a major industrial operation, it is equally important for overall safety management to recognise the increased potential for conventional or non-radiological accidents and to ensure that a proper balance is maintained between protection against radiological and non- radiological risks. In the context of maintaining an appropriate balance, it is also recognised that the D&D safety case is one possible mechanism for addressing and assessing environmental impacts of D&D, as now required by legislation in many OECD/NEA Member Countries.

*Some emerging challenges.*

As noted above, D&D safety cases should be developed on a case-by case basis, but individual elements of such cases may be similar as between different D&D projects. This affords the possibility of sharing experiences and perhaps some international harmonisation of practice. Issues that may benefit from such an approach include the balancing of radiological and non-radiological risks and the handling of environmental impact assessment. These are likely to be features of the work being undertaken to consider whether current arrangements will continue to be adequate for the longer term.

Against the background of some Member Countries abandoning nuclear power after current facilities are shut down, the OECD/NEA work on reviewing the requirements for further regulatory guidance and for regulatory oversight is likely also to address the issue of how to maintain the capability of those bodies responsible for carrying out D&D operations and for their regulation. As regards D&D operations, regulators will need to be satisfied that an appropriate organisation is in place to comply with the site licence. This means, amongst other things, ensuring that sufficient appropriately qualified staff are available, including so far as possible those with knowledge and experience of the relevant operational facility, and that staff changes and development are properly managed over the necessary time-scales. It also requires recognition of the management challenges associated with use of short-term contractors or temporary staff. The experience of ENRESA, and other similar bodies, in dealing successfully with these issues over the longer term will be of substantial value to this OECD/NEA work.

As regards the process of regulation, appropriate organisational structures for the long term will need to be reviewed and, to the extent that regulators are drawn from the

corps of those experienced in practical operations, the same concerns about maintenance of the necessary skills will apply and will need to be addressed. This issue, however, is not unique to regulation of D&D as it will apply also in large measure to the on-going regulation of waste disposal facilities, regardless of whether nuclear power continues to be used.

## 8. FUNDING ARRANGEMENTS.

### *Responsibilities for Funding.*

Arrangements for funding D&D of nuclear facilities must differentiate between state-owned facilities, such as early R&D facilities and demonstration plant, on the one hand, and commercial nuclear facilities, on the other. In the case of state-owned facilities, the costs of D&D fall to the State. Perhaps, as in Belgium, a contribution may be made by those utilities that have benefited from their work.

In the case of commercial nuclear facilities, the responsibility for funding D&D invariably resides with the operator. In the majority of OECD/NEA Member Countries it is a requirement established either directly in legislation, as in Germany, or by way of operating licences, that operators create and maintain funds or financial guarantees for this purpose. These funds are created from business revenues and, in almost all cases, the size of the necessary fund is reviewed on a regular basis, generally between 1 and 5 years. It is then agreed with Government, either directly or by way of the regulator, as in Canada, the US, and Sweden or by way of the waste management body, as in Belgium and Spain. In the cases of Canada and the US, the regulatory bodies provide formal guidance for this purpose. (Where no financial provision has been made in the past, the costs of D&D may be borne by the State.)

### *Management of Funds.*

The way in which such funds are accumulated and managed varies from country to country. In some countries, the calculated sum for D&D, corrected on a regular basis for inflation and changes in technology, is accumulated year by year over the planned lifetime of the facility. In other countries, where the possibility of premature shutdown of the facility is recognised, a deadline in advance of the planned shutdown is set for having the necessary funds in place, although this is seen by some as a heavy financial burden for the early years of operation.

Similarly, some countries allow operators to accumulate and manage their own funds, under appropriate supervision, and in other countries the funds are collected from the operators and managed by separate, independent bodies. In Spain for example, ENRESA collects and manages the funds, because the responsibility for carrying out D&D falls to it, as described above. In Sweden, although the regulatory body is responsible for proposing the size of annual fees to the Government, which then establishes the fee, an independent “Board of the Nuclear Waste Fund” manages the fund. In Switzerland, Hungary and Finland, however, the fund is collected and administered directly by central Government.

### *The costs of D&D.*

As regards estimation of the actual costs of D&D, there are substantial variations for similar types of installation. This is a reflection, in particular, of the variation in assumptions used for costing the elements of the D&D process, and in the specification of these elements. These variations make it difficult to describe typical costs for different types of installation. Against this background, a Task Group on Decommissioning Costs has been set up under the auspices of the OECD/NEA Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects. By way of this Task Group, the NEA, IAEA and EC have agreed to prepare a common list of cost items and related definitions for D&D projects. It is intended that this will lead to more consistency and accurate cost estimation, and the Group has already produced an interim technical document on “A Proposed Standardised List of Items for Costing Purposes”.

It is already clear from current experience, however, that the costs of radioactive waste management dominate the overall costs of D&D of nuclear facilities. In Germany, for example, it has been estimated that about 60% of the costs of D&D are attributable to the costs of waste management, including the costs of storage for 30 years, although the materials declared as radioactive waste comprise only 2% of the materials associated with D&D activity. This fact alone indicates the importance of accurate characterisation of radioactive materials and of maximising opportunities for re-use or recycle of materials in order to minimise the amount of material requiring treatment, storage and disposal as radioactive waste. In this latter context, it is also important that D&D costs are itemised in such a way that the costs of waste treatment, storage and disposal can be separately identified and attributed to the appropriate bodies.

As a general indication of the overall level of D&D costs, although it may have little relevance for other OECD/NEA Member States, the US regulatory body requires companies to have at least \$164 million (at 2000 value) available to decommission a full-size pressurized water reactor and \$211 million (at 2000 value) to decommission a full-size boiling water reactor.

## 9. DECOMMISSIONING STRATEGIES AND TECHNIQUES.

Early experience has shown that the requirements of D&D, and of subsequent waste management, need to be considered at the earliest stage in the life of a nuclear facility, and then kept under review. For this reason, plans and procedures for D&D are now key features in the design of nuclear facilities, and in their subsequent licensing and operation. In most OECD/NEA Member Countries, plans for D&D are now required before issue of an operating licence and they are reviewed regularly throughout the operating life of the facility, as part of the inspection regime.

### *Strategies.*

Detailed plans for D&D depend on the circumstances and policies of individual OECD/NEA Member Countries, as described in Section 4 on “Purpose and Objectives of D&D”. Current thinking, however, generally involves consideration of the following strategies.

Immediate Decontamination and Dismantling: The equipment, buildings, and parts of the facility and site that contain radioactive contaminants are decontaminated to a level that permits removal of regulatory control and are dismantled to the extent necessary shortly after cessation of operations. Residual radioactive waste is treated packaged and removed to an appropriate waste storage or disposal site.

Safe Storage: The facility is placed in a safe stable condition and maintained in that state until it is subsequently dismantled and decontaminated to levels that permit removal of regulatory controls. During safe storage, a facility is left intact, but any fuel has been removed, and radioactive liquids have been drained from systems and components and then processed. Radionuclide decay occurs during the period of safe storage, thus reducing the quantity of contaminated and radioactive material that must be disposed of during decontamination and dismantling.

Entombment: Radioactive structures, systems, and components are encased in a structurally long-lived substance, such as concrete. The entombed structure is appropriately maintained, and continued surveillance is carried out until the radionuclides decay to a level that permits removal of regulatory controls.

The features of Immediate Decontamination and Dismantling include early availability of the facility and site for other purposes, and the fact that D&D operations can be carried out by a work force that is highly knowledgeable about the facility. It may also involve lower overall costs, although it does require a large, initial financial commitment. Part of this initial commitment may arise from provision of thicker radiation shielding or more remote handling equipment in order to avoid higher worker doses, because this option does not benefit from the effects of radionuclide decay. There

may also be a potentially larger requirement for waste disposal capacity.

By contrast, the features of Safe Storage include substantial reduction in radioactivity, with consequent reductions in worker and public radiation exposure and a potential reduction in waste disposal capacity. Conversely, they include possible shortage of trained staff, unavailability of the site and buildings for an extended period and uncertainties about future costs of waste disposal, site maintenance, security and surveillance. In any event, the eventual total costs of this option are likely to be higher than for the immediate D&D option.

The Entombment process is likely to be more suitable for reactors than for other facilities such as fuel cycle plants. By contrast with the other strategies, its benefits are primarily related to the reduced amount of work involved in encasing the facility in a structurally long-lived substance, and the consequent reduction in worker dose by comparison with that from decontaminating and dismantling the facility. In addition, public exposure from transportation of radioactive waste would be minimised. However, because most power reactors will have radionuclides in concentrations exceeding the limits for unrestricted use even after 100 years, this option may not be feasible under the current regulations. In these circumstances, entombment would just be another form of extended safe storage. In the US, three small demonstration reactors have been entombed but no operators have proposed this option for any of the power reactors undergoing decommissioning.

In some OECD/NEA Member Countries, such as the UK for example, D&D strategies may involve some combination of the “Immediate Decontamination and Dismantling” and “Safe Storage” options. For example, early decontamination and dismantling of bulky peripheral equipment may be carried out in order to reduce the visual impact of the facility, the remainder of which may be left under safe storage.

### *Techniques.*

The techniques for D&D are already well developed and, indeed, many of them are based on conventional equipment, simply adapted to nuclear application where necessary. Experience of their use has been shared and compared between Member States by way of the OECD/NEA Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects and more detailed information is available by way of NEA website. The most important techniques required for the wide range of D&D activities, however, are broadly as follows.

Decontamination techniques used for removing contamination from metal, concrete or other surfaces, in order to:

- Facilitate access to working areas and the manipulation of components and equipment to be dismantled.
- Reduce the radioactivity of plant and equipment to facilitate cutting.

- Satisfy the standards governing waste disposal or return of materials to the public domain.

These techniques typically involve various chemical, mechanical, or electrical processes, or some combination of them.

Cutting techniques used to dismantle all the installation, including metal or concrete structures, and plant and equipment of all kinds. These are based typically upon mechanical, thermal, explosive and other principles

Radioactivity measuring techniques used for:

- Drawing up the radioactive inventory of the installation.
- Selecting the decontamination and/or dismantling processes.
- Sorting materials and wastes into categories for conditioning, storage and disposal.
- Batching wastes and packaging them.
- Making arrangements for worker protection,
- Checking that materials, buildings and the site are suitable for release from radiological controls.

Remote control techniques used for working at a distance, or behind radiation shielding, and involving use of:

- Remote manipulators.
- Semi-automatic tooling, allowing staff to work at a distance from radiation sources.
- Lifting and moving equipment used for moving remote manipulators into working areas and for providing access to radioactive areas while maintaining integrity of containment.

Techniques for worker and environmental protection involving use of:

- Temporary moveable shields,
- Airlocks and temporary cells,
- Mobile ventilation and filtration systems,
- Special clothing (breathing air suits, masks, etc.)

Techniques for treating, preconditioning and conditioning wastes so that they satisfy transport regulations and storage and disposal specifications. These include processes for treating liquids and for filtration of gaseous effluents.

The techniques and procedures for regulation and inspection during D&D of a nuclear facility are generally extended from the regime adopted during the operational phase. In addition to ensuring that D&D operations comply with requirements for protection of workers and, in the case of waste disposal and effluent discharge, with the requirements of the relevant waste disposal authorisations, they involve also review of progress against the D&D plans required by the site licence.

## 10. RADIOACTIVE WASTE MANAGEMENT.

The management of radioactive waste from D&D of nuclear facilities is a key consideration in the planning and timing of D&D activities. The availability of waste disposal facilities is an obvious factor in considering when to start dismantling a facility and generating large quantities of waste. If no disposal facility is available it may be judged appropriate to defer D&D until a disposal route is established. If, however, particular circumstances or policies as described in Section 4 lead to selection of the early D&D option in absence of disposal facilities, the only alternative is to dismantle the facility and remove the resulting waste to a storage facility.

### *Basic Principles.*

In most OECD/NEA Member Countries consideration of D&D and waste management now starts at the facility design stage, with selection of appropriate materials and construction techniques. This reflects the first basic principle of waste management, namely that “generation of radioactive waste shall be kept to the minimum practicable”, as described in “The Principles of Radioactive Waste Management” IAEA Safety Series No. 111F, 1995. Beyond this, and in consideration of ecological issues including “sustainable development”, there is emphasis on re-use or recycle of radioactive materials within the nuclear industry and on the removal from regulatory control, or “clearance”, of other less radioactive materials for conventional re-use or recycle. In the final analysis, of course, arrangements must be made the safe management of residual radioactive waste, including its disposal, under the appropriate regulatory regime.

### *Waste Types.*

Much of the solid radioactive wastes arising from D&D of a nuclear facility after cessation of operation are the same as the wastes arising during its operational phase. Depending upon the nature of the facility, these solid wastes comprise:

High Level and Low and Intermediate Level Long-Lived Wastes, in the form of spent fuel, the products of its reprocessing, or materials contaminated with long-lived radionuclides. (It should be noted, however, that such wastes are classified here as D&D wastes because they arise during post-operational clean out, after shutdown of the facility. For most practical purposes, they are operational wastes and are not generally associated with actual dismantling of the facility.)

Low and Intermediate Level Short-Lived Wastes, in the form of irradiated items and materials contaminated with short-lived radionuclides, and including items of plant and equipment or building materials such as steel and concrete containing only small concentrations of radionuclides. It may also include contaminated soil, arising as waste from remediation of radioactively contaminated ground.

Liquid and gaseous effluents produced during D&D activities are also generally similar to those produced during normal operations except, perhaps, in cases where decontamination has involved special chemicals.

In OECD/NEA Member Countries, most of these High Level and Low and Intermediate Level Long-Lived Wastes and Low and Intermediate Level Short-Lived Wastes are managed by way of arrangements in place for dealing with the similar wastes arising from normal operations. Such arrangements are generally well developed and their costs known. Some of the wastes, however, are unique to D&D, with the possible exception of some items arising from major refurbishment of a nuclear facility. It is with these latter wastes that this section is primarily concerned. These wastes include very large items of plant, such as heat exchangers, and so-called “exotic” or special wastes containing toxic or hazardous materials such as graphite, sodium, beryllium, lead or asbestos. They also include relatively large quantities of materials, in which the radionuclide concentrations are close to levels at which they may be released from regulatory control, or “cleared”, with or without conditions being placed upon their further use. These may include materials, such as steel or concrete or other useful materials, which have been decontaminated by way of the techniques described briefly in Section 9. In addition, there are large quantities of waste which are not radioactive but which, because they arise on a nuclear licensed site, are also subject to regulatory control. These are sometimes termed “suspect wastes” because the possibility exists for them to have become contaminated by other materials on the site.

Although procedures for management of the very large items and the “exotic” or special wastes have been developed on a limited scale, further attention needs to be given to their development before D&D activities increase over the next decade or so. As regards the large quantities of waste containing only small concentrations of radionuclides, and suspect wastes, there are substantial incentives to maximise use of the principle of clearance. Firstly, ecological and sustainable development considerations demand maximum re-utilisation of non-renewable resources by way of direct re-use of equipment or buildings and by recycle of useful materials. Furthermore, the intrinsic value of the materials for recycle, in the case of metals, or for use in construction in the case of concrete, is considerable. Also, because the quantities of these wastes are large, the costs associated with their disposal and the difficulties associated with finding a disposal site are substantial.

As was described in Section 8 the costs of treating, storing and disposing of D&D wastes dominate the overall costs of D&D. Hence it is important to have accurate characterisation of radioactive materials and to maximise opportunities for re-use or recycle of materials in order to minimise the amount of material requiring management as radioactive waste and to identify the most appropriate safe and economical methods for its management.

*Application of Clearance.*

The principle of clearance has already been utilised successfully in some OECD/NEA Member Countries, most notably in Germany and Spain for example, and to a more limited extent in other countries such as Belgium, and the UK. Within the European Union, guidance is available by way of the European Commission on its practical use, but EU Member States are free to set their own clearance levels, and any inconsistency in this may cause some difficulty for international trade, or for transboundary shipment. There are also some early indications that the public may not readily accept its use on a large scale, and that this may be reflected in a related reluctance of business to accept such material. It is also interesting to note that, for no immediately apparent reason, the maximum radionuclide levels set for clearance of material from nuclear sources are substantially lower than those for the unrestricted use or disposal of materials from conventional industrial sources containing technically enhanced levels of naturally occurring radionuclides. The rate of production of these materials, and their accumulated amounts, are orders of magnitude greater than the low radionuclide concentration materials from D&D and, in many cases, the radionuclides are longer lived.

For all of these reasons, this is an important subject for continuing study within the NEA and the international community.

## 11. PUBLIC INFORMATION.

All OECD/NEA Member Countries have arrangements for informing the public about plans for D&D and about progress and next steps. These arrangements vary from country to country, but generally involve a combination of statutory requirements for public access to information, together with further voluntary provisions by the various bodies involved, including the operators of nuclear facilities.

In many countries, legislation also requires that regulatory processes are open to the public, with consultation of the public by the regulatory bodies and public hearings being held in the case of major decisions. These requirements are reinforced in certain cases by international conventions or treaties that require provision of information to neighbouring countries that might be affected by D&D activities.

In many countries it is now common practice for operators of nuclear facilities, on a voluntary basis, to maintain information centres for the public and to issue regular information bulletins. It is also now common for the regulatory bodies to publish documents describing the systems, procedures and the technical guidance they apply to regulatory decisions.

A number of OECD/NEA Member Countries have included lists of national sources of information on D&D and Waste Management in their National Decommissioning Fact Sheets, available by way of the OECD/NEA National Decommissioning Fact Sheet Database.

In addition to information provided by domestic national sources, members of the public in OECD/NEA Member Countries have access to further information from OECD/NEA publications and the website (**at.....**). In the field of D&D of nuclear facilities this includes information on:

- General background issues.
- Decommissioning policy and strategies.
- Waste management and material reuse considerations.
- Authorised release of sites and facilities.
- Securing long-term funding, and related responsibility.
- Framework for safety regulation of decommissioning.
- Social dimensions, including public and political relations.
- Decommissioning technologies.

## **12. FURTHER READING.**

**NEA 2002a Regulatory Control of Radioactive Waste Management in NEA Member countries**

**NEA 2002b The Decommissioning and Dismantling Safety Case, NEA/RWM.WPDD(2002) ..**

**member(Related NEA Documents, e.g. CPD Papers on decontamination techniques?, RWMC-RF paper on regulatory control of WM, WPDD Topical sessions, CNRA publication on Inspection Techniques, etc. )**

**(Related IAEA Documents, e.g. Decommissioning Guides?)**

**(Related EC Documents?)**

**(Related USDOE/USNRC Documents?)**

**(Others?)**