The NEA Co-operative Programme on Decommissioning

The First Ten Years 1985-95

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

— to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
— to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
— to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium,Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995) and Hungary (7th May 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of all European Member countries of OECD as well as Australia, Canada, Japan, Republic of Korea, Mexico and the United States. The Commission of the European Communities takes part in the work of the Agency.

The primary objective of NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:

— *encouraging harmonization of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
— *assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;*
— *developing exchanges of scientific and technical information particularly through participation in common services;*
— *setting up international research and development programmes and joint undertakings.*

In these and related tasks, NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

Cover: Process for Reactor Dismantling.
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FOREWORD

In response to the growing interest in the decommissioning of nuclear facilities, the Nuclear Energy Agency of the OECD commenced in 1978 a programme of activities in this field. The work of the NEA was initially limited to the organisation of international meetings of experts and the preparation of surveys and state of the art reports.

Subsequently, the Agency set up, in 1985, the International Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning Projects. This concept of working together among a number of decommissioning projects exchanging information, experience and possibly personnel, and carrying out other forms of co-operation as appropriate, obtained strong support from all OECD countries having one or more important decommissioning projects either underway or in the planning process.

The programme was formally initiated in September 1985 for a first five-year term, and was subsequently extended for a second five-year term in view of its successful performance. As this success has continued with now an even broader range of participating countries and projects, the agreement has been extended for a third five-year period.

The first five years of this programme represented a watershed in the evolution of decommissioning as a mature technical discipline. In its own right, each of the participating projects made a significant contribution not only towards developing various decommissioning technologies, but also in demonstrating them in the field.

In the second five-year period the primary objective has been to contribute to the industrialisation of decommissioning by facilitating the exchange of information and of related experience between participating projects. This objective can be said to have been met, as evidenced by the continuing increase in participating organisations.

For the next five-year period the exchange of information and experience will continue, but there will also be the objective of ensuring promulgation of the valuable information and experience gained to a wider audience. In addition the intent is to be able to influence the international community involved in the definition of regulatory regimes for decommissioning, using the high level of practical expertise and knowledge gained through the participating projects.

This report describes the programme and participating projects, and reviews the results and experience obtained during the first ten years. It is published on the responsibility of the Secretary-General of the OECD and does not commit any Member country or any Organisation.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Introduction

As a consequence of the continued and growing interest in decommissioning of nuclear facilities, the successful OECD/NEA Co-operative Programme on Decommissioning was renewed for a second five-year period starting in 1990.

The basic scope of the Co-operative Programme remained unchanged regarding the exchange of scientific and technical information between projects. This data includes project descriptions, plans, data obtained from research and development associated with participating projects, together with data arising from the execution of plans and operations. Such exchange includes technical visits to participating projects. In addition, special arrangements can be set up between two or more participating projects to further enhance co-operation in fields of specific mutual interest.

Where there were major topics that required and justified further and more detailed investigation than could be undertaken by the Technical Advisory Group, special Task Groups have been created. In addition to project managers presently participating in the Programme, these Task Groups can include other experts having adequate knowledge in the topic under consideration. During the five-year period now finished, Task Groups were set up to consider:

- Decommissioning costs,
- Decontamination required for decommissioning,
- Recycling and reuse of materials arising from decommissioning.

The Programme has grown significantly such that there are now 12 countries and 30 projects participating together with active support from the EC, the IAEA and UNIPEDE. The inclusion in 1992 of the first non-OECD country is the recognition of the continued value in the Programme, together with the increasing awareness to ensure safe, environmentally friendly and cost effective decommissioning, which is vital to the continuation of a nuclear generation programme. Hence the recent decision to renew the Programme for a further five years commencing September 1995.

The Co-operative Programme

The Programme has an increasingly wide range of projects, with growing emphasis now being placed upon commercial size facilities in addition to the experimental or prototype plants, that were the original basis for the Co-operative Programme. This is perhaps not surprising with the early commercial facilities now at the end of their life or about to be so. Apart from the differences that can be expected due to the type of plant concerned, the major influences on any decommissioning project arise from the organisation, the economic, regulatory and other circumstances prevailing in the country and on the specific site concerned.

The Programme now has participating projects that can be grouped as follows:

- 20 reactors
- 7 reprocessing plants
- 2 fuel material plants
- 1 isotope handling facility.

The reactor types include:

- BWR
- PWR
- PHWR
- Gas-cooled/ D_2O-moderated
- Water-cooled/ D_2O-moderated
- GCR
- AGR
- VVER
- HTGR.

As a result of the wide variation in the type of facility being decommissioned and in the environment under which the activity is to be undertaken, and to assist in the comparison of information and experience, this has been carried out under seven broad headings:

- assessment of activity inventories
- cutting techniques
- remote operation
- decontamination
- melting
- radioactive waste management
- health and safety.

This report includes details of the progress of the participating projects over not just the last five-year Programme, but also over the first five years, where relevant. The inclusion of such data has led to a greater depth of knowledge and in some areas the ability to compare results found on various projects.

The assessment of radioactive inventories is seen as the essential first step in defining the requirements of a decommissioning project. Indeed, radioactive inventories are needed for decommissioning planning, waste categorisation, waste transportation and safety assessments. In addition, licensing authorities frequently require information on the radioactive waste inventory. Where measurements have been made, it has been possible to verify calculations against measured inventories with reasonable agreement.

In the various participating projects, a wide range of cutting techniques have been demonstrated and employed on both metals and concrete. For metal cutting, a comparison has been made between the various methods available, and it has been demonstrated, that in some situations, the use of mechanical cutting techniques offers significant advantages in terms of volume of secondary waste produced. The use of diamond saw cutting for pre-stressed concrete has been shown to be a practical method that can be employed to advantage. Other techniques under consideration include the cutting of both metal and concrete without either a lubricant or coolant, using methods such as steel and tungsten carbide discs, milling and dry milling saws. From the studies to date the use of metal discs has proved successful. But, as it was concluded in the first five-year report, there is no ideal cutting method and it is necessary to select the appropriate technique for the material to be cut together with the environment in which it is to be used.

Whilst the use of robotics or autonomous machines only had limited use in the participating projects during the five-year period, confidence is being gained to enable future wider use. These systems are comparatively expensive, but offer sometimes the only practical solution to the dismantling of highly active plant components. In addition there may be advantages in the use of robotics in reducing the workforce exposure in situations where traditional hands on working would normally be considered.

A wide range of decontamination techniques have been employed in the various projects. One major demonstration has been the successful use of the "shaving" technique, using a diamond tipped cutting head for the decontamination of concrete. This has been shown to be over three times as fast as the more usual scabbling method and in addition produced only half the volume of secondary waste.

There are five plants currently melting contaminated metals on an industrial scale. For steel products, if the cobalt-60 contamination is too high, it is considered necessary that such material should be recycled within the nuclear industry. For non-ferrous metals that mostly carry a different nuclide vector, the use of melting should enable this material to be freely released in many cases. Only a brief overview of new developments in this area has been given, but it can be seen that a new industry for minimising the quantity of active metallic waste is being established. This also convincingly demonstrates that significant quantities of metal can either be released for unrestricted use or released for reuse in the nuclear industry.

As can be expected from such a range of projects, a diverse range of waste arisings have to be managed. This has led to a wide variety of methods for dealing with wastes and these are described in the report. However, the most important factors that have to be considered and satisfied are the national regulatory requirements.

The actual radiation doses received by the workforce are in general lower than those calculated when assessing the work. Of particular interest is the work carried out to improve the physical comfort when working in a ventilated suit. A system has been developed that provides both breathing and cooling air. Included are breath activated devices to increase air supply, special air to refresh the operator's face and removal of condensation.

Decommissioning Costs

Cost data from 12 projects has been used to establish a basis for the comparison of costs. From this comparison it has been possible to gain a better understanding of the costs in decommissioning projects. The analysis technique employed cannot be used to predict decommissioning costs for a particular project.

Another important observation made is that a standardized listing of cost items or estimating methodology does not exist for decommissioning projects. Such standardization would not only make cost comparisons possible, but would in addition provide a sound tool for project cost management. A proposal has been made for the listing of cost items and cost groups, that can be used as a standardized framework. A number of projects within the programme have remodelled their cost management structure on the proposed basis. In addition, with the agreement of the Liaison Committee, the standard list of costings is being considered for use by the EC and the IAEA in their respective studies on decommissioning costs.

With the small number of projects involved in this study, there was not a significant basis from which to extrapolate conclusions. Recently the decision was made to restart the study, taking into account information from the larger number of projects now participating in the Co-operative Programme.

Decontamination

A study of the state of the art of decontamination techniques to be used in connection with decommissioning has been undertaken. Decontamination is frequently required in a decommissioning project in order to:

- reduce radiation exposure to the operating staff;
- salvage equipment and materials for possible reuse;
- reduce the volume of equipment and materials requiring disposal in licensed burial facilities;
- restore the site and facility, or parts thereof, to an unrestricted use condition;
- remove loose radioactive contaminants and fix the remaining contamination in place, in preparation for protective storage or permanent disposal work activities; and
- reduce the magnitude of the residual radioactive source in a protective storage mode for public health and safety reasons or reduce the protective storage period.

A number of physical, electro-chemical and chemical processes have been identified that are relevant to decommissioning and the characteristics of each method have been considered. The studies are continuing to enable guidelines to be produced for the selection for any particular application.

Recycling and Reuse

A Task Group was established to examine the means for maximising the recovery of valuable materials, together with minimising wastes for disposal arising from decommissioning operations. The study has been completed with regard to metallic wastes and is to be continued looking at non-metallic wastes.

It has been concluded that, after treatment, significant quantities of waste generated from decommissioning can be recycled and reused. Indeed, recycle and reuse options provide a cost effective solution to the management of waste arisings. The most significant impediment to the use of recycle and reuse is the absence of consistent release standards within the nuclear industry. Several international organisations have proposed standards with the object of agreeing to an internationally accepted set of release levels. However, these proposals do not always address the needs of the decommissioning community, and possibly hinder efforts to recover valuable scrap for reuse.

In order to avoid the possibility of a duplicity of standards, the international community should be encouraged to better co-ordinate the efforts in this area. Also the data obtained to date is believed to provide an adequate basis from which both unconditional and conditional releases standards could be derived.

The Future of the Programme

The Programme to date has been successful in its exchange of technical knowledge and experience in decommissioning. This is in no doubt indicated by the continued and growing support for such a voluntary group. However, during the last five-year period, the emphasis within the Programme changed, moving away from the exchange of knowledge and experience derived predominately from research and development activities in support of decommissioning, together with the decommissioning of prototype facilities, to the consideration of the "industrialisation" of the decommissioning process. This change has been necessary following the recognition that, with the nuclear industry now maturing, commercial scale facilities are being closed and decommissioning started. Thus there has been a need to prove the methodology and processes to be used by decommissioning contractors for safe, reliable and economic performance.

During the last five years, a number of projects for the decommissioning of commercial facilities – power generation, fuel and reprocessing plants – have joined the Programme. The "industrialisation" process will continue, based on experience and technical information primarily gained from these projects, together with others who will possibly join. Whilst this is seen to be of prime importance, the exchange of information on decommissioning methods and techniques will continue, where this is seen to be of benefit in providing practical and economic solutions to problems.

In addition to the above, greater emphasis is to be placed on the dissemination of the knowledge and experience gained to a wider audience. This will be to serve two objectives:

- to make the wider decommissioning community aware of the experience and knowledge available, helping to ensure that best internationally accepted practices are employed
- to bring to the attention of decision makers, who affect the regulatory climate in which decommissioning projects are undertaken, the knowledge and practical experience gained and to ensure that this is taken into account in the formation of any regulations or standards both national and international.

It is intended that more active participation in workshops, symposia, conferences and papers for technical journals will be used as the forum for the promulgation of the knowledge and experience gained by the senior managers responsible for decommissioning projects within the Co-operative Programme. In addition to the above, and in order to further help decision makers and regulatory bodies concerned with decommissioning, members of the Liaison Committee are to use both their personal and their collective influence in the promulgation of the experience and technical knowledge gained within the Co-operative Programme.

Two of the current Task Groups – Decommissioning Costs, Recycling and Reuse of Materials arising from decommissioning – will, together with other groups, continue to consider particular issues where benefit is seen in the commitment of the necessary resources.

INTRODUCTION

The continued interest in decommissioning of nuclear facilities resulted in the renewal for a further five-year period of the successful OECD/NEA Co-Operative Programme on Decommissioning in 1990. This report is produced following the successful completion of this second five-year period, giving the results and conclusions resulting from the programme to date. The conclusions drawn made it evident that the Programme should be renewed for a further five-year period, with a slight change in direction.

The Programme has continued to grow in size and importance, with the number of countries and decommissioning projects increasing significantly over the period (from 19 decommissioning projects from 8 countries to the present number of 30 projects from 12 countries). Since membership is voluntary, continued growth is the best proof of the successful nature of the programme. Indeed, the Programme is the only international forum for such an exchange of data and experience between the countries and projects involving such a wide range of countries.

This exchange of technical information and experience is of value in ensuring that safe, economic and the best environmental options are employed. For some members, who have less experience in this area, the benefit in not having to go through an expensive learning and development programme is invaluable. Of particular importance in this period is not just the increase in membership and projects from OECD countries, but the recent inclusion of non-OECD countries and the active participation of the EC and other international organisations such as the IAEA and UNIPEDE. The fact that this has happened and has been agreed is the recognition of the increasing importance of decommissioning for the future success of the nuclear industry. In addition, it has been recognised that activities undertaken in other countries could have a serious effect on the public acceptability of nuclear power generation. Therefore, being able to demonstrate that the best internationally accepted experience and practices are to be employed in decommissioning, and thus ensuring that safe, environmentally friendly and cost effective solutions are employed, is to be seen as essential.

The first five-year Programme concentrated on the development of ideas and techniques to enable decommissioning to be carried out meeting the respective national regulatory requirements. This led to an exchange of views and ideas on the way forward in decommissioning, to ensure that not only the activities could be undertaken in a safe manner, but to demonstrate this also to others, not just those in the nuclear industry.

This success led to the definition of objectives for this second five-year Programme with the main emphasis set on the "industrialisation" of the decommissioning process. As such, the ideas and experience from the first five-year Programme were used in the decommissioning of large industrial type nuclear facilities. Moreover, to a certain extent, the Programme has moved away from the expensive and time consuming development of new techniques, except in a limited number of areas, where this is still necessary to solve particular problems or to ensure cost effective and practical solutions.

In addition to its regular review of the progress and status of projects, the Technical Advisory Group, which is the principal body where the exchange of experience and ideas takes place, has undertaken a number of detailed studies on particular topics seen as important to members of both the Liaison Committee and the Technical Advisory Group. Since the effort required to undertake detailed studies is not inconsiderable, and in many cases requires knowledge and experience from a wider group of experts than that directly available from within the Liaison Committee and Technical Advisory Group members, a number of Task Groups were set up. These studies include: Decommissioning Costs, Decontamination and Recycling and Re-use of Scrap Metals. Each Task Group has clear objectives. A Chairman and Technical Secretary are appointed. Whilst additional membership was in some cases from existing members of the Liaison Committee and Technical Advisory Group, other recognised experts were also invited to participate. All these studies have collected and analysed data from the large number of participating projects with the results and conclusions published in reports. This further enables a second objective to be met for the promulgation of best practice to a wider audience.

This five-year report on the activities undertaken by the Liaison Committee, the Technical Advisory Group and the various Task Groups, gives the results to date of a very active exchange of information on experience and technical knowledge in practical decommissioning projects, together with the results and conclusions from the studies carried out. This report is all the more important, since it draws on the experience of senior managers and engineers, responsible and directly involved in the successful management of a wide range of decommissioning projects throughout the OECD Member countries.

Chapter 1

THE PROGRAMME AND ITS EVOLUTION

The Co-operative Programme for the Exchange of Scientific and Technical Information Concerning Nuclear Installation Decommissioning is carried out under the supervision of the Nuclear Energy Agency of the OECD. It was set up within the framework of an agreement between a number of organisations operating, planning or with future plans regarding decommissioning of nuclear facilities. The parties to the Agreement include also organisations whose interest in decommissioning is of a more general nature, such as the International Atomic Energy Agency (IAEA), the European Commission (EC) and the International Union of Producers and Distributors of Electrical Energy (UNIPEDE). The countries and organisations participating in the Co-operative Programme are listed below

Countries and Organisations Participating in the Programme

Belgium	• Belgoprocess • Studiecentrum voor Kernenergie/Centre d'étude de l'énergie nucléaire
Canada	• Atomic Energy of Canada Limited/Énergie atomique du Canada limitée
Germany	• Kernkraftwerk Lingen GmbH • Forschungszentrum Karlsruhe (FzK) GmbH • Energiewerke Nord GmbH • Wiederaufarbeitungsanlage Karlsruhe (WAK) GmbH • Arbeitsgemeinschaft Versuchsreaktor (AVR) GmbH
France	• Commissariat à l'énergie atomique • Électricité de France
Italy	• Ente Nazionale per l'Energia Elettrica • Comitato Nazionale per la Ricerca e per lo Sviluppo dell'Energia Nucleare e delle Energie Alternative
Japan	• Japan Atomic Energy Research Institute
Republic of Korea	• Korea Atomic Energy Research Institute (Observer)
Slovak Republic	• Slovenske Energeticke Podniky
Spain	• Centro de Investigaciones Energeticas Medioambientales y Tecnologicas • Empresa Nacional de Residuos Radioactivos SA
Sweden	• Svensk Kärnbränslehantering AB
United Kingdom	• United Kingdom Atomic Energy Authority • Nuclear Electric PLC • British Nuclear Fuels PLC • AEA Technology
United States	• Department of Energy • Public Service Company of Colorado
International Organisations	• European Commission • International Atomic Energy Agency (Observer) – UNIPEDE (Observer)

Note: The organisations listed above are those with projects in the Programme or those associated as observers. In addition, there are a number of organisations who contribute to the Programme by assigning specialists to the various task groups.

The basic scope of the Co-operative Programme is the exchange of scientific and technical information between decommissioning projects. This includes project descriptions and plans, results of research and development work, technical data and experiences collected in the execution of the project plans as well as the lessons learnt from such execution. The scope of the agreement covers also site visits to the various projects for observing the operations in progress.

Participation in the Co-operative Programme is at two levels. Participants without a current project as well as some of the international bodies mentioned above are observers, who give and receive general and overview information on programmes, plans and projects. Participants with operational projects as well as the EC are full members, who participate in-depth with exchange of detailed information and data.

The Programme reports regularly to the OECD Steering Committee for Nuclear Energy through the NEA Radioactive Waste Management Committee.

The Co-operative Programme is implemented by two groups: a governing body and a technical group. The governing body, called the Liaison Committee, comprises representatives of all participants, including the observers. It is responsible for the general conduct and orientation of the Programme, including direction and supervision of the work programme, establishment of criteria for dissemination of the information exchange or generated within the Programme, approval of changes of membership, etc. The secretariat of the Liaison Committee is ensured directly by the NEA Secretariat.

The central forum for the exchange of information is the Technical Advisory Group, which meets twice a year, generally at the site of a participating project. It is composed of technical managers and other senior specialists from the projects. As the Programme Agreement contains provisions and conditions protecting the information exchanged by restricting its use and release, discussions at the Technical Advisory Group are free and open.

A Programme Co-ordinator has been appointed in order to ensure the smooth operation of the arrangements and procedures of the Programme. During the first ten years of the Programme, Sweden has provided the services of the Programme Co-ordinator, who acts as the Secretary of the Technical Advisory Group and as the co-ordinating link between the Technical Advisory Group and the Liaison Committee, as well as with the NEA Secretariat. This is to continue, but with the recognition that additional resources are needed to assist the Programme Co-ordinator play a much expanded role.

During the ten years since the start of the Co-operative Programme, the number of participating projects has increased from 10 to 30. So the Technical Advisory Group had to develop operative procedures to cope with the work load, which has increased due to certain other reasons as well. Some of these procedures are described below:

- Projects have been grouped into 4 categories:
  - Category 1 Projects being worked on actively
  - Category 2 Projects with less intensive ongoing work
  - Category 3 Dormant projects (in Stage 1 or Stage 2)
  - Category 4 Projects which have achieved Stage 3.

  At meetings of the Technical Advisory Group, projects of the first category are given a higher priority than those of the second and so on. In addition, before each meeting, project rapporteurs are requested to announce in advance their wishes regarding required reporting time.

It is important to note that this categorisation is only for facilitating the internal work in the Technical Advisory Group. It changes with time and does not in any way reflect the significance of any project.

- To cope with the diverse types of information produced and reported by the projects, they are encouraged to report their technical progress under the following headings:
  - Overall progress of the project, including:
    - Highlights during the reporting period
    - Comparison between achievement and time schedule
    - Future programme
  - Progress in technical areas:
    - Activity assessment
    - Decontamination
    - Cutting techniques
    - Remote operation
    - Radioactive waste management
    - Health and safety
  - Organisational aspects, such as:
    - Project management
    - Quality assurance
    - Regulatory aspects
    - Public relations
  - Costs
    - Comparison between actual and estimated costs
  - Other matters.

- It was apparent, after the first few meetings of the Technical Advisory Group, that there were a number of specific issues of general interest that required in depth concentrated analyses for which the Technical Advisory Group was not the most suitable forum. This was both due to the proposed time limit for the Technical Advisory Group meetings and to the fact that such issues required the work of specialists. Special groups (Task Groups) were therefore established for making such studies/analyses. Task Groups have worked in the following areas:
  - *Decommissioning costs.* A first study was made in 1989-91. A renewed survey and study has just been started.
  - *Recycling and reuse* of scrap metals.
  - *Decontamination* in connection with decommissioning.

The Co-operative Programme has, over its ten years, evolved in certain other aspects as well. It has opened its doors to selected projects and participants from outside the OECD, partly because it is recognised that nuclear decommissioning, irrespective of where it takes place, should be carried out in an internationally accepted, safe and satisfactory manner and that projects outside the organisation can benefit from the discussions and peer reviews of the type that take place at Technical Advisory Group meetings. Another development worthy of note is that the Programme has started expressing its collective views on issues of central significance for decommissioning, such as the management of contaminated materials.

As mentioned earlier, the Programme has grown from covering ten projects to 30 projects over its 10 years of life. To put this figure into perspective, it should be noted that there are a large number of decommissioning projects being executed outside the Co-operative Programme, many of these by participants in the Programme. In addition, it should also be noted that there are about 210 nuclear ships, mostly submarines, in various stages of decommissioning. This figure can be expected to reach 300 by the end of the century.

Chapter 2

PROJECTS IN THE CO-OPERATIVE PROGRAMME

The Co-operative Programme covers a wide variety of decommissioning projects, ranging from experimental or demonstration reactors, such as Shippingport, BR3-PWR, Windscale Advanced Gas Cooled Reactor (WAGR), Mehrzwecksforschungsreaktor (MZFR), Japan Power Demonstration Reactor (JPDR) etc., to commercial-scale nuclear power plants such as Lingen (KWL), Garigliano, Greifswald (EWN), Vandellos 1 and Fort St. Vrain, to fuel reprocessing plants such as Eurochemic, AT-1, B204, West Valley, WAK, etc. This chapter gives a general overview of the projects in the Programme.

The full list of the projects in the Programme is shown in the Table on the following pages. Of the 30 projects listed, 11 projects have been completed. Of these six have been decommissioned to Stage 3, while the other five are in a dormant state (Stage 1 or a variant thereof or Stage 2).

A perusal of the list of projects shows that:

- the Programme covers 20 reactors, seven reprocessing plants, two fuel material plants and one isotope handling facility,
- the reactors represent a wide selection of types such as BWR, PWR, PHWR, gas-cooled/ D_2O moderated, water-cooled/D_2O-moderated, GCR, AGR, VVER and HTGR,
- 19 of the 30 are to be, or have been decommissioned to Stage 3, namely total dismantling.

Some of the projects are executed as fixed price contracts. Others are being carried out by in-house staff. Yet others are managed in-house, but use a number of sub-contractors.

Many of the earlier projects in the Programme had to do with experimental or prototype plants. The projects which have joined the Programme at a later date have, for understandable reasons, concerned plants of a more standardized and commercial character. Even so, there are still significant differences that can be seen in the planning and execution of decommissioning projects. Apart from the differences that can be expected due to the variation in type of plant, the organisational, economic, regulatory and other circumstances prevailing at each site can strongly influence the decommissioning projects.

The background, status and characteristics of each project are described in Annex I. For the sake of completeness all projects in the Programme, including completed and dormant ones, are covered by this report. However, the descriptions of the project activities are mainly concentrated on those that took place during the second five-year period, *i.e.*, 1990-95.

Projects in the Co-operative Programme

Facility	Type	Operation	Decommissioning	Power or throughput	Project time-scale	Cost estimate	Entry into Programme	Remarks
1. Eurochemic Reprocessing Plant, Dessel, Belgium	Reprocessing of fuel	1966-74	Stage 3	300 kg/d	1989-2004	MBEF 5750 (1987)	1988	Execution by in-house staff
2. BR-3, Mol, Belgium	PWR	1962-87	Stage 3 (partial)	41 MWt	1989-2010	—	1988	EC pilot project
3. Gentilly-1, Canada	Heavy-water moderated/ boiling light-water-cooled prototype	1967-82	Variant of Stage 1	250 MWe	1984-1986	MCAD 25 (1986)	1985	In dormancy
4. NPD, Canada	PHWR CANDU prototype	1967-87	Variant of Stage 1	25 MWe	1987-1988	MCAD 25.3	1988	In dormancy
5. Tunney's Pasture Facility, Ottawa, Canada	Isotope handling facility	1952-83	Stage 3	—	1990-1994	MCAD 13 (1991)	1990	Stage 3 achieved
6. Rapsodie, Cadarache, France	Experimental sodium-cooled fast-breeder reactor	1967-82	Stage 2	20 MWt	1983-1994	MFRF 131.7 (1989)	1985	In dormancy
7. G2/G3, Marcoule, France	GCR, Electricity and nuclear materials production	1958-80	Stage 2	250 MWt each	1982-1993	MFRF 150 (1990)	1985	Stage 2 achieved
8. AT-1, La Hague, France	Pilot reprocessing plant for FBR	1969-79	Stage 3	2 kg/d	1982-1998	MFRF 220 (1989)	1985	Stage 3 achieved, EC pilot project
9. EL4, France	Gas-cooled/heavy-water-moderated	1966-85	Stage 2	70 MWe	1989-1999	MFRF 550 (1995)	1993	-
10. Building 211, Marcoule, France	Reprocessing workshop	1963-94	Stage 3	5 t/a	1995-2010	MFRF 1000 (1994)	1993	Including shutdown operations
11. KKN, Niederaichbach, Germany	Gas-cooled/heavy-water moderated	1972-74	Stage 3	106 MWe	-1994	MDEM 190	1985	Fixed -price contract, Stage 3 achieved
12. MZFR, Karlsruhe, Germany	PHWR	1965-84	Stage 3	50 MWe	1984-2001	MDEM 370	1989	—
13. KWL, Lingen, Germany	BWR (with superheater)	1968-77	Stage 1	520 MWt	1985-1988	—	1985	In dormancy
14. Greifswald Decommissioning project, Germany	VVER	1973-90	Stage 3	8 × 440 MWe	—	—	1992	—
15. HDR, Germany	BWR, nuclear superheat	1969-71	Stage 3	—	—	—	1993	—

16. WAK, Germany	Prototype reprocessing plant	1971-90	Stage 3	—	—	—	1993	—
17. AVR, Germany	Pebble bed HTGR	1967-88	Stage 1	15 MWe	—	—	1994	Stage 3 being planned
18. Garigliano, Italy	BWR (dual cycle)	1964-78	Stage 1 for main containment	160 MWe	1985-1995	MITL 65 000	1985	—
19. JPDR, Tokai, Japan	BWR	1963-76	Stage 3	90 MWt	1986-1996	MJPY 22 500	1985	1981-1986 R&D Stage 3 achieved
20. JRTF, Tokai, Japan	Reprocessing test facility	1968-70	Stage 3	—	1991-2004	MJPY 8 600	1991	—
21. Bohunice A1 project, Slovak Republic	Gas-cooled, heavy-water-moderated	1972-79	Stage 1	150 MWe	—	—	1992	Decommissioning after fuel accident
22. Vandellos 1, Spain	GCR	1972-89	Stage 2	500 MWe	1992-2000	MESP 10 000	1993	—
23. WAGR, Sellafield, United Kingdom	AGR	1962-81	Stage 3	100 MWt	1983-1998	MGBP 58	1985	EC Pilot project
24. BNFL, Co-precipitation Plant, Sellafield, United Kingdom	Production of mixed plutonium and UO_2 fuel	1969-76	Stage 3	50 kg/d	1986-1990	KGBP 2 245 (1990)	1987	Stage 3 achieved
25. BNFL B204 Primary Separation Plant, Sellafield, United Kingdom	Reprocessing facility	1952-73	Stage 2	metal = 500 t/a oxide = 140 t/a	1990-2010	MGBP 90	1990	—
26. Shippingport, United States	PWR	1957-82	Stage 3	72 MWe	1985-1989	MUSD 91.3 (1990)	1985	Fixed -price contract Stage 3 achieved
27. West Valley Demonstration Project, United States	Reprocessing plant for LWR fuel	1966-72	Stage 3	100 t/a	1982-2024	MUSD 1 400	1986	—
28. EBWR, United States	BWR	1956-67	Stage 3	100 MWt	1986-1996	MUSD 19.4	1990	—
29. Fort St Vrain, United States	HTGR	1976-89	Stage 3	330 MWe	1972-1995	MUSD 174	1993	Fixed -price contract
30. FEMP, United States	Hexafluoride reduction plant	1954-56	Stage 3	—	—	—	1993	—

Notes: 1. The decommissioning options are defined according to the IAEA Classification

2. The cost data given in this table are not directly comparable owing to the fact that they refer to plants of different types, sizes and characteristics, to different decommissioning stages and to different time schedules for the execution of the projects.

Chapter 3

PROGRESS IN SELECTED AREAS

The projects in the Co-operative Programme have a broad spectrum of characteristics and cover various types of reactors as well as reprocessing plants. The type of information produced in the various projects differ widely due to this and also because of the different prevailing circumstances and needs at the various sites. In this chapter project experiences with certain technologies are described. The following areas are treated:

- assessment of activity inventories;
- cutting techniques;
- remote operation;
- decontamination;
- melting
- radioactive waste management;
- health and safety.

As in the previous chapter, the progress described covers the entire ten-year period of the Programme, but focuses specially on the technological work and developments during the last five years (1990-95).

Here below are the salient points of the reporting in the various areas. A detailed project-by-project analysis is given in Annex II.

Assessment of Activity Inventories

Activity inventories are needed for decommissioning planning, waste categorisation, waste transportation and safety assessments. Indeed, estimates of inventories are generally a required chapter of the application document to be submitted to the licensing authorities for decommissioning.

There have been reports from nine projects: seven reactors and two fuel facilities. The reported total activity for the reactor plants were in the normal range of 10^{16}-10^{17} Bq. Where measurements had been made to check calculations, there seemed to be reasonable agreement. Two projects reported unexpected results in connection with activity measurements in concrete:

- Core samples taken in the anti-missile slabs over the BR3 reactor at a distance of almost 10 m from the reactor core showed activation levels of about 20 Bq/g in concrete and 120 Bq/g in rebars. This was specially surprising because measurements at 15 cm from the inner surface of the bio-shield, 2 m below core midplane, revealed practically no activation. A study has been started on a long range activation model and the possibility of neutron streaming to explain these contradictory results.

- In the WAGR bio-shield concrete, there was evidence that tritium (from trace lithium) had migrated through the concrete due to temperature and concentration gradients. Preliminary results of modelling to fit the measured values indicate two physical processes:
  - movement of tritium through interlocking pore water,
  - exchange of tritium in the water of hydration.

However, the total effect of the migration of tritium on waste categorisation is small compared with its decay process. The intermediate-level-waste layer at the inner face of the bio-shield is expected to decay to low-level-waste levels by about the year 2020.

Cutting Techniques

Many cutting techniques have been demonstrated and utilised both on metals and concrete in the various participating projects. Among the methods used on metals have been:

- oxy-arc and plasma-arc cutting,
- electro-discharge machining (EDM),
- mechanical methods like circular saws, band saws, reciprocating saws, diamond blade saws, disc cutters, hydraulic shears, grinders, milling, nibblers, etc.,
- arc saws,
- abrasive water jet cutting.

Methods for cutting concrete have included:

- diamond sawing and coring,
- controlled blasting,
- hydraulic splitting tools,
- diamond wire sawing,
- abrasive water jet cutting.

Some of the more significant work in this area is described below:

- Within the BR3 decommissioning project, a comparison was made between mechanical sawing using a milling cutter, electro-discharge machining and plasma arc torch cutting (in a flooded chamber). The 76-mm thick stainless steel thermal shield was used as the test object. Prior to cutting the active thermal shield, the techniques were tested on a mock-up, in order to optimise the parameters and to train the operators.

  Analysis of the results of the comparison showed that:
  - all three methods tried have very low effective cutting speeds: less than 1 m of 76-mm thick stainless steel cut during an 8-h shift,
  - the conditioned volume of the secondary waste is a factor 20 to 60 times the volume of metal removed from the kerf,
  - for the same length of cut, mechanical sawing produces only one fifth of the volume of secondary waste from each of the other two techniques tested.

  The above implied that development/optimisation work needs to be done both to increase the cutting speed and reduce the volume of the secondary waste.

- Work has been going on, within the project to decommission the B204 Primary Separation Plant, on cutting of metals and concrete without the use of lubricants or coolants, this in order to avoid the production of secondary liquid radioactive waste. Initial work with steel and tungsten-carbide discs without lubricants proved to be unsuccessful, but the results of tests on milling without a coolant for cutting steel and composites have been promising. Dry milling saws are also being tested.

- A new hydraulically controlled diamond blade saw has been ordered and successfully tested in the Eurochemic decommissioning project. The machine is currently used for the dry cutting of cast-iron shielding blocks resulting from decommissioning work in the main process building. It can also be equipped with other diamond blades for wet and dry cutting of concrete structures.

- The 4.4-m thick head of the Fort St. Vrain prestressed concrete pressure vessel (PCRV) was removed after being segmented with a diamond wire saw. Five horizontal core bore holes were drilled to form a network of intersecting holes for threading the diamond wire saw at an elevation just above the PCRV top head liner. The diamond wire saw was threaded through the holes to make a horizontal cut just above the liner. Twelve vertical holes were drilled to make radial vertical cuts dividing the top head into pie-wedge sections. Totally about 820 m^2 of concrete was cut with the diamond wire saw technique, resulting in the removal of 1 320 t of concrete.

Remote Operation

As during the first five-year-period of the Co-operative Programme, there has been only limited use of robotic or autonomous machines for remote operation to safely and cost effectively dismantle and treat items of high specific radioactivity. Emphasis has been more on automation to allow remotely controlled operations with minimum operator intervention manually. Some of the more significant experiences are described below:

- The AT-1 project used the ATENA dismantling machine to dismantle the blind cells of the pilot reprocessing plant. It travelled above the containment and introduced its 6 m long manipulator arm through openings in the various cells. A light weight remote controlled carrier on a rail was also used in the later stages of the project for certain blasting operations and making release measurements.

  The use of ATENA is estimated to have saved time and exposure in comparison to a manual dismantling of the plant, but has been relatively expensive. The cost of such a machine should, under ideal circumstances, be amortised over several projects, but its design is normally very project specific, making it difficult to reuse it elsewhere. Decontamination to allow manual dismantling may be an alternative to such machines.

- The most challenging phase of the decommissioning of the KKN Niederaichbach power plant was the remote dismantling of the core region of the pressure tube reactor, *i.e.*, the upper and lower neutron shields, the 351 pressure tubes, the moderator tank and the thermal shield. A remotely controlled manipulator, placed centrally over the vertically oriented reactor structure, was used. The manipulator used a variety of tools, including grinders, drills, milling disks, plasma torches, ring saws and vacuum heads. The experience with the remote manipulator was generally good. Comparison between remotely controlled and manual dismantling showed that the former took about eight times as long as manual disassembly. The machine was specially built for the project and could not be used again on another decommissioning project.

- The B204 Primary Separation Plant decommissioning project has been utilising a BNFL strategy seeking to achieve an acceptable and cost effective mix of men and machines. The CODRO concept (Contact Deployment Remote Operation) envisages the dismantling equipment being erected and maintained manually, but operated by remote control. The project also uses proprietary remote manipulators and deployment systems but customised for nuclear applications. This approach has proved to be cost effective in solving project specific problems.

- A remote controlled electro-hydraulic powered robot, type Brokk 80, has been used by several projects to cut and decontaminate concrete. In the Eurochemic decommissioning project it was fitted with a modified floor scabbler. A later Belgoprocess in-house development was a three-headed and yet later a four-headed scabbler. The latter could be used for decontaminating floor, ceilings and walls. However, vibration and other technical problems led Belgoprocess to a "shaving" technique with a diamond tipped rotary head.

Decontamination

Both concrete and metallic surfaces have been decontaminated in the various projects.

Concrete Surfaces

Apart from scabbling, many other techniques have been used . These are commercially available for the most part, like shot blasting, sand blasting, needle guns. In addition a micro-wave technique was tried out in the JPDR project, where it was found that it was not applicable on aged concrete with low water content. A laser beam technique is being tested on the JRTF project.

The major demonstration for concrete decontamination on a fairly large scale has been of the "shaving" techniques. This uses a diamond tipped rotary cutting head which can also cut through embedded bolts and other metal objects. It has been used on the Eurochemic project, where 400 m^2 of surface were decontaminated. Compared with scabbling, it proved to be over three times as fast, produced only half the secondary waste (for the same decontamination efficiency) and was less tiring for the operator.

Metal Surfaces

Most decontamination of metallic surfaces in the projects have been for dose reduction during subsequent dismantling or for waste recategorisation (from medium-level waste to low-level waste). There has also been some decontamination to achieve free release conditions. Some examples of all these different types of decontamination are given below:

- The SIEMENS/KWU CORD method was used on three projects:

  A full system decontamination (of the reactor primary loop) was performed in the BR3, using the primary pumps and other plant equipment. An average decontamination factor of 10 was achieved after three cycles. The secondary waste in the form of ion exchange resin had a volume of 1.3 m^3.

  Another application of CORD was on the MZFR. Here a number of systems were decontaminated using a mobile facility, AMDA. The aim was to bring as much material as possible under 200 Bq/g. Such material could then be recycled by melting for reuse within the nuclear industry instead of being treated as radioactive waste. Seven cycles of CORD were applied, with a total average decontamination factor of 20.

A steam generator at the Rheinsberg reactor was also decontaminated using the CORD process.

- Comparative tests were made at Belgoprocess on dry and wet abrasive blasting techniques with a view to decontaminate metallic components to clearance levels. Some 32 t of contaminated profiles and plates were used for testing the dry process and 3 t of similar material for the wet. The results showed that the dry process was cheaper and produced less secondary waste. A industrial scale dry abrasive blasting plant will be constructed at Belgoprocess.

Melting

The Co-operative Programme today includes 30 projects from 12 countries and thus in total represent the largest producers of nuclear "recyclable" waste (*i.e.*, excluding fuel and operational waste). A large part of this waste is metallic. Melting has been identified as one of the most important technologies that can make possible the recycling of contaminated metals, thereby significantly reducing the quantity of waste that has to be disposed of underground.

There are five plants currently melting contaminated metals on an industrial scale. These are:

- Carla Plant, Siempelkamp Giesserei, Krefeld, Germany
- Studsvik Melting Facility, Studsvik, Sweden
- INFANTE Plant, CEA, Marcoule, France
- SEG Plant, Oak Ridge, USA
- BNFL Capenhurst Plant, Capenhurst, United Kingdom.

The company MSC has constructed a facility at Oak Ridge, USA. It is jointly owned by BNFL Inc, USA and MSC. In addition extensive tests on melting contaminated metals have been done on a small melting furnace at JAERI, Japan.

The similarities of and the differences between these plants are discussed briefly below:

Background

Siempelkamp is a long established metal melting company which has added the melting of radioactivity contaminated metals to their other melting activities, while the other companies are basically nuclear research and engineering companies that have increased the scope of their waste management activities to include melting.

Operations

Three of the companies (Siempelkamp, CEA and SEG) are concentrating mainly on recycling material within the nuclear industry, *i.e.*, making or planning to make products like shielding blocks, waste containers, etc. Recycling material within the nuclear industry is considered necessary for steel products, as cobalt 60 cannot be removed by melting. For non-ferrous metals (aluminium, copper), which mostly carry a different nuclide vector, a free release will be easier. Therefore, it can be expected that in the future more material will be released freely. Studsvik, has the declared aim of achieving the release of metals for unrestricted use by a combination of melting and subsequent storage for a reasonable period of time. BNFL Capenhurst is recycling aluminium for unrestricted reuse.

Furnace Types

INFANTE is an electric arc melting furnace. Studsvik has an induction furnace for steel and a small electric arc furnace for aluminium. Carla and SEG are induction furnaces.

Metals Treated

BNFL Capenhurst has been treating aluminium. All the other plants melt carbon and stainless steels. In addition:

– Carla	treats aluminium and copper, melting of lead is in the R&D phase
– Studsvik	treats aluminium
– SEG	treats aluminium and is planning to melt copper and titanium.

Charge Size

– Carla	3.2 t
– Studsvik	3 t
– INFANTE	12 t
– SEG	20 t

Products

– Carla	Ingots, shielding blocks and waste containers
– Studsvik	Ingots
– INFANTE	Ingots, shielding blocks and waste containers
– SEG	Ingots and shielding blocks at present. Waste containers and reinforcing steel in the future

Radiological Limitations

– Carla	Maximum 200 Bq/g beta-gamma nuclides Maximum 100 Bq/g alpha nuclides Separate limits for uranium
– Studsvik	No specified limits
– INFANTE	Maximum 250 Bq/g cobalt 60 Other limits for other nuclides
– SEG	Normally < 2 mSv/h Greater dose rates with prior review/approval

Tonnage Melted up to September 1994

– Carla (start Oct. 1989)	7000 t total	6800 t recycled in nuclear industry 50 t released freely
– Studsvik (start 1987)	1500 t total	230 t released freely Rest being stored for decay A minor quantity has been melted for volume reduction and will be sent to the final repository
– INFANTE (start April 1992)	3600 t total	
– SEG (start Sept. 1992)	2000 t total	Recycling in nuclear industry
– BNFL Capenhurst (Start 1995)		No data available

The above brief overview sketches the remarkably quick development of a new industry where established techniques are being utilised for minimising the quantity of active metallic waste. It also demonstrates convincingly that very significant quantities of metal can either be recycled within the nuclear industry or released for recycling without radiological restrictions.

Radioactive Waste Management

As can be expected from a programme involving such a wide variety of types of plants, the radioactive wastes arising and the ways in which they are managed are equally diverse. The specific problems of the various projects and their proposed solutions are described in Annex II. Here below are some aspects of interest:

- About 100 t of the Niederaichbach reactor structure are below 200 Bq/g. This material will be melted at Siempelkamp AG for recycling in the nuclear industry. The remaining 400 t of active metallic waste is sent for disposal at the KONRAD repository in containers measuring 1.7 m × 1.6 m × 1.7 m, with varying wall thicknesses for different activity levels. The available spaces inside the containers have only been filled to less than 20 per cent on an average and the load capacities only utilised to about 25 per cent. These figures reflect the need for more efficient compaction for reducing waste volumes.

- Many projects have been occupied with the conditioning of operational waste.
  - In Garigliano, solid waste is being extracted from a vault and conditioned. Facilities for conditioning ion exchange resins and sludges are being built.
  - At West Valley, the major technical interest is the conditioning of the high level liquid waste. The caesium 137 in the liquid has been removed, the liquid itself has been concentrated by evaporation and stabilised in cement resulting in over 10 000 drums of low-level waste. The sludge will be vitrified in borosilicate glass. Vitrification is due to start in 1996.
  - JRTF is treating its alpha contaminated liquid waste and its spent solvent. Treatment of the unpurified uranium solution and the high level liquid waste will take place when the treatment apparatus for the respective processes are ready during 1996 and 1997.
  - Evaporator concentrates, ion exchange resins and solid wastes from the operation of the reactors at EWN Greifswald and Rheinsberg are being conditioned and prepared for disposal at the Morsleben facility, which has an operational licence up to 30 June 2000.

- Radioactive waste management at the NPP A-1 Bohunice has been complicated by its history of the fuel accident in 1976, which shut down the plant and the later leakage of "Chrompik" (potassium bichromate) in the reactor hall. The "conventional" operational waste will be treated by various methods: compaction/incineration for soft wastes; decontamination/melting/bitumen or cement conditioning for contaminated metals, etc. For this, a radwaste treatment building is being constructed. It is proposed to vitrify the Chrompik and to fix the 50 m^3 of Dowtherm (with a specific activity of 2.5×10^{10} Bq/m^3) in bitumen.

Health and Safety

The actual radiation doses received by personnel in the projects have been less than the calculated doses. There have been exceptions, though, to this general rule.

In the Garigliano project, for instance, the final dose committed to personnel will be higher than earlier planned, in spite of the fact that the actual dose rates in the various working areas are much lower than expected. The higher total doses are mainly due to longer construction and preparatory times.

This latter aspect was noted also in the BR3 project. In the decontamination of the primary loop, the preparatory tasks accounted for 85 per cent of the collective dose, while the corresponding figure in the cutting of the thermal shield was 36 per cent.

The work carried out in cells 904 and 905 of the AT-1 plant has been analysed to take into account aspects of both radioprotection and the discomfort of working in ventilated suits. French regulations permit working a maximum of 2 h/d in ventilated suits. Against this background, preliminary findings indicate that cells with alpha contamination and an ambient dose rate of 50 μSv/h could be dismantled manually in ventilated suits. Work in cells with higher dose rates must be evaluated on a case by case basis.

Important work has been carried out in the Eurochemic decommissioning project on improving the physical comfort aspects of working in ventilated suits. Together with another institute, Belgoprocess has developed a system to provide breathing and cooling air to operators, including breath-activated devices to increase air supply, special air to refresh the operator's face and to remove condensation, etc. The new system has been tested under industrial conditions with positive results.

Chapter 4

TASK GROUP STUDIES

Report from the Decommissioning Costs Task Group

Introduction

The Liaison Committee of the Co-operative Programme established in February 1989, a Task Group on Decommissioning Costs in order to identify the reasons for the large variations in reported cost estimates for the decommissioning of nuclear facilities. Based upon agreed terms of reference the work of the Task Group proceeded as follows:

- Establish a basis for costs to be included in a decommissioning project;
- Define decommissioning tasks (cost items) and grouping of these tasks in cost groups that would be acceptable for the projects in the countries in the Co-operative Programme;
- Establish the scope and period of decommissioning (plant shutdown, Stages 1/2, dormancy and Stage 3) and create a cost matrix for the scope and cost groups;
- Fit the participating projects into a cost matrix for the cost analyses;
- Systematically analyse the raw cost data reported and refine it by a series of questionnaires for the purpose of comparison;
- Eliminate unacceptable and faulty data, perform a statistical model analysis and establish a mean value and a range for each cost group of each model (Model 1: Reactors decommissioned to Stage 3, Model 2: Reactors decommissioned to Stage 1 or 2, Model 3: Fuel Reprocessing Facilities and Model 4: All projects);
- Analyse the factors influencing the cost variations and summarise the lessons learnt during the two years the Task Group has worked on decommissioning costs.

The results of the work undertaken by the Task Group are summarised in Annex III.

Concluding Summary, Lessons Learnt

Cost data from 12 of the 14 projects was used to establish a basis of comparison to be adopted for all projects. This cost data was incorporated into a matrix of cost groups and decommissioning periods.

The cost data was progressively refined. The real project specific discrepancies were identified and analysed ensuring no resulting bias from inconsistent, or in some cases inappropriate data. The grouping of the projects into one of four models gave the opportunity for comparing projects with similar characteristics as well as decommissioning projects as a whole. In addition, other factors were reviewed including issues dealing with political/geographical, technical and economic/financial aspects influencing variations in the estimated costs. These factors were only treated qualitatively, since data could not be separated accurately to analyse their quantitative effects.

In the project specific analysis over two-thirds of the "refined" percentage costs from the projects were found to be comparable and utilised without change. Even in the remaining one-third of the percentage costs, only marginal substitutions (simulations) were made. So the total "simulated" costs in the models are generally close to the raw "refined" figures and the conclusions (ranges of cost variations) are more or less applicable to, and valid for, the raw data from the projects. However, it was observed that project specific aspects and local circumstances have a significant influence on decommissioning costs.

It is important to state that the analysis technique used is not a cost calculation model. It cannot be used to predict decommissioning costs but this technique provides a useful tool for the better understanding of costs in decommissioning projects.

Certainly, in making such comparisons of international projects, there is the potential for making errors. It was evident that the answers to any cost questionnaire must be analysed and refined by follow-up questionnaires to understand the real contents. Numbers taken at face value, without regard to their context, are easily misunderstood and misinterpreted.

Another important observation made is that there is today no standardized listing of cost items or estimating methodology established for decommissioning projects. Such a standardization would be useful not only for making cost comparisons more straightforward and meaningful, but should also provide a good tool for cost effective project management. A proposal was made for the listing of cost items and cost groups that could be used as a standardized framework. A number of projects within the Programme have remodelled their cost management structure on the proposed basis. In addition, with the agreement of the Liaison Committee, the standard list of costings is being considered for use by the EC and the IAEA in their respective studies on decommissioning costs.

It is clear that the small number of projects involved in this exercise does not provide a statistically significant sample to extrapolate conclusions. However, the value of the exercise has demonstrated the merit in continuing this type of analysis for more projects with a view to collecting sufficient basis to support the validation of worldwide decommissioning cost estimates.

Future Work

In November 1994 the Liaison Committee of the Co-operative Programme decided to re-start the work of the Task Group on Decommissioning Costs, looking this time (specifically and separately) at power reactors and fuel facilities. The study will:

- Structure/break down the costs in cost groups/cost items/cost factors, where the scope of each of these will be clearly defined;
- Compare/contrast/explain differences in the results presented in various countries/projects.

The terms of reference/programme of work for this new study were decided as follows:

- The predicted costs of the 12 projects in the 1991 study should be compared to the actual costs (or to the current predictions);
- The listing (groups/items/factors) of the 1991 study is to be compared with other lists (from current studies), and a new "standardized" listing will be prepared;
- A cost inventory covering as many of today's projects as possible will be analysed and scrutinised to identify aspects of discrepancy and the reasons for these. All the projects in the Co-operative Programme are candidates for the cost analysis. The analysis can thus include at least seven reprocessing plants and over a dozen reactors of various sizes and types, including commercially operated plants like EWN Greifswald and Vandellos;

- In addition, the results of the following major studies, that have been performed recently, will also be available with the facility owners agreement:
  - 900 MWe PWR, EDF study, France,
  - 1.000 MWe BWR, SKB study, Sweden,
  - Trawsfynydd Safestore, Nuclear Electric, United Kingdom,
  - TLG studies as from Portland General Electric Company (Trojan NPP),
  - The interest from Japanese utilities is still under investigation.

A time schedule of work for the next months has been agreed on with the aim of producing a final report by the end of 1997.

Report from the Task Group on Decontamination

Introduction

In October 1992 a Task Group on Decontamination was established in order to prepare a state-of-the-art report on decontamination in connection with decommissioning. The decontamination of both metallic and concrete surfaces has been considered. A summary of the report produced is given in Annex IV and the final report will be produced later in 1996.

This overview of decontamination techniques has the objective of describing critical elements to be considered in the selection of techniques to be used for solving a real decontamination problem.

Definition and General Considerations

Decontamination is defined as the removal of contamination from surfaces of facilities or equipment by washing, heating, chemical or electrochemical action, mechanical cleaning, or other techniques. In decommissioning programmes, the objectives of decontamination are:

- to reduce radiation exposure to personnel and the public;
- to salvage equipment and materials for possible reuse;
- to reduce the volume of equipment and materials requiring disposal in licensed burial facilities;
- to restore the site and facility, or parts thereof, to an unrestricted-use condition;
- to remove loose radioactive contaminants and fix the remaining contamination in place in preparation for protective storage or permanent disposal work activities; and
- to reduce the magnitude of the residual radioactive source in a protective storage mode for public health and safety reasons or reduce the protective storage period.

Some form of decontamination is required in any decommissioning programme regardless of the form of the end product. At a minimum, the floor, walls, and external structural surfaces within work areas should be cleaned of loose contamination, and a simple water rinsing of contaminated systems may be performed. The question will arise, however, whether to decontaminate piping systems, tanks, and components. A strong case can be made in favour of leaving fixed contamination within piping and components in a dispersed form on the internal metal surfaces rather than concentrating the radioactivity through decontamination. In most cases, decontamination is not sufficiently thorough to allow unrestricted release of the item being treated; therefore, a savings both in occupational exposure and cost could be realised by simply removing the contaminated system and its components and only performing certain packaging activities (*e.g.*, welding end caps on pipe sections). However, additional cost for the disposal of materials must be considered in this scenario.

A decontamination programme may also require a facility capable of treating secondary wastes arising from decontamination, *e.g.*, processing of chemical solutions by such means as neutralisation and precipitation, filtration, evaporation and demineralisation. The concentrated wastes represent a more significant radiation source that may have to be conditioned and shipped for burial in licensed burial facilities. As an alternative the arising wastes can be treated in a waste reduction/recycling/ reclamation processing facility. The optimal waste reduction configuration must be defined after an economic assessment of treatment versus transportation/disposal costs has been completed. Each of these additional activities can increase (1) occupational exposure rates, (2) increase the risk of a potential release of activity, and (3) the uptake of radioactive material, and could result in even higher doses than those received from removing, packaging and shipping the contaminated system without extensive decontamination. Resolution of this question depends on specific facts, such as the exposure rate to personnel from the contamination, the level of the contamination, and the effectiveness of the containing component and piping (wall thickness) in reducing work area radiation fields.

Summary

A number of processes physical, electro-chemical, chemical have been identified that are relevant to decommissioning and the characteristics of each method are discussed. Further studies still have to be completed considering evidence from a number of decontamination projects to enable guidelines to be produced suggesting the particular method to be used in any particular application.

Report from the Task Group on Recycling and Reuse

Introduction

In October 1991 a Task Group on Recycling and Reuse of wastes arising from decommissioning operations was established to examine means for maximising the recovery of valuable materials together with minimising waste arisings for disposal. The Task Group has completed its considerations with regard to contaminated metals and has prepared a summarised report on its findings in Annex V. A follow on activity to examine non-metal material, particularly concrete, is under review.

The Task Group surveyed current practices and policies that impact on the release of materials from decommissioning projects. In particular the International Commission on Radiation Protection (ICRP) has suggested that to justify particular radiological practices, potential risks and benefits beyond those strictly associated with radiological protection should be considered. Accordingly, the Task Group also evaluated the non-radiological health, environmental and socio-economic implications of recycling and reuse practices. Finally, the Task Group examined available information on the technical limitations and advantages of measurement instruments and various recycling and reuse techniques to determine feasibility and cost-effectiveness.

Conclusions

It was concluded that significant quantities of waste generated from decommissioning activities can be recycled and reused. From a survey of 25 projects considered, more than 360 000 t of material had been released under varying criteria. It is concluded that recycle and reuse alternatives can provide a cost effective solution to the management of waste arisings and involve low levels of radiological exposure. Also it is concluded that there are substantially reduced risks relative to the options relying on disposal and subsequent replacement of material.

The most significant impediment to increasing the use of recycle and reuse practices is the absence of consistent release standards within the international community. Currently, material is either released under varying criteria or on a case-by-case basis, frequently prohibiting countries from best utilising the available recycling technologies and facilities. Several international organisations have proposed standards to meet the need for a consistent, internationally accepted release standard. These proposals do not always address the needs of the decommissioning community and thus possibly hinder efforts to recover valuable scrap for reuse.

The data contained in the final report is believed to provide an adequate basis from which unconditional and conditional release standards could be developed.

Finally, the Task Group encourages the international community to avoid the questionable practice of incorporating overly conservative assumptions when developing radiological standards. Also in order to remove the duplicity of standards and the confusion this causes, the international community should be encouraged to better co-ordinate its activities in the development of the required standards for the release and reuse of decommissioning waste arisings.

Chapter 5

THE WAY FORWARD

As the second five-year Programme drew to a conclusion, consideration was given to the continuation or closure of this Co-operative Programme on Decommissioning. It was agreed by all participants that the previous ten years were of value and very successful. Further areas of co-operation were identified, that were considered to be of sufficient merit to justify the renewal of the Co-operative Progamme for another five-year period.

For decommissioning nuclear facilities, it is important that best practice is known and used by all. This message is understood and accepted by the present Programme members with the recognition of the benefit of an ongoing international forum to act as the catalyst to ensure that this happens in a cost effective way. There are still technical and project issues to be addressed that could beneficially be considered by those actively participating in their countries' decommissioning projects. In addition there is seen to be benefit in considering and understanding the different national requirements and regulatory framework under which the various participating projects work.

Whilst the countries with major civil nuclear industries are gaining significant experience from their own decommissioning programmes, other countries with decommissioning programmes at an early stage can gain significant benefit from the exchange of information and experience of others. In particular this is being seen by the growing interest shown by non-OECD countries joining or considering joining this Co-operative Programme.

The unanimous opinion expressed by the experts participating in the now concluded second five-year Programme was that this should be renewed for a further five years. In addition, some changes in the objectives of the programme, together with the manner it is managed and implemented, were proposed. These changes will assist in maximising the effectiveness of the Programme for the participants with regard to the definition of the technical/project issues to be addressed and the continuing need for the exchange of data and experience. Moreover, it is considered necessary to more effectively disseminate to a wider audience the experiences and lessons learnt within the Programme, and to be able to influence the decision makers who set the regulatory regimes under which decommissioning projects are undertaken.

Organisation

Decommissioning has grown in importance over the life of the present five-year Programme. This is the result of a number of major issues:

- Many countries now have redundant or shortly to be redundant nuclear plants/facilities.
- There is ongoing public uncertainty in the ability to decommission safely.
- In addition, in some countries, the costs of decommissioning are believed to be uncertain and unacceptably high. It is a highly politicised topic receiving much emotive discussion/review.

Thus, the present participants consider that the profile of this highly successful Programmme should be raised, not just to enable its technical programme to be undertaken, but also to enable it to discuss with other international bodies from a position of strength, arising from its significant experience and knowledge and with the support of the OECD/NEA.

The present Programme was, therefore, renewed for a further five-year period with the organisation based upon the present Liaison Committee and the Technical Advisory Group. The objectives of the Liaison Committee are expanded to include:

- Experience and information arising from the Co-operative Programme, and especially arising from the studies undertaken by Task Groups, are to be widely promulgated to external audiences.
- In order to influence the regulatory regimes relevant to decommissioning, every opportunity is to be taken to bring to the attention of senior decision makers within the nuclear industry, the information and experiences arising from the Programme.

Membership

The present membership of the present Co-operative Programme has grown considerably over the period. It is expected that this trend will continue, as decommissioning is seen to grow in importance in countries with a nuclear industry. This will be especially so with the likely growth in interest from countries with aspirations to join OECD and other non-OECD members. This will be of undoubted value to existing members as projects with new and different problems are considered by the Technical Advisory Group. In addition to this, new members will bring new views, ideas and experience, that should enable better solutions and techniques to be made available.

Technical Programme

The major task of the Technical Advisory Group will be the continued exchange and promulgation of data, experience arising from the projects represented. In addition to this, Task Groups will be set up to consider and report on particular topics:

- *Decommissioning costs* – This Task Group already exists and will continue to consider the definition and comparison of costs arising in decommissioning.
- *Recycling/Reuse* – This Task Group already exists and will continue studies on this important topic.
- *Project management* – Whilst project management techniques are well understood and known, there are particular requirements that have to be considered, when decommissioning active facilities. These issues range from how the best option for the decommissioning programme is arrived at, how risks are considered and managed, how the accepted practices of satisfying the ALARP and ALARA principles are interpreted and satisfied.
- *Working in hostile environments* – Consideration of the methodology and practices to be followed to ensure that there is protection of the workforce carrying out the decommissioning, the public and the environment.
- *Task Group on release measurements* – In order to effectively apply release standards based on specific activity or surface contamination, adequate measurement methods must be available to enable concerned parties to demonstrate or verify that material is below the established limits. The Task Group will examine primary radioactivity evaluation methods and selection criteria to determine whether state-of-the-art instrumentation is capable of meeting the requirements of the applicable standards, in the context of the large quantities of candidate material.

With the agreement of the Liaison Committee, the findings and conclusions reached will be promulgated to a wider audience by the publication of papers, presentations at conferences, and in particular cicumstances, where the topic is of wider interest, be the subject of a symposium with the invited attendance of other experts.

Conclusions

The importance attached to the continuance of the Programme is indicated by the fact that it is the participating members who have carried the costs of participation to date, and are willing to continue carrying the costs of continued membership.

In justifying the extension of the Programme for a further five years, a valuable programme of actions has been identified that will undoubtedly help to advance decommissioning technology in larger commercial type activities. This marks a departure from the present emphasis of the decommissioning of experimental/development facilities. In addition to achieving this advance in technology and practical experience, the intention is to raise the public profile of such activities to help secure the industry's future by the removal of the uncertainties presently perceived in the decommissioning arena.

Annex I

DESCRIPTIONS OF PARTICIPATING PROJECTS

1. Eurochemic Reprocessing Plant, Belgium [1]

The plant was originally owned by a 13-nation consortium but was transferred in stages to Belgian ownership after shutdown in 1975. Since 1983, it has been fully Belgian owned. The plant was decontaminated during the years 1975-79 in order to simplify (and cheapen) the safe standby conditions. The company Belgoprocess was established in 1984 to take charge of activities on the site, including the decommissioning project. The company is a subsidiary of NIRAS/ONDRAF. Since 1987, the site has been used as a central interim storage for conditioned radioactive waste. A centralised waste processing facility (CILVA) has been constructed for low-level waste conditioning including supercompaction and incineration.

The decommissioning of the Eurochemic plant is being carried out by an in-house team over a relatively long period. This has fostered purpose-oriented development work on techniques to help solve project problems. Such development work has resulted in significant advances in some areas.

Before embarking on the major project of dismantling the reprocessing plant itself, a pilot project was carried out to check techniques and costs and to train personnel. Buildings 6A and 6B – used originally for the storage of uranyl nitrate and spent solvents – were emptied, decontaminated and demolished. Metallic components were dismantled and removed for decontamination to reduce the quantity to be buried as radioactive waste. The concrete surfaces were decontaminated to such a level (background) that the demolition waste could be dumped on an industrial tip.

After the pilot project, work was started on the main process building which is 80 m long, 27 m wide and 30 m high. The concrete surface area is 55 000 m^2. There are 1 500 t of metals in the building. Some of the cells are several storeys high, the maximum height being 18 m.

The decommissioning strategy is to work from the tail end of the building to the head end. An important factor in the planning has been to reduce the standby costs as rapidly as possible. These costs include those for ventilation, water purification and the three inspections per day.

Cleanable prefilters have been installed to prefilter the exhaust air from plasma cutting of metallic components before it passes through the normal building ventilation system.

One area where development work has been concentrated has been concrete decontamination, at first with scabbling and then, when the productivity figures with scabbling were lower than expected, with shaving. This is performed with a diamond tipped rotary cutting head which gives a smooth surface, which is convenient for measurement and for painting. The head can also cut through bolts and metallic inserts. This method was first used for decontaminating floors and showed many advantages over the earlier scabbling process, such as that it is quicker, produces less secondary waste and is more comfortable for workers. The system has been further developed for use on walls and ceilings.

Another major development area has been the decontamination of metallic components to free release levels by abrasive blasting. Large scale tests have been performed with both dry and wet blasting equipment. The results have shown that the dry process is cheaper and more efficient with less secondary waste production. Compared to treating the original materials as waste (conditioning/ disposal) the dry process is less than one third as expensive per kg. It is expected that 85 per cent of the metallic structures and components can be decontaminated to clearance levels.

Yet another area of development is as a system of ventilated suits and associated equipment for worker protection in alpha contaminated areas. Final tests are in progress under industrial conditions.

The dismantling work is being carried out by four teams of five operators and four support staff. Each operator works two spells of 2 h each during each shift, in the cells to be decommissioned. About 25 per cent of the decommissioning programme for the main process building has been completed.

2. BR3 Reactor, Belgium [2]

The BR3 was the third reactor to be built in Belgium. It was a Westinghouse pressurised-water reactor with one steam generator and two main circulating pumps. It had a rated thermal power of 41 MW gross (11.7 MWe). It was used mainly to train operators of commercial plant and to test PWR fuel. During its 25-year life it had gone through many unique operations:

- replacement of reactor internals (1964-66),
- primary loop chemical decontamination (1975-76),
- reactor vessel thermal annealing (1983-84).

Its decommissioning is an EU supported project in the framework of the EU five-year RTD programme on decommissioning nuclear installations and is being carried out in a number of phases. The first phase of the project (1989-92) consisted of:

- full-system decontamination of the primary loop for dose reduction,
- the testing of three different cutting techniques on the thermal shield in the reactor vessel.

Decontamination of the primary loop was completed in April 1991. The Siemens CORD process was used in three cycles (three steps in each cycle). The three cycles took nine days to carry out and achieved a total average decontamination factor of 10 (40 in the steam generator). The decontamination resulted in 1.3 m^3 of cation and anion resin as secondary waste.

The three cutting methods tested were:

- mechanical sawing,
- electro-discharge machining (EDM),
- plasma arc cutting (in a flooded cutting chamber).

Before the tests, the refuelling pool was filled with water and the lid removed. All reactor internals except the thermal shield were lifted out for storage under water in the pool. The chamber for plasma arc cutting was installed in the refuelling pool in order to keep the debris inside the chamber, thereby keeping the pool relatively clean and reducing the exposure of the operators. The activity of the workpiece was measured to be about 3.7×10^{10} Bq/kg (1 Ci/kg) at the midplane.

Prior to cutting of the active thermal shield, mechanical sawing, EDM and plasma arc techniques were tested on a mock-up of the shield, for optimising the parameters and training operators.

The thermal shield was cut into rings in the vessel using mechanical sawing and EDM. The top ring was cut into segments *in situ* by EDM. The other rings were later cut into segments outside the vessel using the plasma arc.

The main lesson that was learnt from the comparison was that mechanical sawing produced less secondary waste (only a fifth) than plasma arc or EDM and that its cutting speed was acceptable. So, for the second phase of the decommissioning project (1993-94), which covered the removal and segmentation of all the other reactor vessel internals, various types of mechanical cutting were used, such as:

- circular saw,
- band saw,
- reciprocating saw,
- hydraulic shears.

EDM was used as a back-up technique and for "surgical" work.

The main components removed and segmented during Phase 2 were:

- the rod shroud support plate,
- the reactor vessel collar which is a thick carbon steel ring with a stainless-steel cladding from which is suspended,
- the instrumentation basket which consists of small bore pipes of stainless steel,
- the core support assembly.

EDM was used for cutting the bolts holding the shroud plate to the vessel collar. An underwater band saw, capable of cutting components with varying thickness and complex geometries, has been developed. This was used on the vessel collar. The lower core support assembly was first cut horizontally into rings with a circular saw and then segmented with the band saw.

The project is also developing methods for the decontamination of contaminated metals to (free) release levels. Both chemical and wet abrasive methods are being tested. Decontamination and dismantling techniques for concrete are also tested and compared on slightly activated pieces.

As a complement to Phase 2, it is planned to segment the first set of vessel internals (replaced in 1964) to gain experience on material with a 30-year cooling period. A Phase 3 is also being planned covering the dismantling of the primary circuit, including segmenting the reactor vessel and the surrounding neutron shield tank.

3. Gentilly-1, Canada [3]

Gentilly-1 was a heavy water moderated, direct cycle, boiling light water cooled prototype reactor that was shut down in 1979 after 15 years of operation. It was placed in a "static" state – a variant of Stage 1 status – in 1986, and it became the Gentilly-1 Waste Storage Facility thereafter.

During the project to place the plant in the static state,

- a dry fuel storage facility had been constructed for the spent fuel from the stations operations,
- the Service Building had been cleared of all equipment and decontaminated, as also part of the Turbine Building,
- decommissioning waste was stored in parts of the Turbine Building, while other active waste was stored in the sealed Reactor Building.

During its dormancy, the Service Building, which had been cleared and decontaminated, has been converted by the new owners, Hydro-Québec, into a modem office building including a training centre, complete with a full size simulator for the adjacent Gentilly 2 NPP. The spent fuel pool is now used as a calibration facility.

Low-level waste generated during the decommissioning project had been stored in parts of the Turbine Building. This has now been relocated in the Reactor Building. AECL is trying to sell the turbines and generators. If they can be sold, the Turbine Building will be decommissioned. Asbestos insulation from the building has already been shipped off site. The roofing of the turbine building has been repaired.

The cost of maintaining the Gentilly-1 site before the decommissioning project has been C$ 10 million per year since 1979, when it had been shut down. Placing the facility in a static state had cost a total of C$ 25 million over two years. The annual costs for the inspections and surveillance of the dormant plant are of the order of C$ 300 000 (1990). Continuous surveillance of the critical parameters in the Reactor Building is done by telemetry.

4. Nuclear Power Demonstrator (NPD), Canada [4]

The NPD was the 25-MWe prototype for the CANDU-type reactor. The decommissioning alternative chosen was the same as for Gentilly-1, *i.e.*, "static state".

The NPD plant was underground. So the containment had to be upgraded to cope with the possible ingress of ground water.

The decommissioning project started in September 1987. All nuclear systems were drained and sealed. All fuel was shipped off site for dry storage in concrete canisters at Chalk River Nuclear Laboratories. Operational wastes, such as tank sludges, were solified and shipped to Chalk River for disposal. In the static state, there are some 2×10^{15} Bq on site, mostly in the reactor vessel.

The unrestricted access areas were thoroughly decontaminated to radiation levels of under 2.5 μSv/h. All loose contamination was removed from areas to be entered for surveillance.

Static state was implemented in August 1988. Site security is monitored remotely from Atomic Energy of Canada Limited Chalk River Nuclear Laboratories, 40 km away, and complemented with periodic on-site inspections. With the establishment of the static state, the annual maintenance cost are of the order of C$ 0.3 million compared to C$ 14 million before decommissioning. The NPD decommissioning project was budgeted at C$ 18.5 million.

During the dormancy period, clean balance of plant equipment is continuously dismantled and sold.

5. Tunney's Pasture Facility, Canada [5]

The Tunney's Pasture Facility in central Ottawa was used for research, production and worldwide shipping of radioisotopes. After thirty years of operation, it was shut down in 1984. A first decommissioning phase was carried out to reduce the licensing to a possession only level. This phase was completed in 1987. Planning for decommissioning for unrestricted release was started in 1989. The authorisation for starting work on site was received in 1991. This second phase was completed in August 1993.

The total activity inventory in the plant was estimated to be less than 1.48×10^{10} Bq (4 Ci) including a number of difficult to measure nuclides like nickel 63. The radioactivity was mainly located in the ventilation system, which was dismantled first. This was technically not demanding but required nine months of fully suited work and rigorous personnel discipline.

The major engineering work was in connection with the removal of the eight hot cells, typically with 1-m thick walls of heavy concrete, clad with 13-mm carbon steel and 4-mm stainless-steel linings. All contaminated components were first removed. The cells were then cut up using diamond wire saws.

The high background dose due to the accumulation of radwaste from the decommissioning hampered the progress of the project. The radwaste continued to accumulate because of the need to characterise the waste in a manner acceptable to the organisation taking the future responsibility for it, AECL Research. Agreement was finally negotiated between the project and AECL Research and the project rapidly progressed towards completion.

The project employed 30 persons at its peak, divided into three groups: decommissioning, radioprotection and health physics.

The final survey of the site was carried out by project teams, after which the Atomic Energy Control Board (AECB) audited the building and the survey records.

The de-licensing is based on a release level of an average ambient dose rate of 13 μR/h (total, *i.e.*, 5 μR/h above the average background of 8 μR/h), with an assumed occupancy of the premises of 2 000 h/a. This would give a maximum individual dose of 260 μSv/a. The inclusion of the contribution from naturally occurring radioactivity makes it difficult, however, to make comparisons with other recommendations in connection with free release levels, most of which exclude the naturally occurring component.

The facility was formally released by the AECB in January 1994.

6. Rapsodie, France [6]

The sodium-cooled fast-breeder reactor Rapsodie operated at 20 MWt and later at 30 MWt. It achieved criticality in 1967 and was finally shut down in 1984. The project to put the facility in a Stage-2 decommissioning status was started in 1987.

The reactor vessel was emptied. For this the fuel and blanket assemblies were removed from the core, washed and sent to Marcoule for reprocessing. The steel/nickel dummy elements were lifted out and are in interim storage on site. The sodium in the primary systems was drained. The system was washed with ethylglycol and decontaminated with nitro-sulphuric acid process with cerium IV. The systems were then dismantled and about 70 t of stainless steel from the decontaminated primary loop were sent to the INFANTE facility in Marcoule for recycling by melting.

The reactor block was then sealed. The reactor vessel was complemented by an upper closure head, constituting a first leak-tight barrier. The outer Sercoter concrete enclosure was completed with steel caissons on the six sides of the reactor plant, thus forming a second barrier.

The main activity for terminating the Stage-2 decommissioning of Rapsodie was the destruction of 37 t of the sodium coolant. The destruction process, developed by CEA, was a controlled sodium water reaction producing concentrated sodium hydroxide (soda). The 37 t of sodium were destructed in the purpose-built DESORA rig during 16 weeks, resulting in 150 m^3 of 10 M of soda, which will be transported to a COGEMA plant at La Hague for liquid effluent treatment.

On 31 March 1994, a residue of 600 L of sodium was being treated with heavy alcohols for producing a stable salt, when an explosion took place causing the death of one engineer and injuring four others. The explosion occurred in a tank in the gallery outside the containment. The heavy alcohol process had been used earlier for washing the primary system.

A CEA internal inquiry commission, in its preliminary report considers the main cause of the accident to be conditions that led to the thermal decomposition of the mixture under very exothermic reactive conditions. The commission recommends a programme of studies and analyses to be implemented by CEA laboratories and other agencies. Sodium vessels will not be cleaned using alcohol before these studies have been carried out.

7. G2/G3 Reactors, France [7]

G2 and G3 were two 250 MWe gas-graphite reactors that operated between 1958 and 1980. In each reactor the core, with reflector and shield plates, is located within a prestressed concrete pressure vessel, while the four steam generators and associated primary cooling circuits are outside the pressure vessel. This arrangement has made the plants suitable for Stage-2 decommissioning, where the external cooling circuits and steam generators will be dismantled, while the core and other internals will be enclosed in the concrete pressure vessel.

The external cooling circuits consist of about 1 500-2 000 t of carbon steel in each reactor. The direct disposal cost for this steel was estimated to be about FF 240 million. After studies, it was decided to wash the interior of the systems with high pressure water and then melt the piping for recycling the metal.

A decision was taken in October 1990 to build a melting facility (INFANTE) at the G2/G3 site. An electric arc furnace was chosen because it was considered safer from the effects of possible water inclusion in the piping and also because it would allow a larger lid opening than an induction furnace. It has a 15 t/charge capacity. Pipes up to a diameter of 1.6 m can be loaded directly, saving considerable cutting costs. Both carbon and stainless steel have been melted.

The melting results in 25-kg ingots or 4-t blocks, which are monitored for radioactivity. The ingots and blocks are stored in the facility awaiting an agreed very-low-level waste disposal repository or a recycling project within the nuclear industry.

After inactive and active tests during late 1991 and early 1992, operations started in April 1992. By the middle of 1994, the contaminated steel scrap from G2/G3 had been melted at INFANTE and the melting facility has been used for treating steel scrap from some other CEA facilities.

CEA has studied various possible ways of using the material resulting from the melting of the contaminated scrap at activity levels higher than releasable. One has been the production of waste containers using the "integral workform" principle. Here the cast iron is poured into annular moulds of sheet steel (cylindrical) where the cast iron solidifies between the outer and inner steel sheets forming an integral shielded container. Pre-machined inserts have been welded into the sheet steel mould, thus avoiding the need for post-casting machining for lifting points etc. The outer surfaces of the mould are not contaminated and therefore the containers can be handled comfortably. 150 such containers have been produced.

STMI, a subsidiary of EDF and CEA, has been appointed Architect/Engineer for the G2/G3 site with CEA's UDIN Department as the operator. The reactors G2 and G3 have formally been placed in a Stage-2 dormancy status. The dormancy period is expected to be between two and three decades.

8. AT-1, France [8]

AT-1 was the pilot plant for reprocessing fast breeder fuel from Rapsodie and Phénix. It was shut down finally in 1979. The decommissioning unit of the CEA, UDIN, took over the plant in 1982. The first three years were taken up by planning and studies. Dismantling started in 1984 and the whole project is scheduled to be completed during 1994.

The decommissioning has taken place in five steps:

- alpha cells,
- small beta-gamma cells,
- high-active cells using the ATENA,
- storage and fission product cells,
- cleaning out of the plant.

Dismantling started with alpha cells and glove boxes in 1984. This continued during 1985 and 1986 and was taken up again in 1990. During 1987-89, the peripheral equipment was dismantled, the remote dismantling machine, ATENA, was procured and installed. Using the ATENA, which has a 6-m long articulated arm, the highly active cells were dismantled during 1990-92. This has been the major achievement of the project until now.

The ATENA carrier originally started operations with manipulator MA23, which was later replaced by the heavier duty RD500. However, the RD500 suffered a cabling failure in the workshop. So ATENA reverted to the MA23, while the RD500 was being repaired. ATENA had a high reliability, while the manipulators were not so good in this respect.

Following this was the work on cells with limited access such as those for fission product storage and finally the removal of ATENA, dismantling its maintenance cell and decontaminating a number of cells to release levels. Decontamination was by sand and shot blasting, using a robot carrier arm or manual application depending on location. The remote carrier arm can also be used for holding a post-decontamination measuring head. Some volumetric contamination has been found in the concrete walls of the hottest cells, requiring several centimetres deep scabbling before the final dismantling operations.

The AT-1 building will either be released for reuse as office space (within the controlled area) at the La Hague site or totally demolished. If reused, the proposed release limits for the surfaces are:

- 0.4 Bq/cm^2 for alpha-emitters,
- 3.7 Bq/cm^2 for beta/gamma-emitters.

The allowable annual dose (at work, 2 000-h occupancy) for office workers is 5 mSv, compared to 50 mSv for workers in the controlled area.

9. EL-4, France [9]

EL-4 was a heavy-water moderated, carbon-dioxide-cooled 70-MWe pressurised tube reactor which was a dual purpose research and production prototype. It was shut down in 1985 after 20 years of operation. Since then, the fuel has been removed and shipped to Cadarache, the heavy water drained, the circuit dried, the ponds have been emptied, etc.

A decommissioning plan was prepared, which proposed:

- Stage 2 for the reactor building,
- Stage 3 for the other buildings on site.

In the reactor building, it is planned to dismantle the heavy water and helium circuits and the existing electrical and ventilation systems. The penetrations of the reactor vessel will be sealed and new electrical and ventilation systems will be installed, the latter dimensioned to keep the humidity under 50 per cent.

A dormancy period of 50 years is assumed for the reactor building. Safety reports were prepared for achieving the above conditions and for the dormancy period.

The decommissioning plan (for achieving Stage 2 of the reactor building and Stage 3 of the rest) covered the following items:

- prepare a complete documentation,
- make a radiological survey for determining the radiological inventory,
- prepare a manual of items to be dismantled with details of conditioning and disposal,
- defining of controlled areas/organisation of decontamination of the "Stage-3" areas.

The plan was discussed at public hearings at the turn of the year 1994-95 in connection with an application to carry it out. Much of the discussion centred round the necessity for a Stage 2. Environmentalists asked for a study on an immediate decommissioning to Stage 3. A preliminary study is expected to be ready by October 1995.

10. Building 211, France [10]

Building 211 was the spent fuel processing facility of the CEA Marcoule Pilot Shop (APM). The Marcoule site included also the G1, G2 and G3 reactors, the UP1 reprocessing plant and other facilities. Building 211 was constructed and taken into operation between 1960 and 1963. It was first used to develop processes for reprocessing natural uranium fuel and for vitrifying fission product solution. From 1973, the plant was used to reprocess fast reactor fuel from Fortissimo and Phénix reactors. Later additions and modifications were made to be able to treat fuel from the Superphénix reactor and MOX fuel from pressurised-water reactors.

The Building 211 is characterised by the fact that its high and medium level cells are equipped for remotely controlled interventions. Shielded doors separate these cells from the corridor used for handling and transfer operations. The inside of each process cell is of stainless steel and the bioshield is of heavy concrete blocks. All the process cells are located in a large hall.

Before the start of any dismantling, a waste staging station (for sorting, packaging, etc., of wastes) will be established in the mechanical cells. Waste material will be sectioned by robot arms introduced into each cell by a travelling crane.

This assembly of robot arm+crane will be used generally for decommissioning and dismantling work in the cells. Due to the varying requirements in the different cells, the crane will need a number of robot arms with different functions.

During 1994, development work has been carried out on the design of a new "Crane E", which will run on the existing rails at the facility. The crane will, in addition to the robot arm, also have a hoist and an umbilical cord for transmission of power, instructions and video information. It is planned to call for tenders so that an order for detail engineering and construction of the crane can be placed in 1996.

11. Kernkraftwerk Niederaichbach (KKN), Germany [11]

The Niederaichbach nuclear power plant was a 100-MWe prototype with a carbon dioxide, heavy-water moderated reactor. It was shut down in 1974 after having produced the equivalent of 18 full-power days, due to steam generator problems.

A safe enclosure licence was granted in 1982. The licence for complete decommissioning to Stage 3 was granted in 1987, after many years of litigation, public hearings and appeals. Decommissioning on site started in 1988 with the removal of inactive and later contaminated components.

The dismantling of the highly active components of the core region of this vertically oriented pressure tube reactor was carried out with a high precision remotely operated rotary mast type manipulator with suitable tools attached.

The main sections of this core region were:

- the upper neutron shield,
- the 351 pressure tubes,
- the lower neutron shield,
- the moderator tank,
- the thermal shield.

Many techniques were used in the cutting and dismantling of the core components. Among those utilised were:

- grinding,
- plasma torch,
- disc cutters,
- screw removal,
- band saw.

The remote dismantling of the core region and segmenting these components took place between November 1990 and March 1993.

These components amounted to 522 t with a total activity of 8.6×10^{12} Bq. They were packaged into 139 containers ready for disposal at the Konrad repository when it becomes operational. About 20 per cent of this metal is below 200 Bq/g. This fraction will be sent to the Siempelkamp melting facility for recycling within the nuclear industry.

The next project activity was the removal of all activated concrete structures during the period April-November 1993. These structures were, in addition to the biological shield, the upper support ring, the walls of the coolant distribution room and the wedge areas as well as the lower support ring. Hydraulic and pneumatic jack hammers were used for activated concrete removal, in addition to an electrical excavator with a rock chisel. In certain areas, the concrete was cracked by controlled blasting, then removed and packed manually.

All the surfaces in the building were then decontaminated, after which the release measurements were started. The release levels were:

- 0.37 Bq/cm^2
- or 0.37 Bq/g.

About 200 000 measurements were made by project staff. These were checked by about 10 per cent verification measurements by the inspection authority and some more (2-3 per cent) by the environmental authorities. The site was released from the *Atomic Law* in August 1994.

Following the release of the site, conventional demolition could be started in October 1994. The 130-m high stock was demolished in January 1995. The site is expected to attain "green-field" conditions during autumn 1995.

The decommissioning machine, which was used for the remote dismantling of the radioactive details of the core region, was decontaminated by sand blasting. It cannot therefore be reused and will be scrapped.

12. Mehrzweckforschungsreaktor (MZFR), Germany [12]

The MZFR was a 200-MWt (50-MWe) pressurised-heavy-water reactor that operated at the Kernforschungszentrum Karlsruhe from 1966 to 1984. The plant is being decommissioned to Stage 3 in a series of eight steps, each step being defined by a sub-licence. The areas covered by each sub-licence are:

- *Sub-licence 1:*
  - Securing the systems out of operation,
  - Draining and drying (at raised temperature) of the heavy water systems outside the reactor building.
- *Sub-licence 2:*
  - Shutting down redundant systems,
  - Hot drying of heavy water systems inside the reactor building.
- *Sub-licence 3:*
  - Dismantling of inactive systems.
- *Sub-licence 4:*
  - Dismantling of auxiliary systems,
  - Decontamination of primary circuits.
- *Sub-licence 5:*
  - Dismantling of the security fence.
- *Sub-licence 6:*
  - Dismantling of the primary circuits.

- *Sub-licence 7:*
  - Remote-controlled dismantling of the reactor pressure vessel and internals.
- *Sub-licence 8:*
  - Decontamination and demolition of buildings.

To date the work under sub-licences 1, 2 and 3 have been completed. Practically all the 9 650 t of demolition scrap produced by the dismantling of conventional plant could be recycled. The 150-t turbine and 130-t generator are to be reused elsewhere. The decommissioning of the turbine hall was carried out without payment to a contractor, who took the resale value of the turbine in exchange. The turbine hall itself has been handed over to the WAK project for the installation of a test facility.

During the demolition of the cooling towers, 7 100 t of concrete, 185 t of steel scrap, 175 t of asbestos and 450 t of road surfacing were removed and disposed of as conventional waste. In addition, 8 600 m^3 of soil was moved. The release limits were:

• alpha	0.05 Bq/cm^2
• beta/gamma	0.5 Bq/cm^2
	0.5 Bq/g

The primary system decontamination (under Sub-licence 4) was performed in order to allow manual dismantling and to bring as much as possible of the material under 200 Bq/g. Such material could then be recycled by melting for reuse (within the nuclear industry) instead of being treated as radioactive waste. The reactor pressure vessel was not decontaminated.

The Siemens/KWU CORD/UV method was used for decontamination and applied through the mobile facility AMDA. In this three-step, 95°C process, the metals (including the nuclides) are taken up on ion exchange resin and the other chemicals are decomposed into carbon dioxide and water. The MZFR systems were exposed to seven cycles (three steps each) of decontamination.

The average surface contamination before decontamination was 5×10^4 Bq/cm^2, the surface area about 4 200 m^2 and the mass of metal about 400 t. The total activity was estimated to be 2×10^{12} Bq.

An average decontamination factor of 20 was achieved. This varied between 5 and 150. The dose rate was reduced by between 30 and 50. 5.3×10^{11} Bq of activity and 72 kg metals were removed. Final evaluation of the decontamination is still going on.

The fifth sub-licence has been granted. It covers the abolition of safeguarding requirements at the MZFR site. Documents for the licence application for Sub-licence 6, involving the dismantling of reactor primary and support systems inside the reactor building, have been drafted.

According to the present time schedule, the MZFR decommissioning project should be completed during the year 2006.

13. Kernkraftwerk Lingen (KWL), Germany [13]

KWL Lingen was a indirect cycle 520-MWt boiling-water reactor with oil-fired superheater that operated from 1968 to 1977. It was placed in a Stage 1 "Safe Enclosure" (SE) status in 1988. The licence is valid for 25 years. The conditions of the safe enclosure status are essentially:

- The safe enclosure consists of the reactor building, the waste treatment building and the building interconnecting them.

- All pipes penetrating the safe enclosure were cut and sealed, systemsremain open.
- All openings from the safe enclosure are closed, shut and sealed, except for one door.
- All liquids have been drained from the systems.
- A small air conditioning plant has been installed to keep the air below 50 per cent relative humidity.
- A small exhaust system has been installed for the controlled release of air, which is filtered and monitored.

The operation of the plant has been without any incidents. The leakage of air and activity release from the safe enclosure is being monitored under a co-operative programme with Euratom. The only aspect of interest noted was that the relative humidity in the enclosed area was higher than expected. The reason was identified to be the design of the drying system. A new drying system has been taken into operation in 1994.

The plant is inspected periodically. The systems in operation are inspected according to an inspection programme prescribed in an operations handbook. The costs for the operation are under DM 1 million per year.

14. Greifswald and Rheinsberg VVER, Germany [14]

There are eight 440-MWe pressurised-water reactors of the Russian VVER type at Greifswald, and one 70-MWe at Rheinsberg. They were shut down after the reunification of Germany in 1990, mainly due to a lack of political acceptance and secured financing. Energie Werke Nord GmbH was created to decommission these plants in a socially acceptable form.

Four of the eight Greifswald reactors had been in operation between 1973-90. The fifth, which was of a more recent design, had been started in 1989. Unit 6 was ready for operation, while the other two were in the process of construction. The Rheinsberg VVER had been in operation since 1966. The plants have leak-tight enclosures which, however, are not comparable with "containments" as on plants in the West.

At the Greifswald site, there are plants for the treatment and storage of liquid waste and for the storage of solid waste. There is a pond for central fuel storage and a "hot" (active) workshop. Altogether there are 580 t of fuel in Greifswald and 28 t in Rheinsberg. In addition, there are about 1 500 m^3 evaporated concentrates, 550 m^3 ion exchange resin and 2 000 m^3 solid waste. Full system decontamination had been routine and so the dose rates on major components are relatively low.

Direct dismantling was chosen because of lower costs, lower dose commitment and lower volumes of radioactive waste than for the alternative of safe enclosure and deferred dismantling. This is mainly due to the design and site specific conditions. Direct dismantling has also advantages from the point of view of continued employment for the work force. The project itself can be divided into three phases:

The *post-operation phase* comprises: operation of all systems relevant to he safe storage of fuel elements, the removal of fuel elements, conditioning of operational waste, dismantling of not relevant systems (mainly inactive) and system decontamination.

The *dismantling phase* comprises: the dismantling of the contaminated systems, the remote dismantling and conditioning of dismantled material.

The *site restoration phase* comprises: dismantling of remaining systems, building decontamination and demolition and finally the restoration or adaptation of the site for other uses.

The basis and basic principles for the planning can be summarised as follows:

- the dismantling will be performed from systems and areas with lowercontamination/radiation to higher contamination/radiation and finallythe activated components;
- the dismantling will begin in Unit 6 and end in Unit 1, in order to use the experience from inactive and low dose rate units work on the more contaminated and activated units;
- the use of new mobile plants for utilities is preferable to updating old facilities;
- as far as possible market equipment will be used;
- maximum reuse of dismantled material, if technically and economically justified;
- an intermediate storage for waste and fuel will be erected on site in order to be independent from external influences.

The licensing procedure in Greifswald will consist of seven separate licences.

- *Licence 1:*
  A possession only licence to follow on the current operation licence. To establish and operate all systems for safety and infra structure services for carry out dismantling. Dismantling of turbine hall and controlled area of Unit 5.
- *Licence 2:*
  Remote dismantling tests of inactive reactor pressure vessel and core related components in Unit 5.
- *Licence 3:*
  Dismantling of controlled areas of Units 1 and 2.
- *Licence 4:*
  Dismantling of controlled areas of Units 3 and 4.
- *Licence 5:*
  Remote dismantling of reactor pressure and core related components of remaining Units (1-4).
- *Licence 6:*
  Dismantling of waste treatment facilities and remaining systems.
- *Licence 7:*
  Remote dismantling of Unit 5.

The status of the projects in mid-1995 can be summarised as follows:

- The first decommissioning licence has been obtained for both sites and dismantling has started.
- Fuel in being transferred from the reactors to the central wet storage on the Greifswald site (Almost terminated).
- The construction is going on of the Interim Waste Storage Building which will house both the dry storage of fuel as well as the operational and decommissioning wastes arising. Operation will commence in early 1997.
- Operation waste is being conditioned at both sites and being disposed at the Morsleben final repository.
- Decontamination tests on steam generators have been performed with the CORD process as well as with APCE. However no major decontamination will be performed as a prerequisite to dismantling.
- The district heating system at Greifswald has been dismantled.

According to the current time schedule, the decommissioning project in Greifswald will be terminated (including building demolition) in 2012 and in Rheinsberg in 2009.

15. Heissdampfreaktor (HDR), Germany [15]

The nuclear superheat reactor, HDR, at Karlstein had operated only for the equivalent of five full power days when it was shut down in 1971. It was used for various safety related experiments between 1974 and 1991.

The plant is being decommissioned to Stage 3, the licences for which are granted on a sequential basis. The experimental equipment is being removed under its operational licence, which thus can also be seen as its first sub-licence for decommissioning. About 300 t of metals from the controlled area and 250 t from the rest of the plant have been removed, most of which can be recycled without radiological restrictions. The last task performed under this sub-licence was the management of the dioxin contamination.

The Sub-licence No. 2 for the dismantling of the reactor systems including the reactor vessel was granted in December 1994. Some of the original infrastructure, such as the water clean-up and ventilation facilities, will be used during the decommissioning. So the dismantling will take longer than just the straightforward dismantling of the systems. During the first quarter of 1995, components of the primary circuit, the emergency cooling system and the intermediate cooling system have been dismantled.

An application has been lodged for Sub-licence No. 3, which will cover the demolition of concrete structures within the reactor containment. Due to the contamination of the annulus between the containment and the inner concrete wall, the structures will be dismantled in defined sections. At each step, the accessible surfaces will be decontaminated and monitored before release. Then, at each level, the concrete wall nearest the containment will be cut out in sections and the rear side of each section will be monitored and decontaminated if necessary.

The project is expected to be completed by the end of 2000.

16. Wiederaufarbeitungsanlage Karlsruhe (WAK), Germany [16]

The Wiederaufarbeitsanlage Karlsruhe (WAK) is a pilot reprocessing facility located on the grounds of the research centre of Karlsruhe (FZK).

The plant has a design throughput of 35 t of spent fuel/year at a maximum burn-up of 20 000 MWd/tU. The plant was put in hot operation in 1971. Since then it has processed 200 t of heavy metal, including 1.8 t of plutonium. Because of test operation with fuel at a burnup up to 40 000 MWd/tU the average-burn-up was as high as 26 000 MWd/tU.

The owner of the plant is the Federal Government of Germany. The operator is the WAK BGmbH, until 1980 a subsidiary of the chemistry industry and from 1980 until today a subsidiary of the nuclear power station operating utilities.

Reprocessing of nuclear spent fuel in the plant was stopped in accordance with the German decision, taken on political grounds, to stop reprocessing on an industrial scale in the late 80s.

For the stand-by operation and the future programme of dismantling the facility, a letter of understanding was signed between the Federal Government and the utilities. Under this agreement a contract was established between the FZK as the responsible Project Manager and WAK BGmbH as the executing company.

The project is devided into three main tasks:

- stand-by operation,
- transport of the high-level liquid waste (~ 80 m^3) to the PAMELA facility at Dessel, Belgium,
- decommissioning and dismantling of the plant with the goal of achieving a green-fields status.

The plant was rinsed, after shutdown, with inactive solution of natural Uranium. The dismantling of the plant will be accomplished in several steps. Decisions have to be taken at each step to designate areas of relatively low dose-rates (< 0.5 mSv/h) suitable for manual dismantling and those for remote dismantling.

Therefore only a part of the installation can be dismantled by direct manual methods. Special remote controlled handling tools have to be adapted, and additional equipment has to be installed to achieve vertical and horizontal access to the cells for the remote dismantling.

The dismantling project is expected to be completed in the year 2005.

17. Arbeitsgemeinschaft Versuchsreaktor (AVR), Germany [17]

The 15-MWe AVR was a high-temperature, helium-cooled reactor with spherical fuel (pebble bed) developed in Germany. This experimental reactor operated between 1967 and 1988. A licence application has been made for placing the plant in a Stage-1 status. The licence to transform the plant to Safestore conditions (Stage 1-2) was granted in March 1994 and comprises two different phases:

- Phase 1 started with the reactor defuelling. It is 35 per cent completed. In parallel, secondary circuit and cooling water components outside of the reactor building (mainly in the turbine building) are dismantled. Because of delays in defuelling, permission has been sought to shift some decommissioning tasks inside the reactor building from the second to the first Phase, but without major dismantling inside the containment.
- Phase 2 will start after defuelling. It comprises up to now only the dismantling of some low contaminated systems in the containment. To reduce radioactive areas to be safestored, and to better use the personnel's good knowledge of the plant, a licence extension was applied for in August 1995. It will allow the dismantling of a considerable number of components and systems, including the highly contaminated fuel handling system.

The fuel spheres are of two types: low-enriched (LEU) or high-enriched uranium. On extraction from the reactor vessel, each sphere is checked by gamma-spectrometric burn-up measurements to distinguish the enrichment. The LEU fuel elements have, up to now, been returned to the core. As soon as the neighbouring Research Centre KFA obtains a licence to accept LEU fuel in its hot cells (necessary for dry cask storage), the LEU fuel will also be discharged.

The contamination in the plant is mostly strontium 90 and caesium 137. These are bound to the graphite dust which can cause air contamination problems in cutting pipes and components of the gas loops. So such procedures will require local containments with filters and the working personnel will have to be in ventilated suits. The secondary systems are lightly contaminated with cobalt 60 and iron 55. However the radiation levels are low. So the collective dose for the scope of decommissioning licensed at present is estimated to be less than 400 mSv.

More than 99 per cent of the 430 t of metal expected to be dismantled for removal under the current licence can be released for recycling after decontamination or melting.

The decision whether to switch to Stage-3 decommissioning is expected to be made in 1996. To prepare this decision, two consortia, among which AEA Technologies, UK, have carried out detailed studies on this subject. Two major concepts were regarded: one opening and extending the containment at the top so that the steam generator can be removed as a whole unit, and the other leaving the containment intact and cutting the steam generator *in situ*.

18. Garigliano, Italy [18]

Garigliano Power Plant has a 160-MWe, dual-cycle boiling-water reactor which was taken into operation in April 1964. The nuclear section, consisting of the reactor, the two steam generators and the nuclear auxiliary systems, is contained in a 49-m diameter spherical secondary containment. The reactor was shut down in 1978, in 1982 it was decided to place the plant in safe storage (Stage 1).

Fuel has been transported off site. Operational wastes are stored in underground tanks. Dry low-level waste has been supercompacted into 80 × 320-L overpacks.

The operational waste consists of 160 m^3 of resin, 40 m^3 of sludges and 60 m^3 of evaporator concentrates. ENEL is planning to extract and condition in cement these intermediate level wastes. The detail design has been approved by the authorities.

Development work has also been carried out on the extraction and conditioning of the stainless steel channels for fuel assemblies stored in the high-activity pit. These channels were replaced by Zircaloy channels after a few years of reactor operation. Qualification tests have been performed on the conditioning process and equipment.

Plans have also been detailed for the actions to be taken on the reactor containment and its contents to place it in a passive safe enclosure condition. The containment will be isolated from the other buildings and ventilated by utilising the temperature and pressure differences between the inside and outside of the containment.

It is also planned to demolish the stack after decontaminating its inside by scarification of the surface up to a predetermined depth. After decontamination, the stack will be demolished by making it fall in a chosen direction. Stack demolition will take place after treatment of the operational waste and placing the containment into safe storage conditions.

There have been important political changes in Italy which have affected the Garigliano decommissioning project. The most significant is that ENEL has been reorganised as a joint stock company as a step to part-privatisation. The authorities concerned are also being totally re-organised. Both these factors have led to significant delay in the approval process for the various licence applications.

19. Japan Power Demonstration Reactor (JPDR), Japan [19]

The Japan Power Demonstration Reactor was a 90-MWt boiling-water reactor that was in operation from 1963 to 1976. The decision was taken to decommission it to a Stage-3 status in order to

- gain experience of dismantling,
- develop/demonstrate decommissioning techniques,
- assemble data on various aspects of decommissioning.

The decommissioning project was conducted in two phases:

- a five-year Phase 1 starting in 1981, during which an extensive research anddevelopment programme was conducted on the technologies required fordecommissioning,
- a Phase 2, carried out during 1986-1996, during which these technologies were implemented to dismantle the JPDR to Stage-3 green-field conditions.

One of the main aims of the R&D programme of Phase 1 was to develop remote cutting methods to minimise the radiation exposure to workers. Radioactive components and structures were removed in the early stage of the dismantling activities, and the remote dismantling techniques developed in Phase-1 programme were put to practical use in the dismantling activities.

The reactor internals were removed by the underwater plasma arc cutting system. The plasma torch was operated in most cases by a mast type manipulator. Otherwise, the master-slave robotic manipulator was used for the plasma torch to demonstrate and verify its newly developed robot technology. First, each reactor internal was removed from the reactor pressure vessel (RPV) wall, the cut piece was then transferred underwater to the spent fuel storage pool through the canal. These pieces were cut into smaller segments suitable for packaging using another underwater plasma arc cutting system.

After removing the reactor internals, the piping connected to the RPV was dismantled using the rotary disk knife, shaped explosives and conventional cutting tools. Then the RPV was dismantled using the underwater arc saw cutting system. Before assembling the underwater arc saw cutting system, a cylindrical water tank was temporarily installed in the space between the RPV and the biological shield. The tank was filled with water for cutting the RPV underwater.

For removing the biological shield, the diamond sawing and coring system was applied to dismantle upper part of the activated inward protrusion of the JPDR biological shield. The lower part of the inward protrusion was dismantled using the abrasive water jet cutting system. After removing the inward protrusion, radiation levels in the reactor cavity were so low that workers could approach the cavity. The rest of the biological shield was dismantled by using controlled blasting. Vertical charge blasting was used for demolishing the inner portion and horizontal charge blasting for the outer portion. The wastes from the outer portion will be disposed by shallow-land burial at JAERI's site. The other wastes were put into containers which were stored in the waste storage facility.

In parallel with the dismantling activities in the reactor building, components in auxiliary buildings such as turbine building and rad-waste building were dismantled using conventional techniques, such as band saw, reciprocating saw, oxyacetylene torch, and plasma torch. Large components such as the pool lining and the turbine have been cut into small segments and stored in the containers.

Information about the JPDR dismantling activities has been collected and accumulated in the decommissioning database. This database is to be used for:

- managing ongoing JPDR dismantling activities,
- verifying the Code Systems for Management of Reactor decommissioning (COSMARD), and
- planning future decommissioning of commercial nuclear power plants.

As an example of the analysis for utilising the database for future commercial plant decommissioning:

The ratio of manpower expenditure to the weight of dismantled components was evaluated to be 500-2 000 man-hours/t in remote dismantling procedure for highly radioactive components, compared to approximately 80 man-hours/t with manual dismantling procedure in the reactor building. The remote dismantling systems were proved to be effective for general components to minimise the radiation exposure of workers, which was kept to a collective dose of approximately 300 milliman-Sv.

After the removal of the components and systems, the inner surfaces of the JPDR buildings were decontaminated using a number of techniques, including scabblers, needle guns and concrete planers. The total area to be decontaminated and surveyed (radiologically) before release is 12 000 m^2. The buildings have been approved for release by the authorities and later demolished by conventional techniques. The project to decommission JPDR to Stage-3 green fields is expected to be completed by the end of March 1996.

20. JAERI's Reprocessing Test Facility, (JRTF), Japan [20]

JAERI's Reprocessing Test Facility (JRTF) was constructed during 1959-68 and operated for two years before shutdown in 1970. The Purex process was used to recover about 200 g of plutonium.

The facility consists of a main building with the reprocessing plant and two annex buildings for storage of the liquid wastes. The annexes are connected to the main building by ducts. The main building has a floor area of about 3 000 m^2 and the annexes have 160-m^2 and 400-m^2 floor areas respectively.

The project to decommission the JRTF was started in 1990. The project has two phases. During the ongoing Phase 1, the liquid waste arising during operation is being conditioned, the implementation of Phase 2 is being planned and research and development work is being carried out in specific areas.

The liquid waste consists of

- alpha-contaminated liquid waste,
- spent solvent,
- unpurified uranium solution,
- high-level liquid waste.

Most of the 60 m^3 of alpha-contaminated liquid waste has been treated. The treatment of the spent solvent is by washing first to remove plutonium, to incinerate the washed solvent and to condition the ash in cement. The apparatus is ready and the treatment of the solvent has been started.

The plutonium in the unpurified uranium solution is to be adsorbed by inorganic adsorbents, after which the solution will be solidified. The apparatus for this is being manufactured. The caesium, strontium and plutonium in the high level liquid waste will also be taken up on suitable inorganic adsorbers. The apparatus for this has been designed.

To support the planning of the implementation phase, the surface contamination has been nuclide specifically determined on sample pipes cut-out from various typical sections.

The research and development programme includes the following areas:

- A tridimensional CAD system is being developed for the dismantling procedures.
- A robot carrying a TV camera and distance measurement device has been constructed for acquiring data in high radiation areas.

- A remote dismantling (and segmenting) machine has been designed for large vessels and is now being manufactured.
- Concrete decontamination up to a depth of 10 mm by laser techniques is being developed.
- Improved protective suits are being developed for working in alpha-contaminated areas.

21. A-1 Bohunice Nuclear Power Plant, Slovak Republic [21]

The 150-MWe plant was a carbon-dioxide-cooled, heavy-water-moderated pressure-tube reactor with metallic uranium fuel. It started operation in 1972. A first accident occurred in 1976 when a closure plug and freshly loaded fuel assembly were ejected from a pressure tube, leading to extensive carbon-dioxide leakage. The reactor was restarted after repair. However a year later, a new accident occurred resulting in overheating of a fuel assembly and a leakage of fission products into the primary system and the heavy water moderator. Inspection revealed a number of other serious defects both in the reactor and the steam generators as well as in other parts of the plant. In 1979, it was decided to permanently shut down the reactor and to decommission it.

The primary system was alpha contaminated. There was some contamination of the secondary system due to steam generator leakage. The reactor was defuelled and the heavy water drained.

The suggested decommissioning alternative is protective storage (Stage 1) and deferred dismantling of the reactor, which would involve the release of nearly the whole site.

The execution of the Bohunice Decommissioning projects is affected by a number of factors such as:

- no preliminary decommissioning plan,
- no fund collected,
- no regulatory preparation.

A special problem arose due to the corrosion of the fuel in their long term storage cans. The equipment for fuel treatment (EFT), designed to prepare the damaged fuel for off site transport, malfunctioned during active tests. Between 50 and 100 L of "chrompik" (potassium bichromate) leaked on to the floor of the reactor hall. Two fuel elements had been transferred into the transport cask, two others were being processed in the EFT,

In order to achieve a Stage-1 status:

- the reactor hall and EFT must be decontaminated to levels permitting work,
- technology needs to be developed for solving the damaged fuel problem,
- an agreement must be negotiated with Russia to accept the damaged fuel, otherwise one of the other two options described below should be adopted.,
- conditioning of operational radwaste and waste arisings from decommissioning activities.

The main ongoing activities are:

- Creation of the organisation for achieving the Stage-1 status and obtaining approval of the authorities for the organisation.
- In co-operation with AEA Technology, assembling the equipment for removal of caesium 137 in the water of the spent fuel storage pond.
- Checking/controlling the impact of the station on the environment, this by analysing soil and water from bore holes.

– Decontamination of the reactor hall. AEA Technology of the UK, as consultant, has prepared a decontamination plan, a safety analysis and a QA programme.
– Spent fuel management. Three strategies are being followed in parallel:
  - Negotiations with Russia for sending it there.
  - Intermediate dry storage at NPP A-1.
  - Reprocessing/vitrification. Two options have been chosen from international bids. Negotiations are going on.
– Radioactive waste management.
  - Negotiations with authorities on activity level limits for shallow land burial at site and on intermediate storage within reactor building for waste not acceptable for shallow land burial.
  - Assembling hydraulic shears for segmenting metallic wastes.
  - Construction of radwaste treatment building.
  - Conditioning of incineration ash in cement.
  - Experiment on Dowtherm bitumenisation, bitumen conditioning of other radioactive concentrates.

The cans with the two elements trapped in the EFT have been extracted, the tops cut off and the chrompik drained. The lower portions of the cans, containing the fuel elements have been packed and sealed in stainless steel cans and placed in the transport cask.

22. Vandellos 1, Spain [22]

The Vandellos 1 Nuclear Power Plant was a 500-MWe gas-graphite reactor of the same type as the French St-Laurent-des-Eaux plants. It was shutdown in 1989 after 17 years of operation after a fire in the turbines. The nuclear steam supply system was integrated, with the core and the steam generators located inside a 19-m diameter 36-m high internals dimensions) prestressed concrete pressure vessel. The reactor vessel is housed in the reactor building along with the blowers and auxiliary equipment. The site includes also other buildings such as the irradiated fuel building, fuel pool building, auxiliary electrical and power plant buildings, etc.

Three decommissioning alternatives were studied:

- Indefinite maintenance in shutdown state.
- Stage 2 for the defuelled reactor vessel and contents, decontamination of most of the rest of the site.
- Immediate dismantling to Stage 3.

The chosen alternative is that of Stage 2 for the reactor building and a few other buildings to be achieved in 10 years from the shutdown with a 30-year dormancy period foreseen. This would allow 80 per cent of the site to be cleared. The 30-year period was chosen because there would be no significant decrease in activity or dose rates after that.

The process of achieving the dormancy status is planned to be carried out in three phases:

- 1992-94 Basic design and licensing
- 1994-95 Detail design and engineering
- 1996-99 Execution.

The radiological status of the plant has been determined by measurements and calculation. The activation of the structures in the vessel is estimated to be of the order of 7.4×10^{16} Bq (2 MCi), 83 per cent of which is iron 55 and 13 per cent cobalt 60. The surface contamination is estimated to be 4.8×10^{10} Bq (average value) with a concentration of 10^5 to 10^7 Bq/m^2.

Five alternatives were studied for the confinement of the reactor vessel during dormancy, ranging from isolation of the vessel to maintenance of an underpressure or an overpressure inside. The chosen alternative was isolation with all penetrations sealed, mainly because it is a passive system without depending on operating components.

It is proposed to establish a number of levels of activity concentrations for defining the management of the waste materials arising from the decommissioning:

- general clearance levels (0.4 Bq/g for beta/gamma 0.04 Bq/g for alpha)
- waste stream based clearance levels (nuclide specific)
- clearance levels decided on a case-by-case basis.

According to present estimates this would reduce the total mass of waste materials (for the achievement of dormancy status) from 248 000 t to a radioactive waste mass of just over 1 000 t.

23. Windscale Advanced Gas-cooled Reactor (WAGR), United Kingdom [23]

The Windscale Advanced Gas-cooled Reactor was a 100-MWt reactor that operated between 1962 and 1981. After defuelling its decommissioning to a Stage-3 status was started at the end of 1983. A central feature of the project is the remote dismantling of the active internals of the reactor vessel.

During the first years of the project, a waste processing building was erected and a waste route established to it by jacking up two steam generators. All operational waste was processed. The refuelling branches were cut to just above the top dome of the reactor vessel. During 1991, the top dome was dismantled and the refuelling branches were further trimmed to the level of the top of the hot box.

Since then, work has been concentrated on preparations for the fully remote dismantling phase of the project and on the processing of waste.

Calculations had shown dose savings of 444 milliman-Sv by the use of a temporary rotating floor shield that functions both as a shield and as a ventilation seal at the top of the reactor. While the shield was being installed, a test facility was erected adjacent to the reactor for training operators to use the remote dismantling machine (RDM). This allowed full functional testing of the RDM mast, the dismantling manipulator as well as the support services that will be required for performing the various operations the machine is designed for. Most of the effort was on the training of the operators on using the manipulator and its associated viewing equipment. The control room of the WAGR has been cleared out and rebuilt as the control centre for the RDM. The first use of the RDM would be the dismantling of the hot box. Tests were performed on a mock-up. After the functional tests the RDM was transferred to its operational location above the reactor cavity.

A waste box design has been prepared to meet the requirements of NIREX, the UK waste agency. The waste box is of reinforced concrete preformed and manufactured offsite. After being filled with waste, grout is injected into the interspaces. After curing, reinforcement is arranged over the top and a concrete lid is cast on, thus producing a monolithic final product. A prototype waste box has been used to test the operability of the waste route.

Decontamination of the heat exchangers to release levels had been considered early in the project. However, when tests showed that this would lead to unacceptably large quantities of secondary waste, partial decontamination was considered to allow semi-remote dismantling with a moderate dose budget. However, changes in the conditions for acceptance of waste at Drigg, the low-level waste site, has made one piece removal of the heat exchangers a viable option. A planned programme of work to lift out the heat exchangers as four single units has now been completed and the units have been delivered to the low-level waste disposal site at Dirgg where they will be grouted *in situ*.

The WAGR project, its time schedule and its execution have been significantly affected by the extensive reorganisation of the United Kingdom Atomic Energy Agency (UKAEA). During the years that this took place, funding to the project, which was on an annual basis, was reduced and some project activities were delayed.

UKAEA has been reorganised into two main parts, UKAEA Government Division which is set-up as a procurement agency for dealing with the UK nuclear liabilities belonging to UKAEA, and AEA Technology which is set-up as a commercial contracting company to sell its scientific and engineering capabilities to industry within the UK and overseas. In line with UK government policy the WAGR project will be opened up to a wider market of contractors and all work be subject to competitive tendering. The task of reorganising the WAGR project along the new lines was given to UKAEA Government Division under the DTI funded DRAWMOPS programme. AEA Technology has won the contract for overall project management, safety management and procurement. Work will be organised into contract packages which will be put to the widest possible market on a competitive basis.

The principal change will be that the work schedule will be driven to the best practicable technical progress rather than being driven by annual funding as in the past. This will lead to a reduced project duration. There will be a greater emphasis on cost, time and progress, less on research for its own sake, although essential data will still be gathered. There will be greater involvement of external contractors.

The WAGR has been an EU-supported pilot dismantling project and Nuclear Electric and Scottish Nuclear make significant financial contributions.

24. BNFL Co-precipitation Plant, United Kingdom [24]

The BNFL Co-precipitation plant was part of the fuel reprocessing operations at the Sellafield site and produced a mixed powder of plutonium dioxide and uranium dioxide for the first fuel charge for the Dounreay PFR. The plant was in operation between 1969 and 1976. This Stage-3 decommissioning project, was run as a pilot project, for acquiring data on the decommissioning of fuel facilities.

The first decommissioning activities were the post operational clean out and the dismantling of the wet chemistry suite. Some 130 L of flushing liquor containing 900 g of plutonium and 1 400 g of uranium were reprocessed.

The next main operation was the removal of the Ball Mill from its glove box containment. This was the first application of the reusable modular containment (RMC) and demonstrated many of its advantages over a PVC-tent arrangement.

Subsequent removals included the powder transfer equipment as well as the furnace suite. For the latter, a flexible PVC enclosure was used instead of the RMC, thus allowing a comparison of the two procedures. In addition, the geometrically safe plutonium and uranium nitrate storage tanks were dismantled and the removal of the remaining glove boxes completed in October 1990.

Strippable coatings were used as a protective pre-coat on RMC panels before radioactive work or as a tie-down coat to fix loose activity. This also simplified the final clean-up. Small-bore pipe-work was dealt with without loss of containment by means of crimping/shearing tools.

The project was originally scheduled to be completed by late 1988. It was actually completed in March 1991. The main reason for the delay was the prolongation of the R&D activities to maximise the project's usefulness as a pilot project. There were however some other reasons as well such as

- greater than expected fissile material left in the systems,
- differences between drawings and actual plant,
- priority given to production operations over decommissioning projects at shared facilities (*e.g.*, pressurised suit entry facility),
- unplanned maintenance work.

The final cost is anticipated to be £2 245 000 compared to the originally estimated £2 033 000 (both 1989 money values) excluding TRU treatment and disposal costs. The increase in anticipated final cost of £212 000 is attributable to labour costs for the extra dismantling required offset by some savings on Plant and Equipment.

Other project data of interest:

• Person-hours	19 370
• Collective dose	305 milliman-Sv
• Waste	
– plutonium-contaminated material (PCM)	44.4 m^3
– shallow-land burial	12.0 m^3
• MOX recovered	46.1 kg (+ 2.9 kg as nitrate)

25. BNFL B204 Primary Separation Plant, United Kingdom [25]

The B204 building was originally built to reprocess uranium metal fuel and operated from 1952 until 1964 when the plant was superseded. One of the two process lines was converted to reprocess oxide fuel, operating from 1969 to 1973 when a release of activity into operating areas permanently stopped operations.

The building is of a reinforced concrete core about 60 m in height surmounted by a 60-m ventilation stack. The two original mirror image process lines each comprise two highly active cells and a medium active cell. The decommissioning strategy has divided the 20-year project into nine phases with safety and financial sanction sought separately for each phase.

Work has been proceeding on five of the nine phases:

- *Phase 1*

  The construction of a building waste handling facility (WHF) and provision of Medium Activity Cell North (MAN) decommissioning equipment. The site clearance for the WHF was completed in August 1992 at 81 per cent of estimated cost and 30 per cent of estimated dose uptake. After design and tendering in 16 work packages, the building and civil engineering work has been completed and all mechanical equipment has been procured and installed. The plant for decommissioning the MAN cell has been inactively commissioned and is awaiting agreement from the site regulators to commence active work.

- *Phase 2*

  Design studies for remaining project phases and development of project remote handling technology based on the CODRO concept (Contact Development Remote Operation).

  Conceptual design studies for high active and remaining medium active cells have been completed. Before finalising the strategy for the high active cell remote decommissioning, operational data from the MAN cell will be evaluated.

  Development work concentrated on the following areas:

  Remote handling operability trials on the 7-m reach hydraulic manipulator and telescopic deployment system.

  - Development of an hydraulic manipulator remote tool change system in conjunction with an external manipulator supplier.
  - Trials of a heavy duty 3-degree of freedom, 250-kg capacity, manipulator (ROBO WRIST) capable of deploying scabbling or heavy equipment from the telescopic arm.
  - Development of a milling disc system capable of cutting stainless steel and composites without generating excess heat or blade damage in the absence of coolant or lubricants for use in areas where effluent control is problematical.

- *Phase 3*

  Provision of a new filtered cell ventilation system was required before decommissioning operations could commence within active cells. This phase of the project is complete at a cost of £1.5 million.

- *Phase 4*

  A two-year programme for decommissioning the MAN cell has been approved and in-cell operations are due to start in January 1996. Removal of the associated control systems and out-cell services is 50 per cent complete.

- *Phase 5*

  Emptying the stainless-steel hulls silo. This has been advanced by ten years as a result of the Phase-2 design studies, which showed that completion by December 1996 would match an availability "window" at a waste disposal facility. A contract has been let to design, build and install a flask loading facility with a remotely operated loading vehicle. The ambient dose rates in the silo are about 75 mSv/h gamma. The breakthrough into the silo through the wall has been completed and the flashing facility has been constructed at the factory. Works tests will be carried out prior to installation at the end of 1995.

Like the UKAEA, the UK Group of BNF plc has been reorganised. Conceptual design services and manipulator development are provided in-house, detail design/equipment packages are put out competitive tender as is the case also for civil, electrical and instrument installation contracts. Mechanical installation and commissioning will be performed in house.

26. Shippingport, United States [26]

The Shippingport Atomic Power Station was constructed during the mid-1950s under the President Eisenhower's "Atoms for Peace" Programme. The station achieved criticality in December 1957 and was operated by a public utility, Duquesne Light Company, under supervision of the United States Atomic Energy Commission and later the Department of Energy-Naval Reactors Programme until operations were terminated in October 1982. The station's nominal power output was 72 MWe. Over the operating life of the station there were 2246.8 effective full-power days and the total gross generation was 7 374 GWh.

The objectives of the decommissioning project were to:

- demonstrate the safe and cost effective dismantling of a full scale nuclear power plant.
- transfer the experience of such a project to the nuclear industry by using a large number of sub-contractors.
- document these experiences in detail for use in future decommissioning projects.

Conceptual and detailed engineering for the decommissioning project was completed in 1983. The plan was to decommission the plant to Stage 3. The physical decommissioning consisted of the demolition and disposal of 26 various fluid and electrical systems before the buildings could be demolished. In all, about 17 100 m of contaminated piping and 16 800 m of non-contaminated piping, and 1 300 tanks were removed. All buildings were demolished and removed to about 1 m below the ground level. The Reactor Pressure Vessel/Neutron Shield Tank assembly, which measured 12.5 m high by 5.4 m in diameter, transported by barge 13 525 km in 44 days to the burial site. The total radioactivity removed was 6.14×10^{14} Bq, of which 6.09×10^{14} were contained in the reactor vessel. Total project radioactive waste volume disposed of was 6 057 m^3 weighing approximately 4 185 t. Also 11 470 m^3 of non-contaminated rubble was created during building demolition and was used to backfill the below grade reactor building enclosures.

Physical work on decommissioning the Shippingport reactor started on site in September 1985. All physical decommissioning work on site was completed on July 1989, about six months ahead of schedule. The total project cost was US$91.3 million, US$7 million less than the estimated US$98.3 million. The approval for release of site was issued in December 1989.

The most significant part of the Shippingport project was the one piece removal of the reactor pressure vessel (RPV) package and its 8 400-mile shipment. The total cost to prepare, to remove, and to bury the package was US$10.3 million. Work included in this was: re-positioning the non-fuel reactor internal components in the RPV; filling the RPV cavity and the NST annulus with an engineered grout mixture; developing and writing a Safety Analysis Report for Packaging; removing the RPV package as a single package, then loading and transporting the package to the DOE Hanford disposal site for burial, and the required co-ordination of shipment and state notification activities.

The total personal exposure was 1.55 man/Sv to be compared with an estimated 10 man-Sv in the original decommissioning plan.

The main lessons learnt from the project were:

- One piece removal of the reactor vessel was cost effective and practical. It is worthy of note, however that the low radiation levels of the plant and the low burial costs at the government owned burial ground were advantages which may not apply to the decommissioning of large commercial plants.

- Existing technology and equipment can accomplish decommissioning of nuclear power plants at reasonable costs.
- Observation of ALARA practice coupled with careful planning and scheduling can reduce radiation exposure and raise productivity levels.

27. West Valley Demonstration Project, United States [27]

The Western New York Nuclear Service Centre at West Valley, owned by New York State, was the only commercial facility for reprocessing of spent nuclear fuel to operate in the United States. In 1972, the plant was shut down for expansion, but increased requirements for structural safety, environmental considerations, changes in the economics of reprocessing, and a Federal decision against further civilian reprocessing all contributed to the operator deciding to abandon the facility. The New York State appealed to the Federal government for help, which took the form of the *West Valley Demonstration Project (WVDP) Act (1980)*.

The mission of the WVDP is to demonstrate the conversion of 2 000 m^3 of high level nuclear reprocessing waste to durable glass. The waste is 90 per cent liquid and 10 per cent sludge and will result in 300 borosilicate-glass-filled canisters.

The project is planned to be performed in two phases:

- Phase 1: Solidify the high level waste,
- Phase 2: Decontamination and Decommissioning. The part of the WVDP that was offered to the Co-operative Programme is the decontamination and decommissioning within the project.

As part of the first phase, there has been a two and a half year programme to clean up the chemical processing cell to allow for Phase 1 of the non-decommissioning related part of the project. This cell will be used as intermediate storage area for the glass canisters before transfer to the final repository.

In parallel, the main project activities have been

- treatment of the high level liquid waste (supernatant) in the Integrated Radwaste Treatment System (IRTS),
- construction of the Vitrification Facility (VF).

The IRTS is to:

- separate caesium 137 from the supernatant,
- concentrate the resulting low level liquid waste for cementation in drums,
- process the high level sludge for salt removal prior to vitrification,
- transfer it to the VF.

The first two of these operations have been completed. A total of 10 000 drums of cemented low-level waste are now stored on site for future transfer to the Yucca Mountain Repository.

Vitrification is scheduled to begin in 1996 and to be completed in 1998. Phase 2 – the decontamination and decommissioning of the entire facility – is planned to commence in 1999.

28. Experimental Boiling-water Reactor (EBWR), United States [28]

The Experimental Boiling-water Reactor (EBWR) at the Argonne National Laboratory was a demonstration BWR, originally of 20 MWt (5 MWe), then upgraded to 100 MWt. It started operation in 1956 and was shut down finally in 1967. The decommissioning project was started in 1986. The project aims at a status to allow the building to be used as a TRU Waste storage facility.

The first phase of the project – preparatory work for decommissioning – was completed in 1988. The removal of the primary and secondary system components, which constituted the second phase of the project, was completed in 1989. During the third phase of the project, which covers the removal of the reactor vessel and internals, there have been a number of major changes in the schedule and the operations of the project:

- All Argonne site construction activities were shut down between November 1990 and February 1991, ordered by USDOE internal inspection team. The Argonne engineering group provided some support to the decommissioning programme and so this impacted the project greatly even though the project was not criticised by the team. Even after the re-start of activities, planning and implementation of additional management oversight and quality assurance provisions significantly affected the progress of the project.
- The project started as one executed by an in-house skilled Argonne work team, consisting of three to 10 persons. Due to the limited availability of skilled decommissioning technicians the project approach was shifted from using an in-house team to using an external fixed price contractor: the Alaron Corporation.
- Originally, it had been planned to use abrasive water jets to segment the entire reactor vessel, mainly to reduce the fire risks of using "hot" cutting methods. Due to the change of scope at the placing of the Alaron contract and the new time schedule, the vessel was segmented using a WACHS cutting machine which uses a "cold" mechanical cutting technique. Fifty linear feet of the vessel was cut using the abrasive water jet technique. The mechanical milling machine worked very well and this allowed the comparison of the two techniques.
- Two of the four lifting slings broke when transferring the core structural assembly out of the reactor vessel, due to an unobserved protruding lug on the outside of the core shroud fastening in the vessel opening. There were no serious consequences.

The technical activities of the project have since been proceeding smoothly.

The reactor core assembly was transferred to the fuel pool in one piece. It was size reduced for disposal using an under water plasma torch. This technique was used sparingly inside the reactor vessel because of the red wood liner behind the vessel wall.

All vessel wall pipe penetrations were cut using a WACHS split frame pipe cutter. The WACHS split frame inside diameter cutting machine was then used for horizontal cuts, first to separate and remove the vessel bowl and then to divide the barrel of the vessel into five rings. The rings were lifted out from the vessel cavity and size reduced in a cutting tent. An abrasive water jet was used to perform a test cut 15 m long.

Comparison of the three cutting methods used on the EBWR reactor vessel (plasma torch, abrasive water jet, WACHS mechanical cutting machine) showed that, in this particular application, the WACHS machine had the most advantages. A comparison has also been made of all the cutting methods used in the project as a whole.

Part of the bio-shield behind the reactor cavity liner consisted of lead bricks, more than half of which will be recycled (by melting) by a nuclear research facility for use as shielding. The activated concrete was removed using a BROKK machine.

29. Fort St. Vrain, United States [29]

Fort St. Vrain was a 350-MWe high-temperature gas-cooled reactor that was operated by the Public Service Company of Colorado (PSC) between 1976 and 1989. It was shut down mainly due to the poor operational performance (<15-per-cent capacity factor/<30-per-cent availability), high fuel costs and consequently uneconomic to operate.

Originally the spent fuel was to be stored or reprocessed at the Idaho National Laboratories (INEL). As INEL now refuses to accept the fuel, PSC have constructed an intermediate dry storage facility for the fuel on site with a 20-year licence (+20 years option).

Immediate dismantling to Stage 3 was chosen as the decommissioning alternative for a number of reasons, including:

- increasing disposal costs with time (11.9 per cent per year since 1980),
- uncertain long term regulatory situation,
- adequate dismantling technology available,
- technical personnel with intimate knowledge of site would not be available later,
- easier to "repower" the site with a gas fired boiler.

The Westinghouse Team with M K Ferguson as construction contractor won the fixed price contract for decommissioning the plant. The total costs, including in-house costs and that for low-level waste disposal are estimated to be USD$174 million. The dry fuel storage costs have been US$13 million.

One characteristic of the Westinghouse concept is to dismantle the reactor internals after filling the vessel with water. This is done by a 325 000-gallon water system, with two pumps and ion-exchange and 0.3-5 μm filters for keeping the water clear.

First, the central part of the top slab of the prestressed concrete vessel was cut out in 12 wedges using a diamond wire saw, involving the removal of 1 320 t of concrete. A rotary work platform was installed for the continued work. The top head liner was cut up with oxygen lances and removed, after which the reactor internals were removed with the water in the vessel acting as shielding. These activities included the following:

- The graphite from the reactor vessel – 1 770 pieces with surface dose rates up to 3 Sv/h – has been sent off site as low-level waste.
- The upper core barrel (9.15-m diameter, 8.85-m height, 67-mm wall thickness) was segmented under water with a remotely operated plasma arc torch. The segments were shipped to Hanford as low-level waste.
- Two shifts of eight divers, each diver making a 90-minute dive, were utilised:
  - first to clean up debris, etc., from the core support floor,
  - to use underwater jack hammers to remove silica plugs in the core support posts,
  - to use a remote plasma arc cutting tool to free inconel sleeves in the posts,
  - to use handheld plasma arc torches to remove the stainless steel floor thermal seal.

- The inconel sleeves had contact doses of 200-500 mSv/h and so steel work platforms were designed to keep the divers at a safe distance.
- The core support floor was cut loose from its supports during 1 250 dives, performed over ten months. A collective dose of 173 milliperson/Sv was taken.

A 4-inch steel plate had been attached to the top of the core support floor as shielding. This reduced the dose rate from the floor (when lifted out) from 10 mSv/h to 0.5-0.6 mSv/h.

The entire facility is being cleaned up to release limits of 25 per cent of the guide line value of 5 µR/h. It is planned to release the plant with the decontaminated pressure vessel in situ.

30. Fernald Hexafluoride Reduction Plant, United States [30]

The Fernald Material Production Centre was operated from 1952 to 1989 to produce high purity uranium metal for the US Defence Programme. It is located near Cincinnati in Ohio. After defuse production work was permanently shut down in 1989, the Fernald Environmental Management Project (FEMP) was started to clean up the site.

FEMP was structured into a number of "operable" units, each unit covering a grouping of facilities or issues. Operable Unit 3 covers the production area and associated facilities and equipment.

Remedial Investigation reports and Feasibility Studies have to be submitted by the owners (DOE) to be reviewed and approved by the regulator EPA before actual field work is undertaken. In the case of Operable Unit 3, it was considered that the facilities in question were at or beyond their design life and in a state of advanced deterioration. There was danger of structural collapse with the possibility of the release of hazardous substances. So an interim remedial action plan has been prepared (draft version April 1994). When this interim remedial action plan is approved by a joint record of decision by the DOE and EPA, work can start on site.

The interim remedial action plan is by itself very comprehensive and includes the decontamination of more than 200 buildings and structures by removing as well as the off site recycling (by melting) of some dismantling waste.

Plant 7 was the hexaflouride reduction plant and is the tallest structure on the site. The actions proposed are:

- asbestos removal (approved by EPA),
- wash down/contamination lock-down to reduce the loose contamination levels,
- structural steel demolition.

Plant 4 processed uranium trioxide to uranium tetraflouride and blended and packaged it for delivery to the Metals Production Plant. When Plant 4 was shut down in 1989, the equipment was simply turned off, leaving large amounts of process material inside the piping, tanks and other equipment. So the first four months (November 1994-February 1995) were taken up by safe shutdown activities.

The scope of activities for the Plant 4 decommissioning include:

- asbestos abatement/removal,
- surface decontamination,

- above-grade component dismantlement,
- material/waste management,
- environmental monitoring,
- confirmation sampling.

The site contractor is FERMCO (Fernald Environmental Restoration Management Corporation). The current phase is budgeted to cost USD 1.2 M.

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Annex II

PROGRESS IN SELECTED AREAS

Assessment of Activity Inventories

BR3, Belgium

The activity inventory of the thermal shield was determined by calculation and measurement after shutdown (30 June 1987) and after three years of cooling (30 June 1990). The results were as follows, expressed in GBq/kg (mCi/kg):

GBq/kg (mCi/kg)	Cooling time, calculated		Measured
	0	3 years	4-25 years (Dismantling)
Inner surface Cobalt 60 Manganese 54	 112.77 (3048) 18.32 (425)	 76.04 (2055) 1.63 (44)	 64.38 (1740) 0.59 (16)
Half-thickness Cobalt 60 Manganese 54	 37.85 (1023) 10.14 (274)	 25.53 (690) 0.89 (24)	
Outer surface Cobalt 60 Manganese 54	 42.14 (1139) 5.29 (143)	 28.42 (768) 0.48 (13)	

A surprising point was the activation of the anti-missile concrete slabs situated almost 10 m from the reactor core. The slabs were cut by diamond core drills and in order to assess the contamination penetration depth in the concrete, gamma spectrometry measurements were carried out on the drilled "core".

If the contamination (by cobalt 60 and caesium 137) was clearly seen at the surface layer, activation products were also found inside the bulk material. Isotopes like barium 133, coming from the barium sulphate included in the heavy concrete, europium 152, europium 154 and cobalt 60 in the reinforcement bars, appeared to be due to activation rather than to any contamination. Moreover, the distribution shape along the thickness of the piece was quite uniform. The specific activity content amounts to approximately 20 Bq/g (cobalt 60: a few Bq/g and 120 Bq/g in the rebars).This result was rather surprising because the slabs were situated at a great distance from the reactor core: about 10-11 m from the reactor midplane.

The first measurement led to set up a more systematic measurement scheme of the concrete activation level around the reactor. A first "core" was taken in March 1994, in the concrete (bio-shield) situated around the reactor, at a level situated 2 000 mm under the core midplane. The result is still surprising, since there and up to 150 mm of the internal surface almost no activation was measured (the reactor is surrounded by a "neutron shield tank", water filled).

As a result of these very different and apparently contradictory results, a complete study of long range activation modelling has been started. The main goals of this study are the following ones:

- to be able to predict the activation of concrete and infrastructure at great distance from the reactor core;
- to detect the possible "preferential path" through which there can be some neutron "streaming";
- to be able to propose a remedial solution for stopping the neutrons at the right locations.

This problem is important regarding the determination of the radwaste inventory, especially if very low clearance limits are accepted.

MZFR, Germany

The activity inventory at shutdown for the reactor pressure vessel was distributed as follows:

Component	Activity
Pressure vessel lid	1.16×10^{8} Bq
Moderator vessel	7.90×10^{16} Bq
Thermal shield	9.93×10^{14} Bq
Channels for fuel elements	5.47×10^{14} Bq
Channels for control rods	2.39×10^{14} Bq
Biological shield	6.01×10^{12} Bq

WAGR Pilot Dismantling Project, United Kingdom

A complete reassessment of the calculated component activations using the neutron transport code ANISN together with appropriate activation cross-sections and the comparison with sample measurements, where available, has been prepared in order to update the waste volume estimates for the various categories. This exercise has also provided validation for the calculation route showing that sample measurements are generally within a factor of two of the calculation with occasional excursions to a factor of three.

Although this does not seem particularly precise, from the point of view of establishing waste boundaries and quantities it is adequate. The difficulties and expense of producing truly representative samples precluded further investigation.

A work centred on mapping the activity of the bioshield concrete has given results largely as expected, generally following the anticipated neutron flux profile through the concrete. However, there was some evidence that tritium (from irradiation of trace lithium) has migrated through the thickness of the bioshield, due to temperature and concentration gradients.

Modelling work has being carried out to fit the experimentally determined tritium profiles against the predictions from a standard diffusion model. Results so far indicate two physical processes occurring. One relates to the movement of tritium through interlocking pore water in the cement matrix.

The other is due to the exchange of tritium in water of hydration. Overall the effect of diffusion on waste categorisation is small compared with decay process of tritium. The present results from the model suggests that the intermediate-level waste band at the inner face of the reactor bioshield will revert to low-level waste around the year 2020. A physical basis for this model has yet to be determined.

Tunney's Pasture Facility, Canada

The total radioactive inventory facing the second decommissioning phase was less than 4 Ci. The principal radioisotopes responsible for this inventory were: americium 241, thorium 228, radium 226, caesium 137, caesium 134, cobalt 60, europium 152, carbon 14, nickel 63, chlorine 36, antimony 125, uranium 235, cadmium 109 and iodine 129. Most of the radioactive inventory was deposited in ventilation equipment.

KKW Greifswald, Germany

Since the decision to decommission and dismantle the plant in Greifswald, a radiological mapping is going on. Based on these measurements and calculation the global inventory without nuclear fuel was estimated to 3.5×10^{17} Bq with the following break down:

– pressure vessel and core internals	3.4×10^{17} Bq
– used core components	1.0×10^{16} Bq
– contamination in plant systems	1.0×10^{15} Bq
– operational waste	1.0×10^{14} Bq
– radiation sources	5.0×10^{11} Bq

VANDELLOS NPP1, Spain

Five years after last shutdown (19-10-89) the total activity of the reactor vessel and internals amounts to 6.7×10^{16} Bq.

HDR, Germany

As a result of the relatively short operating period of the reactor, the activity inventory and the dose rates were very low. So the activity inventory of the activated materials, consisting of the RPV, the biological shield and the steel liner of the refuelling chamber in the closer vicinity of the reactor, was in the range of just 4×10^9 Bq. The total activity inventory from contamination amounted to approximately 1×10^{10} Bq.

The dose rates measured at the inner surface of the activated RPV at a distance of 0.5 m was approximately 70 µSv/h and at the hottest spot of the primary circuit approximately 80 µSv/h. This permitted access to every section of the plant interior without the need of additional shielding measures.

FEMP Plant 7

In March/April 1991, and again in May 1992, radiological surveys were conducted. The samples were taken at random locations throughout all seven floors, providing an accurate summation of radiological conditions. Each sample collected identified removable alpha and beta-gamma contamination. The readings collected during both surveys are summarised in the following table.

Floor	Alpha Counts (dpm/100cm^2)			Beta-gamma Counts (dpm/100cm^2)		
	Low	High	Mean	Low	High	Mean
One	15	1 209	139	29	3 355	472
Two	23	4 776	208	135	11 080	775
Three	133	3 589	589	198	41 611	2 699
Four	133	7 616	917	130	15 939	3 042
Five	133	33 253	2 300	335	55 620	6 449
Six	133	3 757	892	153	21 246	4 247
Seven	133	10 971	2 332	130	73 296	11 063

JPDR, Japan

At the early stage of planning the dismantling activities, characteristics of decommissioning waste was evaluated based on calculations and measurements. On the calculations, computer code systems were prepared for the estimations of radioactive inventory at the core region. ANISN, DOT 3.5 and ORIGEN were basic computer codes applied to the estimation. On the measurements, more than 4 000 samples were taken to evaluate the amount of radioactive contamination in the whole JPDR facility. In addition, tools for in-situ measurement of radioactivity were developed and applied to the assessment activity inventories.

Cutting Techniques

Eurochemic Reprocessing Plant, Belgium

The main metal cutting techniques used during the dismantling work in the cell blocks of the main process building were:

- Oxy-arc cutting: by this technique, the metal is cut by melting, by producing an electric arc between a hollow welding electrode and the metal surface. The melted metal is evacuated by blowing air through the cutting electrode. Since hand-operated plasma-arc cutters are available, this technique was no longer used.
- Better experiences have been obtained by plasma-arc cutting. Also here the metal is melted by means of an electric arc and melted metal is evacuated by compressed air flow. In the smaller units, up to 120 A, the handtorches are cooled by air flow. In the more powerful units, the torches are water cooled in a closed circuit cooling system. By means of a 200-A unit, it is possible to cut iron up to 50-mm thickness, and aluminium and stainless steel up to 40 mm.
- Other techniques used for metal cutting are nibblers for steel plates up to 10-mm thickness and hydraulic shears for cutting stainless steel pipes up to diameters of 2 inches. The shears are radio controlled and have been mounted on a balancer to reduce weight load to the operators. For the dry cutting of cast iron shielding blocks, hydraulically controlled diamond blade saws are used.

BR3 Reactor, Belgium

For segmenting the reactor thermal shield the methods selected and equipments developed were: mechanical sawing using a milling cutter; electro-discharge machining (EDM); plasma arc torch cutting (in flooded chamber).

The following table summarises the main parameters which can be considered as describing the performances of the cutting techniques used for the reactor vessel thermal shield: consistency with the parameters which were recorded during cold testing and optimisation of the techniques is good.

Cutting method	Cut length (m)	KERF Width/Depth Nox Length (mm)	Cutting speed[1] (mm/min)	Time for cutting + prep. (working shift 8 h)	Effective cutting speed (m/w.s.8)	Metal removed from thermal shield (dm^3)	Secondary waste volume (dm^3)	Ratio waste vol/cut length[1] (dm^3/m)
Vert. EDM	2.92	7/76.2 8 × 365	0.6	23	0.13	1.622	96[2]	33
Horiz. Mech.	4.15	4/18-20 4 × 4150	6	8	0.52	1.262	26.7[3]	6.4
Horiz. Mech.	4.15	4/18-20 4 × 4150	6	10	0.42	1.262	26.7[3]	6.4
Horiz. Mech.	4.15	4/18-20 4 × 4150	6	6	0.69	1.262	26.7[3]	6.4
Horiz. EDM	4.15	7/76.2 12 × 346	0.6	30	0.14	2.208	128[2]	31
Vert. Plasma	14.98	11/76.2 24 × 482 8 × 426	300	17	0.88	12.55	459[4/5]	31

Cutting Technique Performances

The next outlines only two main parameters characterising the technique efficiency: the cutting speed to be maximised and the volume of secondary wastes to be minimised.

The following table shows that compared to mechanical sawing, plasma cutting is not going two times faster and EDM is going only four times slower, but they are both producing five times more waste.

1. For 76.2-mm wall thickness.
2. Fine filters containing activated EDM particles.
3. Coarse filters containing activated chips.
4. Coarse, intermediate and fine filters; demineraliser columns not completely saturated.
5. Not taking into account the waste produced by the air filtration system.

Parameter	Cutting speed mm/min (through SS 76.2-mm thick)		Average effective cutting speed (m per 8-h working shift)		Secondary waste volume for same cut
Cutting Method	**Absolute**	**Relative**	**Absolute**	**Relative**	**Only relative values**
Electro discharge machining*	0.6	1/10	0.13	1/4	≈ 5
Mech. sawing	6	1	0.54	1	1
Plasma	300	50	0.88	1.6	≈ 5

Many considerations can be made on the data of the two previous tables:

- all segmentation methods are characterised by a far too slow effective cutting speed: less than a 1-m length cut through 3-inch (76.2 mm) thick stainless steel per working shift of 8 h: the optimisation has to be mainly focused on a drastic reduction of the time devoted to operations distinct from cutting;
- the total volume finally occupied by the secondary wastes, ready for evacuation into tight canisters, is larger, by a factor varying between 20 and 60, than the volume of metal removed from the cutting kerf; even for mechanical sawing which is producing only metal chips, collecting these chips into strainers and introducing these strainers into tight evacuation canisters, implies a volume enlargement by a factor close to 20; the methodology and equipment for secondary waste collection and evacuation have to be deeply optimised;
- for the same length cut, mechanical sawing is producing a secondary waste volume which is five times smaller than for the other two applied cutting techniques; as the cost for waste evacuation and treatment is volume related and as a dilution of the activity by less than a factor 5 does not imply a modification of the waste category and waste evacuation cost, this is a most interesting aspect of mechanical sawing.

  As a general conclusion, mechanical cutting has been proved to be an efficient and clean method for underwater segmentation of highly activated stainless steel reactor internals.

Regarding the experience gained during the dismantling of the thermal shield, remote mechanical cutting techniques are promoted everywhere it is feasible and reliable.

Different types of mechanical cutting will then be used for the dismantling of the reactor internals: circular saw, band saw, reciprocating saw and hydraulic shears. Moreover, MDM (metal disintegration machining), which is close to EDM (electro discharge machining or electro-erosion), will be used as a back-up technique for difficult operations where the limitation of mechanical cutting could be met.

EDM has also been selected for some delicate "surgery" operations.

The different techniques have been selected following the shape, geometry and characteristics of the pieces to be cut; the segmentation of thinwalled pipes being obviously not carried out with the same tools as the one used for cutting thick carbon steel ring. A summary of the cutting techniques selected for the dismantling of the different internals is given in the following table.

Tools Tested and Used in the BR3 Decommissioning Project
Dismantling of Metallic Components

1. Highly activated components				
Method/Tool	**Used for**	**Capacity of the tool**	**Main problems encountered**	**Main advantage**
Plasma arc torch	• Thermal shield (th: 76.2 mm SS)	Up to 100 mm SS	• Secondary waste • Tool contamination • Vibrations	• Speed
EDM	• Thermal shield LCSA (bolts removal)	Various shapes and dimensions	• Secondary waste • Speed (very slow) • Electrode wear control	•Shape of electrode • Reaction force very low
Milling cutter/ Circular saw	• Thermal shield • LCSA horizontal cutting	• up to 200 mm thick	• Stiffness of the support	• Secondary waste
Band saw	• LCSA vert. cutting • Reactor collar (CS+SS thickness ~ 200 mm) • Plates and grids	Almost unlimited	• Access on both sides of the workpiece	• Secondary waste • Flexibility
Reciprocating saw	• Control rods • Guide tubes • Shroud tubes • Collector (upper internals)	Depends on saw and piece shape	• Slow • Blade wear	• Easy tool (no special skill needed) • Cheap
Hydraulic cutter (scissors)	• Various tubes a nd plates • Pipes and instrumentation	• Up to O.D. 2 inches	• Closure of the pipes and tubes	• Very cheap • No secondary waste • Easy to handle

2. Contaminated components				
Method/Tool	**Used for**	**Capacity of the tool**	**Main problems encountered**	**Main advantage**
Reciprocating saw	• Stand-pipes	Up to 300 mm (depends on the saw machine)	• Quite slow • Installation	• Easy tool • Quite sheap
Automatic pipe cutter	• Stand-pipes	n.d. (specific to the cutter)	• Quite delicate tool	• Quick • Remotely operated
Grinding	• Various tubes plates	Up to 10-15 mm thickness	• Contamination spread • Hands-on	• Flexibility

Rapsodie, France

The totality of the sodium cooling primary system (pipes, pumps, exchangers) has been washed with ethylglycol, decontaminated by flushing at 60°C with acid reagents and adding cerium IV then dismantled by manual cutting.

G2 and G3, France

The dismantling of carbon dioxide cooling circuits has been done with semi-automatic cutting using plasma arcs.

The concrete structures were demolished using a hydraulic stone crusher mounted on a field crane.

AT-1, France

A remote controlled machine (ATENA) has been used to dismantle the process equipment in the three main shielded blind cells (without window or manipulator).

Shears were used for the first cuttings. The important weight of this tool (18 kg) compared with the capacity of the remote manipulator MA23 led to the mounting of a weight-balance system on the take-up of the power cable to relieve the strain on the slave-arm.

Although the work was satisfactory, the use of a circular saw was then essential for its greater usability (7 kg) considering the difficult access to the cells and the shape of some of the parts to cut.

The circular saw was much used by the remote-manipulator MA23. The main failures recorded were breaks of tape and belts and gear wear. The device went back each time to the maintenance station. To shorten the immobilisation period, a second slave arm was put in operation, one could then be repaired while the second was working.

Some vessels in cells exhibiting a fairly high radiological background (2 mGy/h) were dismantled using detonating cord; this technique meant that the work time could be reduced but also that the concrete cell panels had to be shot blasted because of contamination arising from material dispersed by the explosives used for cutting.

KKN, Germany

For the removal of the active and inactive structures made of lightweight concrete or baryta concrete (biological shield), the following techniques were applied (sometimes alternatively):

- Pyrotechnical, controlled loosening explosions; concrete removal by a hydraulic excavator;
- direct concrete removal by a hydraulic excavator;
- loosening of the concrete by means of hydraulic splitting tools ; depending on the accessibility, concrete removal is carried out by means of the hydraulic excavator or manually using pneumatic hammers.

The removal techniques were chosen on the basis of the following criteria:

- activation depth and, hence, depth of removal;
- accessibility;
- density of the concrete reinforcement.

Here, above all economic aspects of the drilling work both for pyrotechnical and hydraulic explosion had to be taken into account. Particularly in the strongly concrete-reinforced areas, time-intensive core drilling had to be applied instead of using solid drill devices and saving time. As the preparatory work for core drilling takes a lot of time, however, this technique could only be used economically at higher drilling depths.

Removal by explosion of the upper support ring, the biological shield and the lower support ring met with wide acceptance due to the positive experience gained (small dust generation, good concrete crushing). Even the decision not to separate the innermost concrete layers before the explosions and, hence, to provide protection against blast-off concrete chunks, proved to be right. The vertical boreholes having a mean depth of 2 m were filled with an average amount of about +500 g ammonium nitrate explosives and located at least 30 cm away from the inner surface of the concrete. Having a maximum of ten boreholes with the individual charges being ignited successively within periods of one millisecond each, an area of about +3 m in length could be loosened.

Using drilling and splitting techniques (hydraulic blasting), above all the wedge cavities and the balcony structures were removed on the outer side near the feedthroughs of the moderator discharge pipes. As only small devices were used, these activities turned out to take a lot of time.

Removal of the activated concrete structures at the upper support ring which was started in the middle of April 1993 after the dismantling of the platform shield proved to be extremely efficient due to the combination of the techniques described. In the middle of July already, dismantling of the biological shield could be begun. While this work was carried out in three steps, *i.e.*, in height ranges of about 2 m, simultaneous activities could be performed in the balcony regions. By the middle of September, the last 400-L drum was filled with the baryta concrete of the biological shield. With the end of the dismantling of the lower support ring at the beginning of October 1993, the phase of the removal of activated concrete structures (maximum concrete activity 20 Bq/g) was completed successfully.

The lessons learned can be summarised as follow:

- The most essential phases of KKN decommissioning (inactive, contaminated, activated dismantling) also apply to modern generations of nuclear power plants – except for the very special remote-controlled dismantling, which is due to the filigree design of the reactor.
- Available dismantling techniques are basically sufficient, the need of developing additional procedures or tools, especially in the field of activated dismantling, rather is an economic question.
- As far as the economic aspect is concerned, the following statements can be derived with regard to the removal of the activated concrete structures of KKN:
  - Small removal depths of up to about 30 cm justified the only use of the rock chisel of a hydraulic excavator due to the high removal speed achieved.
  - Deeper activated areas and in particular the baryta concrete of the biological shield with a slight reinforcement in the region of the bore holes could only be removed rapidly by combining loosening blasting and the use of the hydraulic excavator.
  - Removal in inaccessible areas could be carried out by small equipment only.
  - The combination of loosening blasting and the use of an hydraulic excavator with a rock chisel allowed easy and rapid dismantling of the activated concrete structures within a total of 9.5 months, whereas the plannings had been based on a duration of 17.5 months.

Garigliano, Italy

According to the project the stack (90 m high, with an external base diameter of 4.8 m) will be demolished in one piece, cutting the concrete at its base with a machine operated by remote control. Before this, the stack internal surface will be scarified with a remotely operated rotating water jet (the total estimated radioactivity is 67 MBq and is concentrated in the first few millimetres of the internal surface).

JPDR, Japan

Remote cutting system such as the following had been applied successfully to the actual dismantlement of the JPDR and their performances have been evaluated and compared with the results of mock-up tests:

• Underwater plasma-arc	(Reactor internals)
• Arc-saw	(RPV)
• Rotary disk knife	(Pipes connected to the RPV)
• Shaped explosive	(Pipes connected to the RPV)
• Diamond sawing and coring	(Biological shield concrete)
• Abrasive water jetting	(Biological shield concrete)

The highly activated (2 mSv/h) portion of the biological shield concrete has been demolished remotely using both the diamond sawing and coring technique and the abrasive water jet technique. The outer layer of the biological shield has been dismantled using controlled blasting techniques.

- The diamond sawing and coring system was successfully applied.
- There was a vacancy between the steel liner and the concrete at the upper end of the biological shield. It caused a difficulty to grip a cut block by the remote block clamp. Therefore, the handling method which can be applicable to different shaped blocks should be developed.
- Semi-manual coring machine is applicable to demolish the concrete remotely. Simple machine is useful and it can save much installation time.

The outer layer of the biological shield have been dismantled using controlled blasting technique.

WAGR, United Kingdom

To reduce the length of the standpipes linked to the reactor top dome, plasma-arc cutting techniques were used.

The cutting equipment was deployed by the overhead crane which lowered the equipment into the standpipe. On completion of six cuts, a TV camera, again suspended from the overhead crane was inserted into each standpipe to inspect the effectiveness of cut and a video recording taken. This recording allowed checks to be carried out on all standpipes to ensure that top dome removal would not be restricted by partially cut standpipes.

EBWR, United States

The underwater size reduction of the reactor core assembly has been performed using an underwater plasma arc torch. All remaining reactor internals (such as the steam ducts, shock shields, thermal shields and experimental appendages) were removed from the vessel using a plasma arc torch and transferred to the fuel pool for size reduction. All reactor vessel nozzle penetrations were removed using a split-frame pipe cutter. The segmentation of the reactor vessel has been also performed with this technique.

Some comparisons were made between various cutting methods, such as: plasma arc, oxyacetylene and abrasive water jet. A study was undertaken for evaluate various reactor vessel cutting techniques.

Underwater plasma arc cutting of reactor vessel internals has performed satisfactorily although not without some problems. As the fuel pool conductivity increased the operator was unable to strike an arc or even maintain an arc underwater. Change of the plasma gas to an Argon-Hydrogen resulted in satisfactory performance. Problems with protection from electrical shocks precipitated insulation of the pool handrails and surrounding flooring and the use of non-conducting fuel pool tools. Plasma arc cutting released small amounts of radioactivity from the corrosion layer of irradiated hardware in the pool. These amounts were not detected during the work and resulted in some worker internals uptakes.

Tunney's Pasture Facility, Canada

Three different techniques are used at Tunney's Pasture for cutting metal component of the ventilation system. They are:

- plasma arc
- metal saw
- nibbler.

Technique	Advantages	Disadvantages
Plasma arc	• Fast process • Can cut as much as 0.5 inch thick metal	• Generate fumes that clog HEPA filters
Metal saw	• Clean process with small amount of wastes generated	• Slow process
Nibbler	• Faster than the saw for cutting light gauge sheet metal	• Induces vibration in components and loosens particles of contamination • Can only cut light gauge sheet metal

The concrete structures of the hot cells have been methodically cut down by using diamond wire cutting.

B204, United Kingdom

Residual solvent within the reprocessing plant equipment requires cold cutting techniques to be adopted for the removal of pipes and vessels within the active cells. High pressure water heat cutting and the use of lubricarts on disc cutting saws is not practical due to the problems with control of the resulting liquid effluents. Trials using high speed steel, tungsten carbide and diamond impregnated cutting discs were ineffective due to damage of the cutting discs or work hardening of the cutting samples.

A dry milling disc cutter, reciprocating saw and hydraulic shear have been developed with remote tool charge facilities to interface with a Schilling manipulator for in-cell work.

Hot cutting systems are employed with industrial robots in the Waste Handling Facility especially constructed for conditioning the waste. Initially an air plasma unit with 40-mm cutting capacity was employed but it was found to be difficult to ensure a clean cut when operating near its cutting capacity. The unit has now been replaced with a Hydrogen/Argon plasma system with a 70-mm cutting capacity. The risk of fire and explosion is removed by inerting the vessels with Argon prior to cutting. Proprietary ventilation systems are used to remove dust particles from the fumes prior to treatment by the installed cell ventilation system.

JRTF, Japan

Studies on the following dismantling techniques has been started in 1992:

- Press and cutting techniques of steel pipe.
- Cutting techniques of reinforced concrete by wire sawing.

HDR, Germany

Metals

Mechanical as well as thermal cutting techniques are considered. To minimise radiological exposure of staff through inhalation, local air ventilation units with air filtering are foreseen.

Concrete

For the cutting and segmenting of concrete, the following techniques are scheduled:

- Core drilling.
- Diamond cable cutting.
- Sawing by means of circular saws.
- Conventional methods, such as scabbling or other mechanical descaling means.

Concrete segmentation by blasting is not being considered.

Accumulating cooling – and rinsing water is being removed on the spot by means of suction devices or is being collected otherwise and led away for treatment. Dust and fumes generated are being collected at the cutting zone. The ejected air is being filtered, before being released into the working environment.

Fort St. Vrain, United States

The central part of the top slab of the Fort St. Vrain prestressed concrete reactor vessel was cut out in twelve wedges, using a diamond wire saw, involving the removal of 1 320 t of concrete.

The upper and lower core barrel were segmented utilising a remote operated, track mounted underwater plasma arc torch.

For removal of other internal parts, divers, utilising the diving sledge, were employed. They used underwater jack hammers or hand held plasma arc torches.

Remote Operation

Many of the projects in the programme required the use of remote operations to safely cut and handle waste items of high specific activity. These operations fall into three broad classes:

- long handled tools (used for example in underwater cutting techniques);
- manual or powered tools operated in shielded facilities;
- automatised and computer assisted machines.

It must be emphasised that there has been little use of the so-called robotic or autonomous machines. Decommissioning operations by definition involve the continual changing of the working environment and so almost always need to be directly manually controlled. Computer assistance is useful in allowing the operator to control movements more easily, for example in the manipulations used in JPDR, WAGR and KKN, but overall control always remains with the operator.

A number of straightforward size reductions or handling techniques developed from standard nuclear experience have been applied in several of the projects. Examples of these and the computer assisted large machines are described in the following.

Eurochemic Reprocessing Plant, Belgium

Concrete Structures

For cutting and decontamination of concrete structures first of all use has been made of an electro-hydraulic powered robot, type Brokk 80. This is a remote controlled hydraulic arm mounted on a small transporting system. In its smallest configuration the dimensions of the transporting system are $76 \times 215 \times 1500$ cm, so that it can be passed through a normal standard door. The robot arm can be equipped with a shovel to remove demolished concrete or sand.

If not the complete concrete structure, but only a surface layer has to be removed scabblers are used. To improve the working conditions for the operators, and to increase capacity, scabblers have been automised. First of all, the robotic arm of the Brokk 80 has been equipped with a modified floor scabbler. This combination proved to be useful for scabbling floors and ceilings.

An in-house Belgoprocess development was an automised wall scabbler. It used an adapted three-headed floor scabbler which could be remotely operated. The scabbler could be moved over the wall surface from top to bottom and from the left to the right. The capacity of this system was about 12.5 m^2/h for removing surface layers of 3 to 5 mm. It had a rather long mounting time going up to 2 h. Moreover, due to its construction, a rather important surface area, covered by the installation could not be reached.

To solve this time consuming mounting problem and to increase the working area, a new model of automised scabbler was developed. It consisted of four scabbler heads, fixed to a rotating cross. The system operating from a small desk, moved up and down over a vertical column mounted on a four-wheel driving unit. All the moving parts were powered by four identical pneumatic motors. It could be used for decontaminating floors, walls, ceilings and surfaces under an angle. The capacity of the system went up to 15 to 20 m^2/h for removing concrete surface layers up to 3 or 5 mm. The machine could be dismounted in portable pieces so that it could be brought inside all cells and be re-mounted there again. Mounting time took about 40 minutes.

Metal Components

The feasibility of using welding robots in the dismantling of metal components was evaluated in different contacts and demonstrations. It was made clear that the complicated and time consuming programming of this equipment makes these robots unsuitable for performing the different kinds of applications in Eurochemic decommissioning work.

The feasibility of a robot arm, controlled by a kind of joystick, has been evaluated. A demonstration and additional information gathered showed that:

- the robot arm demonstrated proved to have high lifting capacity (100 kg) and to be well adapted to the work he was created for,
- the robot arm can be used for decommissioning work in non accessible areas,
- force feedback will be necessary to handle most of the tools required,
- at this moment no or not so much adapted tools are available on the market for use with the system,
- working with this manipulator requires a lot of training for the operators,
- the use of such a robot arm requires a second system for operator training and to allow the development of adapted tools,
- using the robot arm demonstrated will certainly not result in higher work efficiency in our decommissioning tasks.

In view of what has been demonstrated, and taking into account the high cost of the installation, the need for further development work on the system, the rather limited applicability and achievable decommissioning efficiency in Eurochemic installations, it has seemed to be better not to go to far in automation of decommissioning work in accessible areas or in areas that are made accessible by extensive decontamination operations.

Therefore, more emphasis has been put on optimisation of used and known techniques and on adapting them to allow the decommissioning work to be done in more comfortable circumstances.

BR3 Reactor, Belgium

For the dismantling of reactor internals, all the cutting operations were carried out remotely and under water. The control of the cutting process (for plasma arc torch, EDM, milling cutter, band sawing, hack sawing etc.) was done from a control cabinet situated on the operating deck of the reactor building, almost 10 to 15 m away from the cutting location. Visual control was carried out both by direct vision through the water and by means of televisual system using remote controlled underwater camera.

The maintenance of the equipment and the tool exchange was executed hands on, after removing the equipment out of the water. The smooth surface of all the equipments (imperative request issued when buying or fabricating the equipment) allowed to decontaminate them by using high pressure water jet system. Almost no dose uptake was done during these operations except for the removing of "plugging" in the sucking and filtration system.

For the dismantling of the instrumentation basket, involving the cutting of a lot of small pipes and tubes by an hydraulic jaw cutter, the use of a telemanipulator (hydraulic powered) was foreseen for positioning the tools and griping the cut pieces. Nevertheless, the cold testing on full scale mock up showed that the time needed for performing the operations was much higher with this telemanipulator than using long handling rods and that probably no dose savings (and even maybe more dose uptake) could be foreseen. Therefore the use of the telemanipulator was completely abandoned.

AT-1, France

An intensive use has been made of the ATENA dismantling machine, equipped with the MA23 telemanipulator. The machine can travel above the containment and introduce the telemanipulator arm into the cells through openings equipped with closure devices, with no break in containment and shielding. It can be moved to a maintenance station located at the end of the cell row; that station consists of a large glove box, inside which the manipulator arm can be fully extended.

A light-weight carrier moving along a rail fixed to the ground, operated in remote-control mode has been used with different tools such as a blasting head or a contamination measuring device (AMANDIN type mosaic counter).

The following relationships exist between the various parameters for manual and remote cleansing, in other words with the carrier, for equivalent areas decontaminated:

- a factor of 1.5 in the time saved,
- a factor of 2.5 in the exposure saved,
- a fivefold reduction in the number of outages associated with maintenance work on the blaster, confirming the benefits to be had from remote decontamination.

The carrier also functions well in radioactive environments.

The lessons learned with use of robot dismantling at AT-1 can be summarised as follows:

- At present, robot dismantling is rather expensive, but the available figures relate to a pilot operation using prototype equipment. Expenses could be optimised by reducing the cost of the machines used and by amortising investments over several sites. However it is not easy to reuse a machine dedicated to a given facility, on another one.
- When direct manual working with reasonable working times is feasible robot operation is not competitive in the current situation.
- The discomfort factor (ventilated suits) is sometimes more of a limitation than the dose absorbed.
- In cases where it is possible, it may be advantageous to reduce activity by decontamination to below the threshold for manual work. The cost of doing this must, however, be compared to the cost of robot operation.
- An initial estimation of this threshold for installations of the AT-1 type is 2.6×10^{10} Bq (0.7 Ci) per tonne of primary wastes.
- Robot procedures can also be used with the aim of "hot spot" removal in order to reduce specific activity to below the above threshold.
- The subsequent use of robots could be facilitated in the design of new installations, either by the use of (maintenance) robot facilities during the productive life of the installations, or by arranging the design in such a way that robots could easily be introduced later, for example by providing a free access zone in the upper part of the cell. The costs of final dismantling could

thus be reduced. In AT-1, for instance, the preparation of the installation to enable robot access represented 20 per cent of the total robot costs.

- Final evaluation of the various options must take account of prior decontamination and the possible differences in packaging and storage costs for the wastes produced.

KKN, Germany

The remote dismantling of the Pressure Tube Reactor has been performed with a remotely controlled dismantling equipment (rotary manipulator, crane manipulator, crushing and packing station etc.; altogether approximately 700 Mg). Due to the specific design of the core of this prototype reactor which lead to a very complex structure, a multitude of individual tools need to be used. Within this context it should be mentioned that the moderator tank is of a height of 6.3 m including the upper and lower neutron shields.

The first step consisted in the removal of the top and bottom shielding plugs that were, during operation, situated below and above the fuel element columns inside each of the 351 pressure tubes. Subsequently the isolation tubes, about 6 m long each, were pulled out and cut into pieces of approximately 10-cm length. After completion of this the lower welds of the pressure tubes were cut off using an abrasive technique. Quality control of this cutting work included the endoscopic inspection of the gaps in all 351 tubes which was recorded on video tape. Due to broader than expected welds, cooling and lubrication problems, this part of the dismantling programme proved to be much more time consuming than expected. After successful execution, the 40 Mg of steel balls, the cavities of the upper neutron shield were filled with, were removed using a vacuum conveyor.

The remote controlled dismantling has so far progressed successfully. Some difficulties, partly due to slight discrepancies between the actual design of the reactor and the situation expected, based on the available documentation, had to be overcome. This could be achieved with minor modifications of the dismantling procedure or of the tool used. Experience showed, however, that the time needed was underestimated.

JPDR, Japan

The main part of the JPDR such as reactor internals and the reactor pressure vessel were dismantled underwater by remote control. The plasma torch was handled by either mast-type or master-slave manipulators for cutting the reactor internals. Different remote control systems were developed for dismantling the reactor pressure vessel, and radiological shield.

WAGR, United Kingdom

The Dismantling module, comprising the mast, manipulator and service module, which was previously installed in a test facility adjacent to the reactor for training and trials, has been successfully transferred into the Remote Dismantling Machine (RDM) over the reactor vessel. Detailed functional testing has been carried out, plus a series of overview tests design to check for general operability and interlock faults.

EBWR, United States

The remotely operated BROKK machine performed very well for the removal of the 42-t reactor cavity shield plug. Once the impact work was completed the machine arm was fitted with a bucket scoop and was used to load the high density concrete rubble into 68-ft^3 shipping containers. The same machine was used to remove activated concrete from the bio-shield. A few mechanical problems with the equipment were experienced, but repairs were made quickly.

B204, United Kingdom

The option retained for in cell dismantling techniques is that of Contact Deployment and Remote Operation (CODRO) as it reduces the dose uptake commitment for in cell working complying with the ALARP principle. A better working environment can be provided, purpose built, to reduce dose uptake to personnel.

The chosen system is based on commercially available robust equipment adapted for the proposed special application thus reducing cost and development time-scales whilst enhancing reliability.

An hydraulically operated remote manipulator capable of lifting 110 kg at 2-m reach has been mounted on a hydraulically operated telescopic deployment arm capable of lifting 3 te at 6-m extension. Development trials have shown the system to be very stable and capable of carrying out cutting operations at almost 8-m reach. During the development work the opportunity was taken to assess the system using two manipulators mounted on the deployment arm. These tests showed the system to be stable but it was difficult to co-ordinate the operation of the two arms and further work would need to be carried out on a more flexible manipulator mounting system. This work is, however, outside the scope of the current development programme.

The manipulator has been fitted with up to six cameras to enable remote operating trials. The systems used to date have been conventional two dimensional pictures. Cutting and drilling operations have been successfully completed but were relatively slow due to the lack of spatial awareness of the operators. Although operators will become more proficient with experience trials with a variety of three dimensional camera systems are currently underway with a view to improving speed of operation.

A selection of cold cutting tools have been tested on the manipulator.

The in-cell manipulator has been commissioned and operator training started in an inactive test facility. The manipulator has remote tool change capabilities with hydraulic and AC/DC electrical power being delivered through the manipulator arm. Software has been developed for automatic tool change and successful testing completed. Tool rack design and location have been optimised during operator trials.

Size reduction of vessels is carried out in a specially constructed Waste Handling Facility. Two convential 6-axis industrial robots are controlled to provide cutting and handling functions. Vessels for size reduction are mounted on a turntable which has been linked to the cutting robot control system to provide a seventh axis of control.

A 3D computer programming system, IGRIP, is used to plan the removal of vessels from the active cells and to programme the size reduction cutting paths for the industrial robots. A hydrogen/argon plasma cutting system is used for size reduction. A laser guidance system is used to control the stand of distance for the plasma arc. Vessels are inerted prior to cutting operations by an Argon atmosphere to reduce the risk of fire and explosion from residual solvent. The plasma cutting controls are interlocked with an oxygen measuring system to prevent the arc being struck if oxygen is present within the vessel.

JRTF, Japan

• A 3D-CAD system, which can express arrangements of components in an area dismantled to simulate the dismantling procedure has been developed.

The robot has the characteristics as follows:

- small and light (400 mm long × 400 mm wide × 1,000 mm high, about 100 kg)
- flexible movement
- climb up and down (< 30°)
- step over pipe (250 mm high from floor)

The robot consists of body section, mobile section such as main drive wheels, assister wheels and hip joint, vision equipment such as TV camera, laser pointer/range finder, and pan/tilt mechanism.

• Development of remote dismantling apparatus for large vessels: the apparatus consists of a transfer system, a number of remote exchange devices, maintenance system, cut piece transfer system and remote control system.

The transfer system has five axes; *X* and *Y* axes move horizontally, *Z* axis extends vertically, Ø axis rotates the remote exchange devices, and θ axis bends them. The remote exchange devices are installed to the end of *Z* axis and can be exchanged by their remote detachable connectors which consist of decontamination device, grinder, plasma torch, grabbing and cutting device, and vacuum pad.

The manufacturing will be completed in 1997.

Greifswald and Rheinsberg, Germany

The remote dismantling will be necessary for the pressure vessel, the core internals and the annular water shield. The pressure vessel and the core internals will be removed from their implantation position, cut and conditioned for disposal in two caissons (one dry and one wet). These caissons will be installed beside the original position of the pressure vessel in the steam generator room.

For the cutting operations specially a band saw and CAMC (Contact Arc Metal Cutting) will be applied.

The overall system, techniques and tools will be tested in the controlled area of unit 5 with non-active components from Unit 6, 7 or 8.

Building 211, France

Research was carried out in 1994 into a new machine named "Crane E". This device will be used to introduce the robot arms into the cell. This new crane must be built to respond to the latest capabilities and the obsolescence of existing resources ("cranes" and robot arms).

These new "cranes" and robot arms will be used:

- for decommissioning work on the cells:
  - disposal of any operating waste still present,
  - unplugging and connecting pipes to allow decontamination work on systems in the reprocessing line cells,
- for dismantling equipment, pipes and their support structures from the reprocessing line cells.

At an early stage, it was decided to carry out research into the new machine because it would have to be used in all the steps involved in the decommissioning of Building 211. The machine consists of a vertical travelling crane and an arm. In view of the different levels of dexterity needed for the operations involved between unplugging/connecting pipes and the dismantling work, it was decided that the crane could optionally be fitted with:

- an MA23 M slave robot arm from La Calhène, for work requiring a high degree of dexterity,
- a hydraulic robot arm, *i.e.*, Shilling Gamma 2 arm or a Cybernétix Remo II arm.

The new crane will adopt the same design principles used for previous cranes because it will move along the same tracks. The crane will consist of the following:

- a mobile chassis,
- a robot arm carrier capable of vertical travel to extend the reach to the upper parts of the cells,
- an interface specific to each robot arm.

In addition to a robot arm, the crane will be fitted with a 1.5 kN hoist. This hoist will be used to attach slings to equipment before detachment and to transfer waste bins between the cell being dismantled and the cell corridor. The hooks will be symmetrical about the vertical axis to enable work in cells to the right and left. Modifications to the configuration of the machine will be made in the maintenance rooms.

An umbilical will transmit power, instructions and video pictures to and from the machine. A connector is provided opposite each cell. The crane can move along the cell corridor, between each cell and between the cells and the maintenance room by means of a transfer platform.

Decontamination

Decontamination of Concrete Surfaces

Eurochemic Reprocessing Plant, Belgium

- Floor shaver as an alternative for floor scabbling:

The evaluation of the decommissioning programme progress at the end of 1993 showed that, especially at concrete decontamination, lower actual waste production rates by scabbling were achieved than expected. This was mainly due to the technical problems with an automised 4-headed rotating scabbler, manual scabbling resulting in too low production figures.

Consequently an intensive search was carried out in view of adapted techniques for concrete decontamination. As a result, a floor shaver as an alternative for floor scabbling has been used. The machine is similar to a normal floor scabbling unit.

It has a quick change diamond tipped rotary cutting head designed to give smooth surface finish, easier to measure and ready for painting. It proved capable of cutting through bolts and metal objects, something with a traditional scabbler would have resulted in damage to the scabbling head.

Actual cutting performance results in:

- a 3.2-times higher mean working rate for floor decontamination (13.6 m^2/h effective shaving, compared to 4.3 m^2/h effective working with a normal floor scabbler);
- a 30 per cent lower waste production than by scabbling with a comparable decontamination efficiency;
- much less physical load on the operators due to the absence of machine vibration.

- Automatised wall shaver as a solution for concrete decontamination of larger surfaces:

Based on the positive experience with the floor shaver mentioned, a remote controlled diamond wall shaving system has been developed as a solution for concrete decontamination of larger surfaces.

The machine consists of a simple xy-frame system to be fitted with vacuum pads to the floor and the wall to be decontaminated, allowing continuous operation, and carrying the shaving head with dust control cover for connection to existing dust extraction systems. It removes concrete layers in a controlled, low noise and vibration-free manner, following the contours of the surface being removed, and depth adjustment can be set manually between 1 mm and 15 mm per pass. Depending on the concrete characteristics, the system can remove a 5 mm surface-layer at 15 to 25 m^2 per effective shaving hour.

Meanwhile, 400 m^2 of concrete surfaces have been decontaminated successfully. Compared to scabbling, concrete waste production rates proved to be 30 (compared to hand scabbling) to 55 per cent (compared to automatic scabbling) lower at equivalent decontamination efficiency. At the same time different tests were continued to prove that the end products (concrete dust, eventually including remaining parts of a paint layer), combined to suitable additives, can be incorporated in a cement matrix with an additional volume reduction factor.

- Mini electro-hydraulic hammering unit

A mini electro hydraulic hammering unit (weight only 350 kg) has been used in those areas where contamination has penetrated deeply into the concrete surface, increasing the decontamination possibilities and reducing significantly the work load for the operators.

BR3 Reactor, Belgium

An R&D project has been initiated with the Belgian Building Research Centre for testing dismantling and decontamination techniques on concrete. These techniques include the use of a remote controlled jack hammer, explosive blasting, heating of the rebars, etc. Tests will be carried out on full scale mock-ups of the bio-shield and pool wall; final demonstration testing will be carried out on contaminated and activated concrete anti-missile slabs.

AT-1 (Cell 905), France

The technique adopted for decontamination was blasting the surfaces with recovery of used blast; two blasters were used: one for manual operations, and the other for remote-controlled operations.

Once the equipment was installed in the cell, the concrete walls were blasted, starting with the vertical parts, for which it proved possible to use the carrier in conjunction with the blaster. Next, the top parts of the cell were decontaminated; this could only be performed manually, owing to the large number of penetrations and pipes and the large number of civil engineering sills. Due to the recently discovered volumetric contamination in the concrete walls of cell 903, scabbling will be used instead of sand blasting.

JPDR, Japan

Several methods have been applied to the decontamination: scabbler, shot-blasting, and needle gun for surface contamination, and scabbler and breaker for immersion contamination. Data on decontamination performance of each method were collected in the decontamination activities. For example, the decontamination speed was measured in the surface decontamination work as follows:

Tool	Area (m^2)	Cutting depth (cm)	Cutting time (min)	Efficiency (m^2/min)
Floor scabbler	3	1.5	196	0.015
Floor scabbler	19	~ 0.5	139	0.137
Needle gun	9	~ 0.5	601	0.015
Air chipper	2	~ 0.5	107	0.019

In addition of these commercially available decontamination tools, a micro-wave decontamination machine was developed and it was applied to decontamination of the JPDR facilities. It was found that the micro-wave decontamination was not applicable to the aged concrete in which the water content was small.

JRTF, Japan

Method is developed to dismantle the contaminated concrete surface less than 10-mm depth in JRTF using laser beam. Scanning irradiation with laser beam, two phenomena present as follows:

- Melting the elements of concrete which are silicon, aluminium and calcium, the surface of concrete change to glass layer.
- Generating pressure by evaporation of water in concrete, the surface of concrete is torn off and hopped off.

Decontamination is carried out by removing glass layer and tearing off the surface of concrete.

Development of this technique started in 1994.

Decontamination of Metallic Surfaces

Eurochemic Reprocessing Plant, Belgium

The comparative demonstration programme on dry and wet abrasive blasting techniques to decontaminate metallic components has shown that it is economically interesting to decontaminate such components to clearance levels, when all costs for conditioning and disposal of resulting wastes are considered.

Using adequate dry blasting, 32 t of contaminated profiles and plates have been decontaminated to clearance levels, avoiding intrusion of contamination into the material to be decontaminated. As a second part of the evaluation programme, in a wet abrasive blasting system another 3 t of metal components has been decontaminated and measured to be below clearance levels after a second measurement campaign.

The results of these tests indicated that the wet abrasive technique showed much higher costs, less efficiency, much higher secondary waste production and much greater difficulties at measurements to clearance levels.

Based on the results of the demonstration programme, a technico-economic proposal has been developed and discussed to install an industrial and automised dry abrasive blasting system in the Belgoprocess central decontamination infrastructure. Based on a complete cost evaluation it has been shown that the unit cost for decontaminating metallic components to clearance levels in such a dry abrasive blasting installation can be limited to one-third of the total costs for waste treatment, conditioning, intermediate and final disposal of the material as radioactive waste.

BR3, Belgium

- *Full-system decontamination*

A decontamination of the reactor primary loop was performed before any dismantling in order to reduce the dose rate in the vicinity of the primary loop components and piping, and to reduce the risk of contamination spread when cutting these elements. The chemical CORD process, proprietary of SIEMENS/KWU was used to perform the operation. The system allowed to use mostly the equipment of the plant (ion exchanger, primary pumps etc.) to carry out the operation. Nevertheless, additional ion exchange resins container had to be used for achieving the operation. The average decontamination factor obtained is 10, with variations from 0.1 to 40 on specific locations.

Another result of the operation was the cleanliness of the internals (facilitating their dismantling afterwards) and even their waste recategorisation (changing from medium-level waste to low-level waste, according to Belgian regulation) implying a dramatic reduction in the waste cost.

- *Elimination of hot spots*

During the dismantling of the upper internals, dose rate measurements showed that up to a very close distance of the core (± 500 mm), the activation level of the dismantled stainless steel pieces was low enough to be considered as "standard" low-level waste (below 200-mR/h contact dose rate following Belgian standards). Nevertheless, some pieces presenting complex geometries showed still some hot spots (up to 1.5 R/h) due to a remaining contamination (and deposit) which had not been removed by the decontamination process of the primary loop as result of their complex geometry. These hot spots could then be removed by further decontamination (high pressure water jet rinsing followed by chemical or electrochemical decontamination).

- *Decontamination of a heat exchanger*

The Regenerative Heat Exchanger (RHX) was removed from the purification loop of the reactor and connected to the DECOLOOP installation for further decontamination.

First the modified CORD process (concentration of oxalic acid of 20 g/L) was applied in three successive decontamination cycles, then the cerium process without regeneration was applied. This decontamination resulted in an overall DF of about 90 corresponding to a mean residual contamination level of about 50 Bq/cm^2. Afterwards, the RHX was cut into pieces with a reciprocating saw, the pipes separated from the shell and the shell pieces were further decontaminated to reach free release levels *i.e.*, lower than 0.4 Bq/cm^2 beta-gamma.

- *Chemical decontamination with the cerium IV+ process*

The regeneration of the cerium solution is further studied at laboratory scale. Two techniques are compared: the regeneration with ozone and the electrochemical regeneration.

- *Physical decontamination with abrasives*

A Vapormatt commercial equipment has been purchased for the decontamination of metallic pieces with abrasives under wet conditions. This equipment will be installed in a large decontamination booth (main dimensions: 3 m long; 3 m wide; 3 m high) which will allow the decontamination of large pieces of equipment. The abrasives are recycled and the water is cleaned by sedimentation and filtration. Different types of abrasives will be tested; the preference will be given to long life abrasives such as zirconium oxide or stainless steel.

AT-1 (Cell 905), France

Decontamination of the inner walls of pipes: Almost all the pipework penetrations are located at the top of the cells, level with the civil works bevels at the point where the walls range in thickness from 1.2 to 1.4 m and there were two possible solutions to the problem: either ordered core drilling of the pipework penetration zones, or internal decontamination of the pipes.

The amount of waste generated by core drilling technique and its high cost, resulting mainly from the need to carry these operations out in the dry phase for the purposes of effluent management at the site, led to this technique being abandoned at the AT-1 Building.

Shot peening was therefore adopted to decontaminate the pipes (using once-through shot) blown into each pipe using compressed air (7 bars).

Some 500 pipes were shot peened using this technique, and then plugged.

MZFR, Germany

The primary system of the MZFR was decontaminated with the following objectives:

- decreasing the dose rate to allow the hands-on dismantling,
- reduction of the specific radioactivity of the material to a value of less than 200 Bq/g. This material can then be classified as material suitable *e.g.*, for melting and therefore will not have to be treated as radioactive waste.

The interior of the reactor pressure vessel was not decontaminated, because the contamination is relatively low in comparison to the activation.

Initial Situation

The following systems were selected for decontamination:

- primary system, consisting of two circuits and two steam generators,
- moderator circuits with two heat exchangers,
- pressuriser system,
- volume control system,
- draining system,
- drying and handling systems for fuel elements.

These systems were drained and dried. The average dose rate of the components was 3 mSv/h before the contamination. The average contamination value was 5×10^4 Bq/cm². The total mass of the aforementioned systems is approximately 400 Mg with an internal surface of about 4200 m² and an activity of about 2×10^{12} Bq.

Decontamination Process

The decontamination was carried out by the company SIEMENS/KWU with the mobile decontamination facility "AMDA". The chemical decontamination process "CORD/UV", developed by SIEMENS/KWU, was applied.

The AMDA consists of the main components:

- circulation pump,
- heater,
- UV-skid,
- ion exchanger.

The AMDA was connected to the systems to be decontaminated with flexible high pressure pipes. Each circuit of the systems selected for decontamination could be filled separately with deionate and heated up to 95 °C.

The decontamination process is as follows:

- Step 1: Oxidation

  Dosing of permanganic acid ($HMnO_4$) for converting the chromium in the oxide layer into chromate.
- Step 2: Reduction / decontamination

  Dosing of oxalic acid ($C_2H_2O_4$) for the reduction of permanganic acid and the subsequent dissolving of the oxide layer is the beginning of the decontamination were the metal ions are dissolved as complexes.
- Step 3: Binding of the corrosion products and the manganese to the ion exchange resin and decomposition of the oxalic with hydrogen peroxide (H_2O_2).

After this procedure all chemicals are decomposed. The remaining water is relatively clean and can be reused for the next decontamination cycle. The carbondioxid will be released into the exhaust air stack.

Decontamination Results

In components, which were well circulated by the decont liquid, the dose rate was reduced by a factor of 10 to 30. In some parts of the systems a factor of up to 150 could be achieved. In parts were the liquid flow was not sufficient the decont factor was 3 to 5 only.

The average value of the decont factor is 20. Therefore it can be stated that the decontamination was a successful operation. The final evaluation of the results has still to be done. The specific radioactivity of the masses will be determined by measuring samples taken from different positions of the systems to demonstrate, that the value is below 200 Bq/g and the material can be released for melting.

In total a radioactivity of about 5.3×10^{11} Bq was taken off with the decontamination process.

The waste masses generated are:

- 3 m^3 resin
- 62 m^3 water
- 72 kg metal removed from the inner surfaces of the systems. The waste will be taken to the waste treatment plant HDB in FZK for treatment and intermediate storage.

JPDR, Japan

One of the JPDR dismantling activities is the study on decontamination of dismantled components. Two kinds of decontamination methods were studied. These are electropolishing and chemical methods. The electropolishing decontamination is applied to relative simple shape of dismantled components and the chemical method is applied to relative complex shape of dismantled components. First, decontamination tests were conducted by electropolishing. The results showed that the pipes of forced circulation system (radioactivity: 65 000 cpm) was decontaminated to be in the background level (80 cpm) after treatment by 80 per cent phosphoric acid (temperature: 333 K) for 15 minutes with 2 A/cm^2 current density.

WAGR, Germany

An options study for heat exchanger dismantling has shown that a degree of decontamination is still part of the optimum strategy. Full decontamination to allow virtually unrestricted dismantling has been ruled out because of the secondary waste generation, but partial decontamination using a recycling spray technique appears to be effective in allowing semi-remonte dismantling within a satisfactory dose budget and with modest secondary waste production.

EBWR, United States

The use of disc grinders and drills provided the means to decontaminate and free-release the reactor vessel closure head. This metal was released for recycle. The bio-shield lead bricks were not contaminated and the majority had no detectable activation. Extensive use of grit blasting allowed for the release of a large fraction of the condenser unit.

Greifswald and Rheinsberg, Germany

The decontamination of one steam generator in Rheinsberg with the CORD-process from SIEMENS has been terminated. The results can be summarised as follows: material removal 2 µm, mean DF 2 – 3 (originally, maximum 137 Bq/cm^2, and after decontamination, maximum 20 Bq/cm^2) secondary waste 0,18 m^3 ion exchanger and 0.1 m^3 evaporator concentrate.

The decontamination of the primary loop of Unit 5 at Greifswald has been performed with the APCE procedure. In total 250 m^3 solution was used for the decontamination. In addition to this, 2 800 m^3 condensate was used for rinsing. In total 30.8 kg of iron, 3.8 kg of cerium, 3.0 kg of nickel and 1.73×10^{10} Bq were removed. With the data available for the moment it is only possible to state that the DF varied roughly from 2 to 200 depending on the measurement place and that on most surfaces the activity is below 3 Bq/cm^2.

The decontamination of the main components in the primary loops (steam generator, main cooling water pump) in situ, will not be performed. This is mainly due to the adapted dismantling strategy. Local decontamination (or shielding or dismantling) of hot spots will however, be performed to lower the general radiation field (expected level < 10.µSv/h). Thus, with these efforts and shorter dismantling time (complete components) the dose commitment can be minimised.

Bohunice, Slovak Republic

Long term research objectives of the decontamination programme are:

- characterisation of the radioactive deposits on circuit surface.
- selection, development and verification of chemical decontamination for pre-dismantling of NPP A-1 systems.
- development of economic processes for chemical and electrochemical decontamination of metals (stainless steel, mild steel) from nuclear power plants for unrestricted release and verification of these processes under pilot plant conditions.
- development of criteria for evaluation whether it is actually worth to decontaminate the systems and metals and for selection of the decontamination process.

On the basis of the corrosion layers analysis we one suggest that the contaminated corrosion layers have different chemical and phase composition on surfaces of different systems.

Dissolution rates of synthetic powder of iron 304 in formic, oxalic and citric acids, EDTA and their mixtures depending on agent concentrations, pH, etc. were investigated and compared. Optimisation of decontamination solutions composition from the view point of decontamination objectives during decommissioning gave optimal solution composed of: acid complexing agent (EDTA, $EDTANa_2$, $EDTANa_4$) -corrosion inhibitor. This solution provides sufficient and required decontamination efficiency for pre-dismantling and in combination with ultrasound even for post-dismantling decontamination, and its efficiencies is proved by the results obtained from the laboratory and pilot plant verification on samples of carbon steels from various NPP A-1 systems.

Diluted nitric acid has been effective decontamination solution for auxiliary circuits connected with the primary circuit. It had been used for pre-dismantling decontamination of explosive mixture combustion system and carbon dioxide purification system. Decontamination enabled to reduce dose rate of equipment so much that dismantling needs not be done remotely.

Screening tests for selection of suitable electrolyte components to the electrochemical decontamination of carbon and stainless steels for unrestricted release have been used: oxalic, formic, citric, sulphuric, nitric and some organic sulphoacids. Additives as ammonium nitrate, surfactants, complexing agents etc. were given to the electrolytes for their property modifications.

Experiments showed that for the materials of the primary circuit, electrolyte based on citric and sulphuric acids appear to be universal, having sufficient efficiency. Electrolyte is suitable for low current densities, about 5 A/dm^2. To prohibit formation of explosive mixture during electrolysis, certain amount of ammonium nitrate is added to the electrolyte. Cathodic reduction proved to be the most appropriate polarisation in all electrolytes except oxalic acid.

Radioactive Waste Management

BR 3 Reactor, Belgium

The highly radioactive pieces cut in the reactor pool are transported to the deactivation pool (spent fuel pond) in the auxiliary building by means of a specially designed transfer cask. Up to $2\,775 \times 10^{13}$ Bq (750 Ci) can be transported in this cask.

As regards the high-level waste pieces resulting from the dismantling of the internals, they have to be evacuated to BelgoProcess (Belgian radwaste conditioner, subsidiary of ONDRAF/NIRAS) in 400-L drums (ONDRAF/NIRAS imposition) with a weight limit of 800 kg per drum.

Therefore, and to keep the doses as low as possible, specific racks and baskets were developed to load the different segments; these racks and baskets fit directly in a 400-L drum, thus limiting the handling operations to a minimum.

The racks and baskets are easily handled under water and then put in a shielded cask for transport to Belgoprocess where they are loaded in a drum and grouted in concrete.

Low-level solid waste (*i.e.*, contact dose rate $\leq$ 2 mSv/h) is directly packed into 200- or 400-L drums.

The whole path for the low-level waste and the very-low-level waste coming from dismantling, is as follows: storage, sorting, decontamination (wet abrasive or chemical), measurement, evacuation. A new procedure for the release of solid material is currently being prepared and will be tested in the BR3 project.

A total of 9 t of highly radioactive metal pieces representing 128.7 TBq (3 480 Ci) has already been evacuated.

KKN Niederaichbach, Germany

The total mass of the pressure tube reactor parts amounts to 500 t. Specific radioactivity of approximately 20 per cent of this material is below 200 Bq/g. This portion will be melted for restricted reuse. The remaining 400 t with a maximum specific radioactivity of 2×10^5 Bq/g have to be disposed of. The following table gives a survey of the masses and the average specific activity of the main groups of components disassembled so far. Due to their neutron irradiation history their specific activation declines with increasing distance of their position from the axis of the moderator tank.

Survey of the Dismantled Components of the Moderator Tank

Component (quantity)	Total mass (Mg)	Average specific activity (10^3 Bq/g)
Upper shielding plugs (351 pcs)	13.4	5.7
Lower shielding plugs (351 pcs)	13.7	82.3
Steel spheres	45.8	1.9
Insulating tubes (351)	22.5	5.3
Sleeves upper neutron shield (351)	13.8	0.3
Girders upper neutron shield (23)	39.0	1.0
Pressure tubes (351)	23.0	80.0

The disassembled parts are put into waste containers (type II, according to the preliminary waste acceptance criteria of the planned KONRAD-repository). Their outer dimensions are 1.7 × 1.6 × 1.7 m. Four versions with increasing shielding wall thicknesses are used corresponding to four classes of specific activity. Considerable efforts are made to exhaust their load capacity in order to minimise waste volume. The overall degree of filling by weight is in the order of 25 per cent. Usually the disposable space inside the containers is only exploited by less than 20 per cent. These figures show, that the use for more efficient compaction techniques would result in further reductions of volume of conditioned waste.

The loaded containers are transported on rail to the Karlsruhe Nuclear Research Centre, where conditioning with concrete is being carried out. Until the opening on the KONRAD-repository they are stored there.

Garigliano, Italy

- *Extraction and conditioning of solid waste from high-level vault :*

The first three containers (of six) have been conditioned. The activities are lasting longer than planned mostly because of the need for continuous water filtration and clarification to improve the visibility inside the vault. An ad-hoc system has been designed and built to remove the mud and to clarify the water, the maximum flow rate of the centrifugal separator of this system is 7 m^3/h and has proved somewhat low for operational needs. The total amount of water in the vault varies during the operations from 26 to about 115 m^3.

- *Extraction and conditioning of intermediate-level waste (resins, sludges, etc.) :*

The construction of the shed and of ancillary systems has begun. Problems have arisen regarding fulfilling the anti-fire tech spec for the shed. The seismic verification of the buildings that will be used for the interim storage of the conditioned waste has been started.

WAGR, Germany

A review of the operability of the waste route has been carried out with specific studies on the handling of low-level waste and the grout and concrete pouring mechanism. Physical handling trials have been performed using a prototype concrete intermediate-level waste container. This work has resulted in recommendations for improvements.

Other work in this area includes the design of an low-level waste container specific for use in the WAGR waste route and an assessment of the most cost effective way of procuring a grout and concrete supply for operation of the waste route.

West Valley Demonstration Plant, United States

The major technical interest at the project is a permanent disposal methodology for high-level waste utilising borosilicate glass. This technology will produce a durable, solid waste disposal form. The end result will be 300 glass-filled stainless steel canisters that are to be stored at the project pending the availability of a repository.

Prior to solidification in glass, the former plant operations high-level liquid waste (supernatant) and the accompanying sludge has been neutralised for processing in the project Integrated Radwaste Treatment System. This is comprised of these four systems: Supernatant Treatment, Liquid Waste Treatment, Cement Solidification and the Drum Cell.

The Integrated Radioactive Waste Treatment System components will:

- separate caesium 137, the principal radioisotope in the liquid waste (supernatant),
- concentrate liquid waste by evaporation and stabilise it by cementation in drums,
- process sludge for salt removal in four wash operations, and
- transfer sludge to a Vitrification Facility for high-level waste vitrification.

The liquid waste concentration produced more than 10 000 drums of low-level waste that are being stored in a drum cell building on site pending full identification of environmental factors for their disposal.

Completed in 1992, the first of four sludge wash operations for the removal of salts from the sludge which would impair glass solidification of the sludge. A major improvement in sludge processing has been achieved by loading a column in the Supernatant Treatment System with titanium coated zeolite. This enhances liquid waste ion exchange processing by removal of plutonium not captured in filters following their normal degradation and loss of efficiency during waste processing operations cycles. Treatment of the liquid waste from the first sludge wash operations is continuing.

Vitrification of sludge is planned to start in 1996.

EBWR, United States

Containers of radioactive waste are being transferred to the Argonne Waste Management group for shipment to the Hanford, WA DOE disposal site. Containers of mixed waste are also being transferred to Waste Management for shipment to the Hanford DOE site for storage. By the end of March 1995, over 2,600 ft^3 of CH-low-level waste has been shipped to Hanford, Washington, for disposal. Nineteen 55-gallon drums of RH-low-level waste has been transferred to ANL-E Waste Management for shipment to Hanford. These wastes contain over 2.03×10^{12} Bq (550 Ci) of radioactive materials.

Tunney's Pasture Facility, Canada

Volume reduction of metal components is achieved by cutting and packaging into containers.

Consumables such as boot covers, gloves and disposable coveralls are compacted into 45-gallon drums.

Filters are left in their housing for disposal. The open ends of the filter housings are capped with metal plates to form a sealed package.

JPDR, Japan

The total amount of 24 400 t of solid waste including approximately 3 700 t of low-level radioactive waste were produced in dismantling JPDR. The wastes were classified into four levels (or more detailed levels in some cases) on the basis of on-site measurement of radioactivity

The components are put into 200-L drums steel containers (3 m^3, 1 m^3), or shielded containers according to their characteristics such as radioactive levels and volume. All radioactive waste is stored in JAERI's waste storage facility except for extremely low level waste which arose from dismantling of the biological shield and building surface decontamination.

JRTF, Japan

Treatment of liquid waste:

- *Alpha-contaminated liquid waste*

  Alpha-contaminated waste of about 60 m^3 has been stored. This liquid waste has been separated into supernatant and sludge by coagulation and sedimentation process to remove plutonium since 1986. The treatment of this liquid waste finished about 85 per cent, and will finish in 1997.

- *Spent solvent*

  Spent solvent about 1.7 m^3 has been stored in JRTF. This solvent has been washed with alkaline solution to remove plutonium, and after then, the washed solvent has been incinerated. The residual ash has been solidified with cement and spent washing solution has been treated by alpha-contaminated liquid waste treatment apparatus.

  This treatment system consists of two parts, a "washing apparatus" and an "incineration apparatus" as follows, and was manufactured in middle of 1994. In this period, treatment of the spent solvent started, and will finish in 1996.

  – washing apparatus

  The treatment capacity is 8-L batch and the main parts of this apparatus are installed in glove-box.

  – incineration apparatus

  Phosphoric acid is generated by TBP incineration. This may cause corrosion to the incinerator and clogging of filters. Therefore, calcium octylate has been added to generate calcium phosphate. The residual ash has been solidified in cement, canned, and stored at JAERI's Radioactive Waste Treatment Facility (JWTF).

  The treatment capacity of this incinerator is about 3 L/h and the main parts of this apparatus are installed in hood.

- *Unpurified uranium solution*

  Unpurified uranium solution of about 1.7 m^3 has been stored in JRTF. This liquid waste was generated, because the JRTF had no uranium purification process. The unpurified uranium solution is treated by adsorption process using inorganic adsorbents (fibrous activated carbon (FAC)) to remove plutonium.

  Manufacturing of the treatment apparatus is on going and the treatment will start in 1996.

- *High-level liquid waste*

  High-level liquid waste of about 11 m^3 has been stored in JRTF. This liquid waste was generated from co-decontamination process. Removal of the main impurities of caesium, strontium and plutonium from this liquid waste is also necessary for the interim storage in JWTF. So, the high-level liquid waste is treated by an adsorption process using inorganic adsorbents (hexacyanoferrate for caesium, titanium oxide for strontium, FAC for plutonium).

  In this period, the detail design for the treatment apparatus was completed. The treatment apparatus will be manufactured from 1995 to 1997, and the treatment will finish in 1998.

Radioactivity and Volume of Liquid Waste

Categories	Radioactivity (Bq/L)		Volume
	Alpha	Beta (gamma)	(m^3)
Al-decladding liquid waste	2.2×10^6	3.2×10^8	0.8
Alpha-contaminated liquid waste	$3.7 \times 10^1 \sim 1.1 \times 10^7$	$1.3 \times 10^3 \sim 5.2 \times 10^7$	56.5
Unpurified uranium solution	1.4×10^7	9.8×10^6	1.7
Spent solvent	$4.8 \times 10^4 \sim 1.4 \times 10^6$	6.3×10^4	1.7
High-level liquid waste	3.6×10^6	7.4×10^9	11.0

Greifswald and Rheinsberg, Germany

A new interim storage facility has been designed for all radioactive wastes from operation and dismantling and all nuclear fuel from the Greifswald and Rheinsberg plants. This was necessary due to the uncertain final disposal possibilities and the lack of other intermediate storage capacities in Germany.

After the reopening of the Morsleben disposal site the basic strategy is to treat and condition all operational wastes, see Table 1 for disposal in Morsleben (operation license ≤ 30 June 2000).

The dismantled material will be stored in as large parts as possible in the interim storage. Subsequently it will be treated in the treatment and conditioning area (five large caissons) of the interim storage, see Table 2.

In this way bottlenecks are avoided in the material handing system and a continuous dismantling can be guaranteed.

The construction of the facilities is going on and hot operation is foreseen in January 1997.

To allow for an early use, *i.e.*, to store components from the dismantling of Unit 5, one of the storage halls (No. 7) will be taken into operation in November 1995 for low active metallic material with a separate license.

Table 1. Summary of Operational Radioactive Waste on Site in Greifswald and Rheinsberg (1995-2008)

Category	Amount (in m^3)	Activity (in Bq)
KGR		
Evaporator concentrate		
liquid	954	2.1×10^{13}
sludge	95	7.1×10^{12}
solidified	45.1	7.6×10^{11}
Sludge monitored area	655	4.8×10^{9}
Ion exchanger		
low activity	72	3.7×10^{11}
medium activity	129	2.1×10^{13}
mixture with sludge	220	4.1×10^{13}
turbine hall Unit 1-4	330	1.6×10^{9}
Solid waste		
not burnable and burnable	912	1.8×10^{12}
metal	203	3.3×10^{8}
KKR		
Evaporator concentrate		
liquid	190	2.4×10^{12}
Ion exchanger, mixture with sludge	140	3.4×10^{12}
Solid waste	870	1.1×10^{13}
metal	330	1.0×10^{14}

Table 2. Different Materials from the Decommissioning to Be Treated in Greifswald (December 1994)

Material		From Greifswald	From Rheinsberg	In total from KGR + KKR
Carbon steel	(CST)	42 929 Mg	5 628 Mg	48 557 Mg
Austenit	(AUS)	11 122 Mg	1 458 Mg	12 580 Mg
Electric motors	(ELM)	3 138 Mg	411 Mg	3 549 Mg
Cables	(KAB)	5 979 Mg	784 Mg	6 763 Mg
Insulation wool	(ISW)	1 325 Mg	174 Mg	1 499 Mg
Electric parts	(ELP)	2 023 Mg	265 Mg	2 288 Mg
Non-ferrous meals	(NFM)	2 188 Mg	287 Mg	2 475 Mg
Others	(OTH)	503 Mg	66 Mg	569 Mg
Concrete	(CON)	26 021 Mg	4 229 Mg	30 250 Mg
Total		**95 228 Mg**	**13 302 Mg**	**108 530 Mg**

Bohunice, Slovak Republic

Operation and partial dismantling of NPP A-1 was source of radwaste types and quantities that are introduced together with proposed technology for processing in the following table :

Present State of Radioactive Waste Processing at NPP A-1

Type of RW	Amount (in m³)	Total activity (in Bq)	Proposed technology	State of project
Chrompik	20 18	2.2×10^{14} 3.6×10^{13}	Vitrification	Construction 12/92
Dowtherm	50	2.5×10^{12}	Bituminisation	Licensing
Storage pool water	500	3.5×10^{14}	Cleaning by sorbents	Design 12/92
Biological shielding water	360	7.9×10^{9}	Cleaning by sorbents	Study design
Concentrate	292	1.1×10^{13}	Bituminisation cementation	Licensing
Sludges	150	2.10×10^{10} 4.7×10^{12}	Not solved	

In addition to this waste, following ones are to be processed:

- soft solid waste
  - Treatment : compaction or incineration.
- contaminated steels
  - Treatment : decontamination, melting, bitumen or cement packaging process.
- contaminated concrete
  - Treatment : cement packaging process.

In the field of waste processing following ones were under development for NPP A-1:

- processing of dowtherm
- processing of "chrompik".

Dowtherm is a liquid organic medium (the mixture of diphenyl diphenyloxide) used for spent fuel storage in cans of long term storage pool. Specific activity of dowtherm is 5×10^{10} Bq/m^3.

Incineration on a floating bed was under development for the dowthem processing. Required equipment has been developed and the technique has been successfully verified in non-active tests.

Because of some problems encountered during R&D requiring longer time for research (handling, fixation and safety storage of radioactive residue from the floating bed, management of gases and control) and looking for low-temperature process are the reason why the process for dowtherm treatment hasn't been chosen yet.

Under the term "chrompik" it is understood a water solution of $K_2Cr_2O_2$ with concentration of 3-5 per cent used for storage of fuel assemblies in cans of long-term storage pool. Apart from the liquid itself there are also residues (sludges) of fuel and fuel cladding corrosion in the cans.

A vitrification has been developed for chrompik fixation and equipment tested under non-active condition. Wide range of glass matrixes was tested with good results in UJV Řež.

This technology is under construction inside the reactor building, in the rooms of explosive mixture combustion system, dismantled for this purpose. Parts of the equipment has been already tested.

Vandellos 1, Spain

Waste management depends on the type of material in question, the following having been considered: metallic scrap (steel), concrete from scraping, electrical cables (PVC, copper and aluminium), thermal isolation and graphite (fuel assembly cladding).

Two types of treatment are foreseen for the metallic scrap: decontamination and off-site melting, with a view to reducing the final volume of wastes and managing most by means of conventional methods. Also contemplated is the possibility of conditioning such scrap on site for subsequent dispatch to the definitive disposal facility.

Two methods are also foreseen for electrical cables: decontamination when the cables are only slightly contaminated, and stripping when there are higher levels of contamination, with a view to managing the PVC casing and metallic cores differently, in view of the fact that the latter will probably not be contaminated.

Other wastes will be conditioned for dispatch to the definitive disposal facility, with the exception of graphite, which will be pre-conditioned pending final disposal.

The radioactive effluent (liquid and gaseous) generated during dismantling will be subjected to different treatments (filtration, ion interchange, etc.) prior to controlled release.

WAK, Germany

Classification of Radioactive Wastes, Principles and Limiting Values

Legal principles. Section 2(1) of the German *Atomic Law* differentiates between radioactive materials and wastes which due to their negligible radioactivity are not subject to the requirements of particular waste management regulations because they are not considered radioactive in the sense of the law.

The above-mentioned minimisation of wastes according to Article 9a(1) of the *Atomic Law* requires radioactive wastes (especially dismantled radioactive components) to be reused wherever possible without doing any harm. Both the state of the art and science and the aims specified in Article 1(2-4) of the *Atomic Law* determine the feasibility of the utilisation of radioactive wastes.

Limiting values. At present, there are no regulations available for nuclear facilities to control the procedures subject to the Atomic Law as far as the limiting values relevant to the activity and surface contamination of radioactive wastes are concerned. For the time being, reuse or disposal, respectively, are subject to licensing in each individual case. As a rule, planning therefore can only rely on and propose the licensed limiting values of past plant operation or decommissioning licensing procedures on the basis of Article 7 or 9 of the *Atomic Law*.

KfK/HDB is among the reference plants. According to its relevant license, contaminated components are not to be released to be utilised or used in areas other than controlled areas unless concentrations remain below the respective limiting values. Their restricted reuse presupposes a specific activity of $\leq$ 100 Bq/g and – taking the mean of 100 cm^2 – a non-bonding surface contamination of $\leq$ 0.05 Bq/cm^2 for alpha contamination and $\leq$ 0.5 Bq/cm^2 for other radionuclides. Apart from observance of the above limiting surface values, the free disposal of wastes as ordinary wastes requires the specific activity per gram not to exceed 5×10^{-5} times the value of the limits specified in Annex IV, Table IV 1, column 4 of the *Radiation Protection Ordinance.*

According to the same Table, the sum of the ratios of activity concentration (Bq/g) and limiting values of the individual radionuclides has to be $<1 \times 10^4$ in the case of radionuclide mixtures. The total activity per charge transported must not exceed the tenfold value of the limits specified in the *Radiation Protection Ordinance*

WAK decommissioning schemes are expected to be essentially coping with alpha contamination meaning that apart from beta/gamma limiting values proposals will have to include alpha limiting values.

Treatment and Management of Radioactive Wastes

Depending on their residual contamination after the decontamination, dismantling and postdecontamination processes (where applicable), all wastes coming from the controlled area are classified as follows and usually after having passed a given release measuring procedure are treated and disposed of according to these categories:

- conventional wastes (non-radioactive),
- reusable materials or
- radioactive wastes,

On principle, four categories are planned for the disposal of waste:

- ordinary wastes coming from areas other than the controlled area,
- free wastes coming from the controlled area,
- utilisable radioactive wastes,
- radioactive wastes.

They are defined as wastes defying decontamination if:

- they cannot be decontaminated for technical reasons or
- measurements fail to deliver the proof relevant to their release or
- efforts going into their decontamination cannot be justified from the viewpoint of radiation protection.

Radioactive liquid wastes apart from HAWC are transferred to, processed and disposed of by KfK/HDB.

Waste Quantities

Radioactive metallic wastes will probably total about 3 400 $m^3 \cong$ 1 490 Mg. Some 520 $m^3 \cong$ 150 Mg can possibly be melted down for restricted reuse.

Non-metallic radioactive wastes are assumed to be in the order of magnitude of about 1 350 $m^3 \cong$ 3 100 Mg.

Health and Safety

Eurochemic Reprocessing Plant, Belgium

Training Programme

The whole decommissioning team, on a regular basis, gets a retraining in fire protection industrial first aid, evacuation techniques when working with movable platforms, as a lift truck driver and in the use of different decommissioning tools.

Working in Ventilated Suits

A prototype model for a qualified and uniform system to provide breathing and cooling air to the operators in their protective clothing when carrying out intervention activities in contaminated areas, especially with alpha-contamination, has been finalised.

It contains a new in-line breathing air filter, fitting in an adequate synthetic housing, a special synthetic distribution block to provide controlled air for both breathing and cooling, a low profile automatic, first breath activated, positive pressure demand valve, a special facemask, similar to the type of facemask being used before, but with two standard connections, and a safety device, allowing breathing through an absolute filter when the normal air supply has dropped. A bypass on the positive pressure demand valve allows additional air supply to refresh the operator's face and to remove excessive moisture.

Special attention has been paid to minimise weight and dimensions of the components and to improve carrying comfort.

The whole system has been tested under industrial circumstances by the decommissioning and decontamination operators. The results were very positive. No contamination has been detected, neither on filters, nor on other components. No problems have been reported with respect to mask, cooling or automatic breathing device.

A prototype of a new supply unit to provide filtered breathing air (with emergency supply and alarm systems) to the operators has been constructed and successfully tested.

Using the newly developed equipment, in co-operation with a specialised institute, the physical condition and the work load on the operators, wearing ventilated suits during decommissioning activities carried out in contaminated areas, have been measured based on pulse rate and rectal temperature registrations. The results of these tests still have to be discussed with the medical experts.

The data and the technical files of all the elements of the system are available and are assembled in a descriptive report.

BR3 Reactor, Belgium

The radiological cost of Phase 1 is as follows:

Operations		Man-mSv
Primary loop decon	Part 1 Preparatory tasks	135.5
	Part 2 Decontamination operation	6.4
	Part 3 Post-decontamination tasks	18 (so far)
Total Decon		**[160]**
Thermal shield cutting	Part 1 : Preparatory tasks	22.6
	Part 2 : EDM vertical cutting	7.5
	Part 3 : Three horizontal cuts	8.3
	Part 4 : Horizontal EDM cutting	7.1
	Part 5 : Arc torch segmentation	9.2
	Part 6 : Post-cutting operations	7.7
Provisional total cutting campaign		**[62.4]**

For Phase 2 of the pilot project, concerning the dismantling of all the reactor internals, the dose uptake is summarised below:

Operations		Collective dose (man-mSv)
Upper plate desolidarisation		5.35
Reactor Vessel Collar desolidarisation		3.07
Upper internals		1.96
Lower internals:	Circular saw	11.21
	Band saw	20.62
Evacuation		not yet defined
Total		[42.21] (so far)

This indicates that for the whole operation of underwater internals dismantling, the total dose uptake was less than 110 man-mSv.

AT-1, France

Radioprotection/Discomfort Factor

As a general rule one considers that long duration work is no longer possible once the ambient dose rate in a cell exceeds 2 mSv/h (200 mrem/h). Further, at rates below 50 μSv/h (5 mrem/h), if the operatives work 2 h every day (legal limit for work in ventilated suits), the total annual absorbed dose amounts to less than 20 mSv (2 rem) (CIPR 60). The criteria for radioprotection can thus be expressed as follows:

Manual operations	<	Undefined	<	Robot operations
50 microSv/h				2 mSv/h

This first approach takes account only of the mean ambient radiation and it is sensible to balance it against the presence of localised "hot spots" which can influence the actual doses absorbed by the personnel.

According to the data collected during the manual dismantling of cell 905, 18.25 mSv (1.8 rem) were absorbed during 932 h of work in the cell (corresponding to an average of 19.6 μSv [1.96 mrem] absorbed per working hour). The activity present was around 3.7×10^{10} Bq (1 Ci) for 21 t of equipment (a specific activity of 1.76×10^{9} Bq/t or 0.05 Ci/t). One operative working about 2 h a day in the cell (making about 400 h in the year) absorbs in these conditions an annual dose of 7.8 mSv (0.78 rem). The annual limit of 20 mSv/a is thus not reached, the limiting factor being the discomfort, *i.e.*, wearing the ventilated suit.

One may assume that the mean dose absorbed per working hour is proportional to the initial specific activity of the cell. By this hypothesis the limit of 20 mSv/a(2 rem/a) would be reached only when activity was 2.5 times greater, at about 4.4×10^{9} Bq/t (0.13 Ci/t).

The first conclusion which can be drawn is thus:

- robot operation was justified in cell 904 since the ambient rate was around 3 mSv/h (300 mrem/h),
- ambient conditions in 905 were at the lower limit of the undefined zone, being 50 μSv/h (5 mrem/h), and the dose rate criteria favour manual working.

KKN Niederaichbach, Germany

The Tritium monitoring system consisting of two redundant highly sensitive proportional counters with a minimum detection rate of about 360 Bq/m³ and a continuous liquid scintillation counter monitor with a detection limit of about 3 Bq/m³ were installed and put in operation. After several difficulties with the scintillation counter monitor had been overcome also this system is working satisfactorily.

The actual emissions carried with the exhaust air are in the order of 1.5×10^{3} Bq/month for aerosols and 5×10^{7} Bq/month for tritium. The extremely low emission rate for particulate radioactivity, also during the dismounting of the activated reactor tank, can mainly be attributed to the HEPA filter system that cleans the exhaust air of the inner containment with extremely high filtering efficiency.

Garigliano, Italy

Extraction and conditioning of solid waste from high-level vault: The dose rate fields in the working area are well below the design values. The following table shows the actual and the calculated dose rates in the working area and around the conditioned waste.

Calculated and Actual Dose Rates [in mSv]

	Calculated	Actual
Above water*	1.04	0.07 - 0.18
Above working pedestal*	0.8	0.03
Outside pool wall at contact*	0.35	0.008
Outside pool wall at 1 m*	0.19	0.003
Conditioned waste at contact	0.40	0.036 - 0.06
Conditioned waste at 1 m	0.20	0.01 - 0.03

* With the basket containing the waste at its maximum level.

The final committed dose to the personnel will be higher than planned. This is mainly due to the construction and preparatory activities that were longer than evaluated.

EBWR, United States

There has been one OSHA reportable injury, no lost time incidents and no cases of over exposure to ionising radiation. Total project radiation exposure at the end of July 1995 is 156 mSv (15.6 rem) versus a planned amount of 189 mSv (18.9 rem).

Fort St. Vrain, United States

Low exposures are obtained due to effective as low as reasonably achievable (ALARA) controls:

- Average annual estimated decommissioning exposure 1.33 manSv/a (133 man-rem/a)
- Typical exposures at operating LWRs 3-4 manSv/a (300-400 man-rem/a)
- Total 44-month project estimate 4.33 manSv (433 man-rem)
- From 1 September 1992 to 31 March 1995:
  - Estimate 3.02 manSv (302.2 man-rem)
  - Goal 2.42 manSv (241.7 man-rem)
  - Actual 2.33 manSv (233.3 man-rem)

- Project approximately 73 per cent complete, with only 54 per cent of the 4.33 manSv (433 man-rem) exposure estimate utilised.

Annex III

REPORT FROM THE TASK GROUP ON DECOMMISSIONING COSTS

Introduction

The Liaison Committee of the Co-operative Programme established on 21-22 February 1989, a Task Group on Decommissioning Costs in order to identify the reasons for the large variations in reported cost estimates for the decommissioning of these nuclear facilities. Based upon an agreed terms of reference with the Liaison Committee, the two years work of the Task Group proceeded as follows:

- establish a basis for costs to be included in a decommissioning project;
- define decommissioning tasks (cost items) and grouping of these tasks in cost groups that would be acceptable for the projects in the eight countries in the Co-operative Programme;
- establish the scope and period of decommissioning (plant shutdown, Stages 1/2, dormancy and Stage 3) and create a cost matrix for the scope and cost groups;
- fit the participating projects into the cost matrix for the cost analyses;
- systematically analyse the raw cost data reported by the project managers and refine it by a series of questionnaires for the purpose of comparison;
- eliminate unacceptable and faulty data, perform a statistical model analysis and establish a mean value and a range for each cost group of each model (Model 1: Reactors decommissioned to Stage 3, Model 2: Reactors decommissioned to Stage 1 or 2, Model 3: Fuel Reprocessing Facilities and Model 4: All projects);
- analyse the factors influencing the cost variations and summarise the lessons learnt during the two years the Task Group has worked on decommissioning costs.

The results of the work submitted by the Task Group are summarised in a final report(1).

Basis of Cost Estimation

In this report the term "Decommissioning Costs" includes all costs from the termination of operations up to the achievement of a "green-field" condition at site. It has been applied to research and power reactors of all types as well as to fuel reprocessing plants. In addition, it covers both delayed and immediate dismantling of all such nuclear facilities. The back end costs of the fuel cycle such as the costs of reprocessing of fuel and the disposal of its secondary wastes or those of the intermediate storage or final disposal of fuel have not been included.

Overview of Cost Items and Cost Groups

A broad division was made of decommissioning into tasks(2) that may have to be executed for delayed or immediate dismantling of all civil nuclear facilities. The decommissioning tasks, i.e. cost items, were classified into the following cost groups:

01	Predecommissioning operations	02	Facility shutdown activities
03	Procurement of equipment and material	04	Dismantling activities
05	Waste treatment and disposal	06	Security, surveillance and maintenance
07	Site clean-up and landscaping	08	Project management, engineering and site support
09	Research and development	10	Fuel*
11	Other costs		

A matrix overview table has been established of cost groups versus four periods of decommissioning: Plant shutdown, Stage 1/Stage 2(3) decommissioning to achieve dormancy state, Dormancy, and Stage-3 decommissioning to achieve "green-field" status.

The task and cost groups have been derived to establish a basis for comparison. The projects did not necessarily estimate or report costs on this format. In order to facilitate the comparison of costs between the projects, the costs for each cost group were further subdivided into the respective component costs for labour, capital equipment/material and expenses.

Cost Comparison of Projects in Co-operative Programme

Acquisition of Cost Information

Copies of the matrix table described in the preceding section were sent to the managers of the 14 projects that were in the Co-operative Programme at that time. Replies were received from 12 out of the 14 projects, thus providing a basis for analysis. The replies varied in the detail in which the cost figures were shown, again depending on the local circumstances. A scrutiny revealed that:

- in many cases the cost figures given, straddled over more than one cost item or group so that it was impossible to identify the cost figures explicitly for each group;
- the "zero" costs reported for many cost items/groups represented, in many cases, actual costs that may have been reported outside the project;
- terms like "labour", "capital equipment/material" and "expenses" have not been used to denote the same type of costs in the various projects.

The Task Group has spent many hours in the interpretation and understanding of the reported cost figures and progressively refined the information received. It was evident from this diversity in the methods used in cost estimation and reporting, some adjustment of the first reported figures was essential on a broad basis for making them comparable. So the Task Group prepared general sets of questionnaires on labour costs, costs for capital equipment/material, and expenses, as well as specific lists of questions for each project. The project managers were requested to fill them as completely as possible, making intelligent guesses where exact information was difficult to give.

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* The cost group "fuel" was in the original listing. When the decision was taken later to exclude the costs associated with the back end of the fuel, the matrix model was not changed. In the comparison however all projects have zero costs for this cost group.

At the same time, it was pointed out that many projects used the term "no data available" for several cost items. The project managers were requested to identify their particular "no data available" as being of the types A, B or C: A being the work had been done within the scope of the project, but the costs were not identifiable, *i.e.*, really not available, B there had been no work done or costs incurred, *i.e.*, really a "zero", and C the cost item in question was not applicable because, for instance, such costs did not arise in that kind of project.

The collected answers were fed into the matrix and copies of the revised figures were sent back to the project managers for making sure that their answers to the questionnaires had been correctly interpreted. Even after these stages of refinement of information, the data from certain projects had to be verified by direct contact between members of the Task Group and the respective project managers at the Technical Advisory Group meeting (TAG-9) at Argonne, USA, in October 1990. After this exercise, the difficulties detected in the first answers were, for the most part, cleared up and the Task Group felt confident that it acquired a reasonable information base to make its comparative analysis.

Table 1 lists the 12 international projects from which cost data was received, and includes information such as type and size of facility, location, etc.. It also shows the acceptability of cost information for each cost group of all the projects in the various "project groups", where "accepted" cost groups are designated with "**" and those not acceptable or for which data was not available are shown with "---". In this comparison, the projects were grouped into three "Project Groups" based on the type of facility (reactor or fuel reprocessing) and decommissioning scenario (Stage 1/2 or Stage 3, or Stage 3 + Dormancy):

- Project Group I covers reactors decommissioned to Stage 3;
- Project Group II covers reactors decommissioned to Stage 1 or 2;
- Project Group III covers fuel reprocessing facilities.

Cost Analysis

The three project groups have been categorised into four "Models" for the purpose of the cost analysis: Model 1 – Project Group I, Model 2 – Project Group II, Model 3 – Project Group III and Model 4 – all 12 projects.

Raw data – Based on the actual and estimated costs (in local currencies), the percentage costs of each cost group and the distribution of costs (in per cent) for labour, capital equipment/material and expenses for the 12 projects in the analysis have been calculated. It is to be noted that by using percentage costs as a basis of comparison, the difficulties of dealing with costs in different currencies have been avoided.

Elimination of unacceptable data – Based on the responses from the project managers of each project to the questionnaire, unacceptable data in cost groups of certain projects have been eliminated. New percentage distributions for each cost group for each project have been recalculated. After rearranging and bringing the totals to equal 100 per cent, the corrected cost data formed the basis for further comparisons between the projects. For each cost group, the ranges and mean values of percentage costs based on the raw data, and the corrected mean values after the replies to the questionnaires were incorporated, have been presented in Table 2.

Application of mean value models – The corrected cost data for certain projects after the last iteration had been left with no data in some cost groups since the unacceptable raw data was eliminated. In each model, new figures were introduced, into these cost groups based on the percentage mean values

Table 1. List of Projects andAcceptability/Availability of Cost Groups

Project Group	No.	Name	Type and Size	Estimate Date	Project Status	Cost Groups 1	2	3	4	5	6	7	8	9	10	11
I Decommissioning to IAEA Stage 3	2	Gentilly 1*, Canada	BWR (D_2O moderated) 250 MWe	1983	Stage 1 Complete 1986	**	**	**	**	**	**	**	**	**	---	**
	7	KKN Niederaichbach, Germany	HWGC 100 MWe	1989	Expected Completion 1993	**	---	**	**	**	**	**	**	**	---	**
	8	KWL Lingen, Germany	BWR 520 MWt	1990	Stage 1 Complete 1988	**	**	**	**	**	**	**	**	---	---	**
	10	JPDR Tokai, Japan	BWR 90 MWt	1989	Expected Completion 1992	**	**	**	**	**	**	**	**	**	---	**
	11	Windscale AGR, United Kingdom	GCR 100 MWt	1989	Expected Completion 1999	**	**	**	**	**	**	**	**	**	---	**
	13	Shippingport, USA	PWR 72 MWe	1989	Actual Completion 1989	**	---	---	**	**	**	**	**	---	---	**
II Decommissioning to IAEA Stage 1/2	4	Rapsodie Cadarache, France	FBR (Experim. reactor) 40 MWt	1989	Expected Completion 1992	**	---	**	**	**	**	---	**	**	---	**
	9	Garigliano, Italy	BWR 160 MWe	1989	Expected Completion 1995	**	*	**	**	**	**	---	**	**	---	**
III Decommissioning to IAEA Stage 3	1	Eurochemic, Belgium	Reprocessing plant (Pilot project) – 300 kg/d	1989	Complete 1990	**	---	**	**	**	**	**	**	**	---	**
	6	AT-1 La Hague, France	Pilot reprocessing plant 2 kg/d	1989	Expected Completion 1991	**	---	**	**	**	**	**	**	**	---	**
	12	Coprecipitation Plant, United Kingdom	MOX fuel manuf. plant 50 kg/d	1986	Expected Completion 1990	**	**	**	**	**	**	---	**	**	---	**
	14	West-Valley, USA	Reprocessing plant (demonstration plant) 100 t/a	1988	Expected Completion 1994	----	**	**	**	**	**	---	**	**	---	---

* Gentilly 1 has been decommissioned to a "static" state (between IAEA Stage 1 and Stage 2), but costs have been calculated for achieving a Stage 3 decommissioning after 53 years Dormancy. Similarly, costs have been calculated for Lingen placed in a Stage 1 status + 25 years Dormancy and Stage 3.

** Accepted for comparison.

--- Not available for comparison.

Table 2. Total Costs (Raw and Corrected Data for All Projects)

		Range of total	Overall Mean Values: No Simulation, Fuel Excluded (%)							
	COST GROUPS	costs for all	Group I		Group II		Group III		All Projects	
		projects(%)	Raw Figures	Corrected Figures	Raw Figures	Corrected Figures	Raw Figures	Corrected Figures	Raw Figures	Corrected Figures
1	Pre-decommissioning Operations	0.0 – 14.3	3.3	3.4	9.6	9.6	2.6	3.5	4.1	4.5
2	Facility Shutdown Activities	0.0 – 15.4	5.1	5.9	6.7	13.3	2.7	5.5	4.6	6.8
3	Procurement of Equipment and Material	0.0 – 29.0	9.4	11.4	2.3	2.3	9.2	9.3	8.2	9.0
4	Dismantling Activities	9.5 – 48.2	31.2	31.7	25.2	25.2	17.6	17.9	25.6	26.0
5	Waste Management and Disposal	1.4 – 37.6	7.8	7.9	6.2	6.2	16.6	17.8	10.5	10.9
6	Security, Surveillance and Maintenance	0.7 – 43.4	11.5	11.6	28.7	28.7	14.7	15.2	15.4	15.6
7	Site Clean-up and Landscaping	0.0 – 06.8	2.5	2.5	0.0	0.0	1.0	2.1	1.6	2.4
8	Project Management, Engineering and Site Support	4.6 – 20.5	14.5	14.7	7.2	7.2	16.9	17.3	14.1	14.3
9	Research and Development	0.0 – 25.1	6.8	10.3	1.5	1.5	7.9	8.1	6.3	7.6
10	Fuel	0.0 – 00.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	Other Costs	0.6 – 16.4	7.9	8.0	12.7	12.7	10.7	10.7	9.6	9.6
	TOTAL		**100.0**	**107.3**	**100.0**	**106.7**	**100.0**	**107.4**	**100.0**	**106.8**

of the same cost groups from the other projects included in that model. In this exercise, cost groups with accepted values were left untouched. The cost groups with corrections represented only a third of the total costs of each of the projects analysed.

A statistical analysis using the student "t" distribution (due to the small sample of data) was then performed to determine the "range" of cost variation for each model at various confidence levels – 80 per cent, 90 per cent, 95 per cent, 98 per cent, 99 per cent. It was observed that due to the widely varying contents of our projects, in order to obtain confidence levels of 90 per cent and above, the interval between the lower confidence limit and the upper confidence limit had to be stretched so wide that the lower limit showed negative costs in the case of certain cost groups. This was unrealistic when compared to the range of costs (based on the corrected data) for each project. The results at the 80 per cent confidence level represented a more reasonable range of costs when compared to the data.

Table 3 presents the results of these operations of introducing "simulated mean" costs. It shows the range of costs based on the corrected data, the simulated mean values, the upper and lower limits at a 80 per cent confidence interval. The progressive refinement of data can be visualised by comparing Table 3 to Table 2. The values at the 80 per cent confidence interval can be considered as a true representation of the majority of the projects in the analysis.

Table 4 gives the ranges of distributed costs into labour, capital equipment/material and expenses based on the corrected data, the simulated mean, the upper and lower limits at the 80 per cent confidence interval. Again, as shown in the analysis using cost groups, these values are representative of the modifications which resulted from the dialogue between the Task Group and the managers of the 12 projects.

Factors Influencing Cost Variations

One of the responsibilities of the Task Group has been to identify aspects of discrepancies and variations in cost estimates as well as possible reasons for such variations. The Task Group has worked in this area in two ways: identification of general factors of significance influencing project costs, and identification of discrepancies specific to the projects covered by the analysis.

General Factors

Three broad categories emerged as factors having significant effect on project costs. These are political/geographical, technical and economic/financial. With the available information it was not possible to quantify the effect of these factors and, as would be expected, their importance varies widely. Discussion of these factors has been extensively dealt with by another OECD expert committee study(4), to which the Task Group has made significant contributions through the experience gained with the 12 projects in this programme. In this paper, very briefly some of the factors are listed below with short notes on their qualitative effect on project costs.

Political/Geographical Factors

- *Location* – It was observed that, countries with large land areas and low population densities have adopted decommissioning strategies which include longer dormancy periods. In contrast, the smaller, high population density OECD countries have opted for strategies of immediate dismantling or shorter delay periods between decommissioning stages. With the decommissioning industry being in its infancy, this latter group is generally facing increased costs.

Table 3. Model 4 (All Projects) – Range of Total Costs and Mean Values at 80 per cent Confidence Interval

	Cost Groups	Range of Total Costs (%) for All Projects	80 per cent Confidence Interval (%) Lower Confidence Limit	Mean Value (M)	Upper Confidence Limit
1	Pre-decommissioning Operations	0.4 – 14.0	0.7	4.2	7.6
2	Facility Shutdown Activities	0.0 – 14.3	3.1	6.5	10.0
3	Procurement of Equipment and Material	0.0 – 29.0	1.1	8.6	16.0
4	Dismantling Activities	9.1 – 47.9	13.1	24.5	35.9
5	Waste Management and Disposal	1.4 – 35.7	1.6	9.8	18.1
6	Security, Surveillance and Maintenance	0.7 – 43.4	2.1	14.7	27.4
7	Site Clean-up and Landscaping	0.1 – 05.4	0.9	2.1	3.3
8	Project Management, Engineering and Site Support	4.5 – 20.3	8.5	13.2	17.8
9	Research and Development	0.6 – 25.1	0.9	7.4	13.9
10	Fuel	0.0 – 00.0	0.0	0.0	0.0
11	Other Costs	0.6 – 15.2	4.6	8.9	13.3
	TOTAL		**66.9**	**100.0**	**133.1**

Table 4. Model 4 – Range of Total Cost Distribution (%) and Results at 80 per cent Confidence Interval

	Cost Groups	Range of Total Cost Distribution (%)	80 per cent Confidence Interval (%) Lower Confidence Limit	Mean Value (M)	Upper Confidence Limit
1	Labour Costs	24.2 – 87.5	42.5	56.8	71.2
2	Capital Equipment and Material	06.9 – 40.8	11.1	22.0	32.9
3	Expenses	05.1 – 52.6	8.2	21.2	34.1
	TOTAL		**42.1**	**100.0**	**157.8**

- *Political* – The eight countries represented by the projects vary significantly in the national (and to some extent regional) statutes relating to nuclear plant decommissioning. The policies of individual governments have significantly influenced the choice of decommissioning strategy. The effect of these legal and political factors is to vary the timing and period between decommissioning stages.

- *Regulatory Aspects* –The regulation of the decommissioning process is common to all countries but has not been consistent between projects. In particular there are wide differences between countries in the time taken for decommissioning licensing and in who pays for licensing. In most cases the fee is charged directly to the plant owner but for a substantial minority of countries this is a charge borne by the taxpayer.
- *Waste Management* – Regulations and requirements for the classification, conditioning, transport and disposal of various categories of radioactive waste vary widely in different countries. This is equally true regarding the costs for such activities, specially disposal. Disposal sites for waste are in use in some but by no means all countries, and where not available increased on-site storage charges are incurred. Clearance levels are not available in most countries and the case-by-case values for release differ from country to country. Reprocessing of spent fuel is not the current universally adopted solution to the management of this material, leading to different volumes of waste generated when projects are compared.
- *Site* – The plant being decommissioned may be on a single or a multiple nuclear facility site. In the latter case the costs of monitoring, surveillance and security for the duration of the project (including dormancy) are greatly reduced.

Technical Factors

- *Facility Characteristics* – The 12 projects in the programme represent various types (Reactors: BWR, PWR, HWGC, GCR and FBR, and Fuel Reprocessing and Manufacturing Facilities), and sizes (Reactors 40 MW to 250 MW and Fuel Facilities 2 kg/d to 100 t/a). The decommissioning scenarios vary from Stages 1, 2 and 3, Stage 3 with dormancy and reuse or green field condition.
- *Decommissioning* – Single-piece removal of large components like reactor vessels or steam generators can be compared with segmenting. Both methods require special purpose equipment. An extensive decontamination may have been required in some cases, if a spread of activity occurred during operation. Health physics/Industrial safety requirements vary widely, with correspondingly varying costs. Some projects included R&D costs in their budget. Others did not account for it or did not have any R&D. Costs for defuelling/intermediate storage/shipping off-site are sometimes included in the decommissioning budget. Sometimes they are covered by the operational budget or elsewhere.

Economic/Financial Factors

Budget or accounting issues such as: When is the starting point of the decommissioning budget? Where are the operational/maintenance costs budgeted, after shutdown but before start up of decommissioning? have been difficult to obtain clarifications from the 12 projects. They also seem to have adopted various estimating methodologies and the lack of standard methods might have led to the overlooking of important cost items in some cases. Cost estimates made at different points in time (year of estimate) must be indexed for comparison. This problem was avoided, however, by using percentages. Budgetary reasons for lengthening or shortening the duration of the project may also have influenced cost variations. Labour costs and project management costs seem to also vary considerably, depending on the country, the facility ownership (private or state) and duration of the project.

Different levels of productivity, length of facility operations affecting the cost of dealing with operational waste (if treated under decommissioning), the use of own staff or equipment instead of subcontracting, and the energy costs during decommissioning and dormancy stage can vary from project to project and from country to country. In most cases, negative costs, the incomes from the recycling of steel, components and heavy water were not considered.

Providing a contingency allowance in the decommissioning estimate is not a universal practice. It can vary from zero (for certain state financed projects) to very high figures for other projects. Escalation of costs in the estimate and especially if the project runs for several years certainly must be considered. Long dormancy periods can lead to low present worth values of total costs in terms of discounted funds. However, since all estimates have been converted to percentages, no significance was attached to estimates from different times or for future value of funds to be spent for a delayed decommissioning scenario.

Discrepancies specific to projects analysed

The 12 projects were scrutinised to identify specific reasons for cost discrepancies after refining the raw cost data to make them comparable. The features special to specific projects lead to more or less broad deviations in the mean values for each model.

Except for the two projects decommissioned to Stage 1 or 2 (Model 2), the figures for the other projects (Models 1, 3 and 4, Model 4 for all projects) in the different cost groups show a fairly good agreement. As due to their particular status, not all activities related to Stage 3 are incorporated in the cost figures for the projects under Model 2, their results differ on an overall basis. In this model, for example, due to local circumstances, licensing costs for one project were reported low compared to other projects in the analysis; no dormancy costs were shown either. Further analysis was not done on this model due to its sample size.

In the Model 1, Reactors Stage 3, and Model 3, Fuel Cycle Facilities, the reasons for the important deviations from the individual mean values in different cost groups can be summed up as follows:

- *Cost Group 1 – Pre-decommissioning Operations*: No or low licensing costs were quoted due to local circumstances in some projects since these costs do not exist or are not to be included in the project.
- *Cost Group 2 – Facility Shutdown Activities*: Some projects show lower cost figures as costs for a longer predecommissioning operation period are not shown, but are included in the operational costs for the facility. Other projects show high reported costs, as due to an unforeseen shutdown of the facility, they may be dealing with a longer shutdown period where all the operational crew stayed on site preparing for the real decommissioning period.
- *Cost Group 3 – Procurement of Equipment and Material*: Some projects show lower cost figures as decommissioning is executed only using equipment available on site from normal operation, or as no special equipment is expected to be used due to the method of dismantling used for components or to lower radiation levels after a long dormancy period. Other projects have higher costs due to specific characteristics of the installation that require special tools and equipment to make decommissioning feasible.
- *Cost Group 4 – Dismantling Activities*: Some projects show lower dismantling costs as dismantling activities may be cheaper due to a longer dormancy period. Other projects show higher figures as they include other costs as for example costs related to a long Stage 1 preparation period, which cannot be identified separately.

- *Cost Group 5 – Waste Management and Disposal*: Some projects do not include costs for final disposal of decommissioning wastes as no disposal facilities exist. High waste treatment costs, as for example for the vitrification of high level liquid waste from reprocessing, have been reported by some other projects. Considering these costs under decommissioning operations is not universal.
- *Cost Group 6 – Security, Surveillance and bMaintenance*: Projects with long dormancy periods show extremely high security, surveillance and maintenance costs, but lower dismantling costs as indicated before.
- *Cost Group 7 – Site Clean-up and Landscaping*: Projects with lower costs in this cost group do not include demolition of buildings after decommissioning.
- *Cost Group 8 – Project Management, Engineering and Site Support*: No special elements of discrepancy distinguished.
- *Cost Group 9 – Research and Development*: Some projects do not include special research and development costs due to changed working conditions and assumed evolution in technical methods after a long dormancy period. Other projects show high research and development costs as the R & D character is part of the objective of the project itself.
- *Cost Group 11 – Other Costs*: Some projects show lower cost figures as no overhead costs or contingencies have been incorporated.

Elimination of Influencing Factors

The discrepancies described above indicate the specific character of every individual project in the different cost groups.

If, as a second order approach, in the Models 1, 3 and 4, the specific percentage cost values, due to the discrepancies, are changed to the mean values of the other projects with no discrepancies in the individual cost groups, new cost distribution ranges as shown in Table 5 could be constructed. Comparing Model 4 figures to the ones in Table 3, it can be seen that they differ only to a limited extent. This can be seen as an indication that the simulation models present fairly good correlation in different cost groups to account for the cost discrepancies.

Further, if new mean values are again calculated as indicated in Table 5 for these models, a pattern of cost distribution emerges for hypothetical mean projects with distinct characteristics – a reactor decommissioning project (Model 1), a fuel cycle facility decommissioning project (Model 3) and an overall mean decommissioning project (Model 4). These projects could be considered as meeting a simulated condition with no long term dormancy, where the facility is decommissioned to an IAEA Stage 3 after final shutdown has been declared.

Comparing mean values of Model 1 (Reactors Stage 3) to Model 3 (Fuel Facilities), a shift in cost figures from Cost Group 4 (Dismantling Activities) to Cost Group 6 (Security, Surveillance and Maintenance), Cost Group 8 (Project Management, Engineering and Site Support) and to Cost Group 11 (Other Costs) has been observed. This could be attributed to the specific nature of the decommissioning work performed in a nuclear power plant compared to a fuel cycle facility. The Model 4 seems to be a good mean value representation of all 12 projects when the discrepancies have been eliminated.

Table 5. Results of Second Order Analysis for Project Groups Models 1, 3 and 4

		Range of Total Costs (%)			Tentative Overall Mean Values for Project Groups Models 1, 2 and 4 (%)		
	Cost Groups	Model 1	Model 3	Model 4	Reactors Stage 3 Model 1	Fuel Facilities Model 3	All Projects Model 4
1	Pre-Decommissioning Operations	01.1 – 06.3	03.0 – 06.8	01.1 – 14.0	3.0	5.0	5.0
2	Facility Shutdown Activities	03.1 – 14.2	05.3 – 06.6	03.1 – 14.3	7.0	6.0	8.0
3	Procurement of Equipment and Material	02.1 – 24.9	00.0 – 21.8	00.0 – 24.3	11.0	10.0	9.0
4	Dismantling Activities	15.7 – 41.8	15.0 – 29.3	12.5 – 42.9	33.0	19.0	25.5
5	Waste Management and Disposal	05.9 – 13.7	02.7 – 16.2	01.6 – 16.0	9.5	10.5	9.5
6	Security, Surveillance and Maintenance	02.8 – 07.2	00.7 – 22.7	00.7 – 30.6	5.0	10.5	10.0
7	Site Clean-up and Landscaping	00.5 – 04.6	01.6 – 02.7	00.5 – 05.3	2.5	2.0	2.5
8	Project Management, Engineering and Site support	04.9 – 18.8	16.0 – 22.2	04.5 – 22.0	13.5	19.0	15.0
9	Research and Development	00.8 – 10.5	01.1 – 09.8	00.8 – 10.3	7.0	6.0	5.0
10	Fuel	00.0 – 00.0	00.0 – 00.0	00.0 – 00.0	0.0	0.0	0.0
11	Other Costs	00.7 – 15.1	08.6 – 13.8	00.2 – 15.2	8.5	12.0	10.5
	TOTAL				**100.0**	**100.0**	**100.0**

Concluding Summary, Lessons Learnt

The Task Group on Decommissioning Costs was set up early in 1989 to identify the reasons for the large variations in reported decommissioning cost estimates of 14 projects in the OECD Co operative Programme. The Task Group gathered cost data from 12 of the 14 projects, established a basis of comparison and decommissioning tasks to be adopted for all projects, prepared a matrix of cost groups and decommissioning periods, and incorporated the project cost data into these matrices.

The cost data was progressively refined by a dialogue between the Task Group and the project managers in order to improve the basis of comparison and to make the data more uniform. The projects were divided into groups of projects with similar characteristics (Models) to facilitate the analysis of the cost distribution, *i.e.*, the relative comparison of cost groups in each group of projects. The inconsistent data was eliminated and substituted by calculated mean values ("simulated values") of the corresponding cost groups from the remaining projects in the group. By this process, the real project specific discrepancies were identified and analysed without bias resulting from inconsistent, or in some cases inappropriate data. The grouping of the projects into the four models gave the opportunity of comparing projects with similar characteristics as well as decommissioning projects as a whole. This was done both on a cost group basis as well as by comparing the costs divided under the headings of "labour", "capital equipment and material" and "expenses". In addition, the Task Group has also reviewed some general factors which include issues dealing with political/geographical, technical and economic/financial aspects influencing variations in the estimated costs. These factors were only treated qualitatively, since data could not be separated to analyse their quantitative effects.

In the project specific analysis, however, over two-thirds of the "refined" percentage costs from the projects were found to be comparable and utilised without change. Even in the remaining one-third of the percentage costs, only marginal substitutions (simulations) were made. So the total "simulated" costs in the models are generally close to the raw "refined" figures and the conclusions (ranges of cost variations) are more or less applicable to, and valid for, the raw data from the projects. However, it was observed that project specific aspects and local circumstances have a significant influence on decommissioning costs.

It is important to state that the analysis technique described in this report is not a cost calculation model. It cannot be used to predict decommissioning costs. The Task Group feels that its technique provided a useful tool for better understanding the distribution of costs in decommissioning projects.

One of the lessons learnt by the Task Group is the potential for making errors and the difficulties encountered in performing quick international cost comparisons. It was evident that the answers to any cost questionnaire must be analysed and refined by follow-up questionnaires to understand the real contents. Numbers taken at face value, without regard to their context, are easily misunderstood and misinterpreted.

Another important observation the Task Group has made is that there is today no standardized listing of cost items or estimating methodology established for decommissioning projects. Such a standardization would be useful not only for making cost comparisons more straightforward and meaningful, but should also provide a good tool for cost effective project management. In their report, the Task Group has made a proposal for a listing of cost items and cost groups that could be the framework for such a standardization. It is encouraging to note that one of the projects in the Co-operative Programme has remodelled its cost reporting along these lines.

It is clear that the small number of projects involved in this exercise does not provide a statistically significant sample to extrapolate conclusions. However, the value of the exercise has demonstrated the merit in continuing this type of analysis for more projects with a view to collecting sufficient basis to support the validation of worldwide decommissioning cost estimates.

Future Work

At its meeting in Paris on 2-3 November 1994, the Liaison Committee of the Co-operative Programme decided to re-start the work of the Task Group on Decommissioning Costs, looking this time (specifically and separately) at power reactors and fuel facilities. The study will:

- Structure/break down the costs in cost groups/cost items/cost factors, where the scope of each of these will be clearly defined;
- Compare/contrast/explain differences in the results presented in various countries/projects.

In a first meeting of the Task Group the terms of reference/programme of work for the present study were discussed and decided as follows:

- The predicted costs of the 12 projects in the 1991 study should be compared to the actual costs (or to the current predictions);
- The study will cover the decommissioning costs of:
  - Commercial nuclear facilities/projects in or related to the Co-operative Programme,
  - Reactors and fuel facilities in two separated groups;
- The basic principles to be followed are:
  - For participation, access must be given to all available information, *i.e.*, observance of give-and-take principle,
  - Confidentiality of supplied information, which will be circulated only within a circle to be agreed on within the Task Group;
- The listing (groups/items/factors) of the 1991 study is to be compared with other lists (from current studies), and a new "standardized" listing will be prepared;
- The participating organisations will fill in the relevant cost figures in the standardized listing and thus a new inventory of cost estimates will be produced;
- This inventory will be analysed and scrutinised in order to identify aspects of discrepancy and the reasons for these.

The following projects/calculations were identified as candidate cost material and as available for the Task Group:

- All the projects in the Co-operative Programme are candidates for the cost analysis. The analysis can thus include at least 6 reprocessing plants and over a dozen reactors of various sizes and types, including commercially operated plants like Greifswald and Vandellos;
- In addition, the results of the following major studies, that have been performed recently, will also be available:
  - 900-MWe presssurised-water reactor, EDF study, France,
  - 1 000-MWe boiling-water reactor, SKB study, Sweden,

- Trawsfynydd Safestore, Nuclear Electric, United Kingdom,
- TLG studies as from Portland General Electric Company (Trojan NPP),
- The interest from Japanese utilities is still under investigation.

It has been identified that the depth of detail to which these calculations have been carried out is going to the "cost item" level and in many cases to the "cost factor" level.

It was pointed out that there were two types of "customers" for the results of the work of the Task Group:

- organisations planning to decommission, and
- organisations estimating how much to put aside for decommissioning in the future.

A time schedule of work for the next months has been agreed on, aiming to produce a final report somewhere end 1996.

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Annex IV

REPORT FROM THE TASK GROUP ON DECONTAMINATION

Introduction

In its thirteenth meeting from 20-23 October 1992 in Rome, the Technical Advisory Group of the Co-operative Programme established a Task Group on Decontamination in order to prepare a state-of-the-art report on decontamination in connection with decommissioning. The work has been focused on decontamination for dose reduction as well as for waste decategorisation. The decontamination of both metallic and concrete surfaces has been considered.

During its early meetings, the group has developed a questionnaire to be sent to different project managers. The information requested in this questionnaire covered the technical aspects as well as the economical aspects of the selected decontamination technique. The questionnaire was to be completed for each specific application of a given process, including actual data on efficiency of the process and data on operating and investments costs.

This overview of decontamination techniques has the objective of describing critical elements of choosing techniques for a practical decontamination problem.

Definition and General Considerations

Decontamination is defined as the removal of contamination from surfaces of facilities or equipment by washing, heating, chemical or electrochemical action, mechanical cleaning, or other techniques. In decommissioning programs, the objectives of decontamination are to:

- reduce radiation exposure;
- salvage equipment and materials;
- reduce the volume of equipment and materials requiring disposal in licensed burial facilities;
- restore the site and facility, or parts thereof, to an unrestricted-use condition;
- remove loose radioactive contaminants and fix the remaining contamination in place in preparation for protective storage or permanent disposal work activities; and
- reduce the magnitude of the residual radioactive source in a protective storage mode for public health and safety reasons or reduce the protective storage period.

Some form of decontamination is required in any decommissioning program, regardless of the form of the end product. At the minimum, the floor, walls, and external structural surfaces within work areas should be cleaned of loose contamination, and a simple water rinsing of contaminated systems may be performed. The question will arise, however, whether to decontaminate piping systems, tanks, and components. A strong case can be made in favour of leaving adherent contamination within piping and components in a dispersed form on the internal metal surfaces rather than concentrating the radioactivity through decontamination. In most cases, decontamination is not sufficiently thorough to allow unrestricted release of the item being treated; therefore, a savings both in occupational exposure and cost could be realised by simply removing the contaminated system and its components and only performing certain packaging activities (*e.g.*, welding end caps on pipe sections). However, additional cost for the disposal of materials must be weighed in this scenario.

A decontamination program may also require a facility capable of treating secondary wastes from decontamination, *e.g.*, of processing chemical solutions by such means as neutralisation and precipitation, filtration, evaporation, and demineralisation. The concentrated wastes, representing a more significant radiation source, must be solidified and shipped for burial in licensed burial facilities unless properly treated in the waste reduction/recycling/reclamation processing configuration (the optimal waste reduction configuration must be defined after an economic assessment of treatment versus transportation/disposal costs has been completed). Each of these additional activities can increase: (1) occupational exposure rates, (2) the potential for a release, and (3) the uptake of radioactive material, and could conceivably result in even higher doses than those received from removing, packaging, and shipping the contaminated system without extensive decontamination. Resolution of this question depends on specific facts, such as the exposure rate of the gamma-emitting contamination, the level of the contamination, and the effectiveness of the containing component and piping (wall thickness) in reducing work area radiation fields.

Objectives and Selection Criteria

There are two main reasons for considering the use of decontamination techniques. The first is the importance of removing contamination from components or systems to reduce dose levels in the installations. Access to the installations could then be made easier so that it could be possible to use hands-on techniques for dismantling rather than the more expensive use of robotics or manipulators. The second reason is that it may be possible to reduce the contamination levels of components or structures such that derived wastes can be disposed of at a lower, and therefore more economical, waste treatment and disposal category or, indeed, disposed of as waste exempt from regulatory concern.

Several decontamination techniques have been developed to support maintenance work in ar installations. With relative success, the same techniques have also been adopted when decommissioning nuclear installations and components (Table 1). Objectives differ between these applications, however.

In maintenance work, the highest degree of decontamination is sought, avoiding any damage to the component so that it can be adequately reused. In contrast, the main aim of decontamination for decommissioning is the removal of as much activity as possible so that clearance levels are met and the material from the system can be reused without radiological restrictions. In many cases, it will be necessary to remove a thin layer of structural material in order to achieve this aim. Therefore, much more aggressive decontamination methods are required than those used during the service life of a plant. In this view, technical methods presenting high decontamination factors at high contamination levels do not always allow achievement of the very low levels required to release the material without restrictions.

During decontamination for maintenance, components and systems may not be damaged and the use of very aggressive decontamination methods is not appropriate. In decontamination for decommissioning however, it is mainly the use of somewhat destructive techniques that present the possibilities of meeting the objectives to release the material at clearance levels.

Table 1. Decontamination for Decommissioning

⇒ Decontamination before Dismantling • Reduction of Occupational Exposure	Pipe Line System Decontamination	Chemical Method Mechanical Method
	Pool, Tank	Hydro Jet Method Blast Method Strippable Coating Method, etc.
⇒ Decontamination after Dismantling • Recycle of Contaminated Metal • Reduction of Radioactive Waste	Pipes, Components	Electropolishing Method Chemical Immersion Method Blast Method Ultrasonic Wave Method Gel Method
⇒ Decontamination of Building • Unrestricted Release of Building • Reduction of Radioactive Concrete Waste	Concrete Surface	Mechanical Method * Scabbler * Shaver * Drill & Spawling * Steel Grit Blast Thermal Stress Method * Microwave Irradiation * Flame Scarfing

Other factors presenting differing influences on the choice of techniques are, for example, secondary waste production and the possibilities to recycle products from decontamination processes. In decontamination for maintenance, both factors have only relative importance, while in decontamination for decommissioning they are part of the parameters for decision making.

Another aspect in which techniques for thorough decontamination of materials differ from maintenance or laboratory scale decontamination is their industrial size. The large amount of contaminated materials produced during decommissioning procedures and available for decontamination, generally do not favour methods or techniques that are labour intensive or difficult to handle, or that present difficulties when automation is envisaged.

Finally the absolute requirement to effectively obtain residual contamination levels below clearance limits is also a factor of primary influence when making adequate choices of decontamination techniques to be used. Even if techniques for the decontamination of complex geometries (*e.g.*, pipe bends, small diameter piping) exist, the non-accessibility of areas may prevent the radiological measurements required to show that the clearance levels are met and that the material can be released without any radiological restrictions.

Industry currently is in a transition phase, growing from decontamination techniques for maintenance to decontamination for decommissioning. Limited data on the efficiency of usable techniques to meet the low unrestricted release criteria at decommissioning are available. In most cases, using available techniques, the clearance levels are only met in an asymptotic way. Not all methods and techniques available present the possibility of decontaminating to below the required clearance levels. So, in some cases, decontamination is carried out in different stages, the last stage specifically aiming to obtain the required objectives.

Based on these considerations, when selecting a specific technique for system and/or component decontamination, mainly the following requirements must be considered:

- *Safety*: application of the method should not result in increased radiation hazards due to external contamination of workers or even inhalation of radioactive dust and aerosols formed during its implementation;
- *Efficiency*: the method should be capable of removing radioactivity from a surface to the level which would enable hands-on work instead of robotics, or which would permit recycle/reuse of material or, at least, a lower waste treatment and disposal category after material removal;
- *Cost-effectiveness*: where possible, equipment should be decontaminated and repaired for reuse, however, the method should not give rise to costs which would exceed the costs for waste treatment and disposal of the material; and
- *Waste minimisation*: the method should not give rise to large quantities of secondary waste, the treatment and disposal of which would result in excessive requirements for workpower and costs, thereby causing additional exposures.

In addition, the choice of a process or of a combination of several processes will finally depend on several other factors such as:

- the specific nature of the application, the characteristics of the surface, of the nature of the contamination, of the complexity of the system;
- the final objective of the decontamination operation;
- the radiological aspects;
- the feasibility of industrialisation; and
- the cost/benefit analysis taking into account all aspects of the decontamination operation.

Characteristics of Some Selected Decontamination Techniques for Segmented Components

Simplified overviews of some decontamination techniques in view of their efficiency regarding some selection criteria can be found in literature. Practical experiences however indicate that these overviews have to be considered with great care. Small changes in details of application of the selected techniques can have significant impacts on the qualification of influencing parameters. Though the objective of this paragraph is not to provide a detailed overview of all advantages and disadvantages of available techniques, some specific considerations on selected categories of decontamination techniques are mentioned.

There are two primary categories of decontamination equipment or techniques: chemical and mechanical.

Chemical decontamination uses concentrated or dilute solvents at temperatures of 50 to 70°C and over, in contact with the contaminated item, to dissolve either the base metal or the contamination layer covering the base metal. Required decontamination levels can be obtained by continuing the process as long as necessary, taking care to ensure that tank walls or piping are not penetrated by corrosion.

In soft chemical decontamination processes, dissolution of the layer is intended to be nondestructive to the base metal and is generally used for operating facilities. Aggressive chemical decontamination techniques involving dissolution of the base metal should only be considered in decommissioning programs where reuse of the item will never occur. Chemical flushing is recommended for remote decontamination of intact piping systems.

Chemical decontamination has also proven to be effective in reducing the radioactivity of large surface areas such as drip trays as an alternative to partial or complete removal. They are also suitable for use on complex geometries as well as for a uniform treatment of inner and outer pipe surfaces. These techniques however require efficient recycling of reactive chemicals. Insufficient recycling of decontamination products results in very large amounts of secondary wastes which are difficult to treat.

Electrochemical decontamination can be considered in principle to be a chemical decontamination assisted by an electrical field. Nevertheless the best electropolishing is a process widely used in non-nuclear industrial applications to produce a smooth polished surface on metals and alloys. It can be considered the opposite of electroplating as metal layers are removed from a surface rather than added as a coating.

Electrochemical decontamination has been applied by soaking in an electrolyte bath, or using a pad moving over the surface to be decontaminated, the passage of electric current involving the anodic dissolution and removal of metal and oxide layers from the component. The electrolyte is continuously regenerated by recirculation.

These processes can only be applied to conducting surfaces. They are highly effective and give a high decontamination factor. Their use is limited (1) when soaking is used, by the size of the bath, and (2) with the pad, by the geometry of the surfaces and the available clearance around the part being treated. This makes the method almost inapplicable for industrial decontamination of complex geometries (*i.e.*, pipes). The volume of effluents is minimised, however, handling the parts to be soaked or the pad, can lead to additional worker's exposure.

Decontamination by melting presents the particular advantage of redistributing a number of radionuclides among the ingots, slag and filter dust resulting from the melting process and so decontaminating the primary material.

Melting may provide an essential step when releasing components with complex geometries, simplifying monitoring procedures for radioactive metal characterisation. In addition to its decontamination effects, the problem with inaccessible surfaces is eliminated and the remaining radioactivity content is homogenised over the total mass of the ingot. So melting can be a last step in the decontamination and release of components with complex geometries after these pieces have been decontaminated by *e.g.*, chemical methods, removing *e.g.*, radionuclides such as cobalt 60 that remain in the ingot after melting.

Mechanical and manual decontamination are physical techniques. More recently, mechanical decontamination has included washing, swabbing, foaming agents, and latex-peelable coatings. Mechanical techniques may also include wet or dry abrasive blasting, grinding of surfaces, and removal of concrete by spalling or scarifying. These techniques are most applicable to the decontamination of structural surfaces.

Abrasive blasting systems, both wet and dry, have been used with success. They provide mechanical methods, derived from the conventional industry, that give very high decontamination factors. The longer the operations are continued, the more destructive they are. However, wet abrasive systems produce a mixture of dust and water droplets that might be difficult to treat. Care must be taken not to introduce the contamination into the material surface (hammering effect) so that the ability to meet clearance levels could be compromised.

These techniques are not appropriate for complicated surfaces where uniform access can not be guaranteed.

In recent years, many innovative decontamination techniques have been proposed. For the most part, these emerging technologies are hybrid technologies comprised of one or more of the following methods: chemical, electrochemical, biological, mechanical, or sonic methodologies.

Characteristics of Some Selected Decontamination Techniques for Building Surfaces

When decontaminating building structures, mainly surface-removal techniques have to be considered. Surface-removal techniques are used when future land-use scenarios include reuse, when it is impractical to demolish the building (*e.g.*, a laboratory within a building), or in view of waste minimisation. The techniques considered remove various depths of surface contamination (*e.g.*, floors versus walls), and may be used to reduce the amount of contaminant to be disposed of. For example, if a contaminated building is demolished, all the debris is considered contaminated and requires special handling. However, by first using a surface-removal technique, the volume of contaminant is limited to the removed surface material. The eventual demolition can then be handled in a more conventional manner. In this instance, a cost benefit analysis should be prepared that considers such potential concerns as packaging, shipping and burial costs for a surface-removal technique versus conventional demolition and disposal.

Decontamination processes to be used for contaminated concrete depend greatly on the characteristics of the concrete surface to be cleaned. They can vary from very simple hand-based processes, to jackhammer or drilling removal techniques. The former is normally used for cleaning painted or smooth surfaces covered by loose contamination and the latter for decontaminating concrete in which the contamination has penetrated deeply.

Simple processes have been widely used since the need for decontamination/cleaning was first noted in nuclear industry, and each nuclear facility has to some extent a certain practical experience of these kinds of decontamination processes. Among these simple processes are brushing, washing and scrubbing, and vacuum cleaning. These processes are generally labour intensive, but they have the advantage of being versatile. They are often used as a first step, before or during dismantling, to prepare items for more aggressive decontamination using stronger processes.

Other, more aggressive techniques are grinding, spalling and drilling, high pressure water jetting, foam decontamination, the use of strippable coatings, high frequency microwaves, and induction heating. The use of most of these techniques is limited to specific applications in specific cases. Some of them can create important spread of contamination, or produce a lot of secondary waste. Most of them are also less suitable for industrial applications.

When decontaminating concrete surfaces, mainly scarifying techniques are used as needle scaling and scabbling, or shaving as a special alternative for scabbling or grinding.

Scarifiers physically abrade both coated and uncoated concrete and steel surfaces. The scarification process removes the top layers of contaminated surfaces down to the depth of sound, uncontaminated surfaces. Today's refined scarifiers are not only very reliable tools, but also provide the desired profile for new coating systems in the event the facility is to be released for unrestricted use.

Needle scalers are usually pneumatically driven and use uniform sets of 2, 3, or 4-mm needles to obtain a desired profile and performance. Needle sets use a reciprocating action to chip contamination from a surface. Most of the tools have specialised shrouding and vacuum attachments to collect removed dust and debris during needle scaling.

Needle scalers are an exceptional tool in tight, hard-to-access areas, as well as for wall and ceiling surface decontamination. This technique is a dry decontamination process and does not introduce water, chemicals, or abrasives into the waste stream. Only the removed debris is collected for treatment and disposal. Production rates vary depending on the desired surface profile to be achieved.

Scabbling is a scarification process used to remove concrete surfaces. Scabbling tools typically incorporate several pneumatically operated piston heads to strike (*i.e.*, chip) a concrete surface. Scabbling bits have tungsten-carbide cutters. Both electrically and pneumatically driven machines are available. Because scabbling can cause a cross-contamination hazard, vacuum attachments and shrouding configurations have been incorporated.

Scabblers are best suited for removing thin layers (up to 15 or 25-mm thick) of contaminated concrete (including concrete block) and cement. It is recommended for instances where (1) no airborne contamination can occur, (2) the concrete surface is to be reused after decontamination, (3) waste minimisation is envisaged, or (4) for instances in which the demolished material is to be cleaned before disposal. The scabbled surface is generally level, although coarsely finished, depending on the bit used. This technique is suitable for both large open areas and small areas.

As an alternative for scabbling, shaving machines have been developed. These machines are similar to normal units. They have a quick change diamond tipped rotary cutting head designed to follow the contours of the surface being removed, and to give smooth surface finish, easier to measure and ready for painting. Depth adjustments can be set manually to create a minimum of waste. The machine proves capable of cutting through bolts and metal objects, something with a traditional scabbler would result in damage to the scabbling head. Production rates vary depending on the structure and the hardness of the concrete, the depth setting, the cutting speed and the type of diamond used.

Overview of Decontamination Processes for Decommissioning

For the preparation of a state-of-the-art report on decontamination in connection with decommissioning, the Task Group on Decontamination has identified a list of processes as being of interest for decontamination (Table 2). The decontamination of both metallic and concrete surfaces has been considered. For decontamination of metals, the processes are divided into chemical, electrochemical and physical processes. Moreover, a distinction has been made between the processes used in closed systems, *e.g.*, full-system decontamination of the primary circuit of a reactor or the partial decontamination of closed loops, and the processes used in open tanks, *e.g.*, decontamination of dismantled pieces. For the decontamination of concrete, surface decontamination processes and demolition processes have been selected.

Future Work

Having identified the decontamination processes that can be used in connection with decommissioning, the Task Group on Decontamination has asked its members as well as selected correspondents, to answer questionnaires on specific applications. When all the answers to the questionnaires have been received, it is proposed to write a final report including some general considerations on decontamination for decommissioning, completed with a listed overview of the information received on the selected techniques.

Table 2. Overview of Decontamination Processes for Decommissioning

Metal decontamination	Closed systems	Open systems
Chemical processes		
Oxidation processes		
• ODP/SODP	•	
• Cerium/sulfuric acid		•
• Cerium/nitric acid		•
• Oxidation-reduction processes		
• APCE/NPOX	•	•
• TURCO	•	•
• CORD	•	•
• CABDEREM, CANDECOM		•
• CONAP		•
• AP/NP + LOMI for PWR	•	
• EMMA	•	
• LOMI for BWR	•	
• Phosphoric-acid-based processes		•
• Foams	•	
Various reagents		
• HNO3 + HF	•	•
• HNO3/NaF	•	•
• HCl	•	•
• DECOHA		•
Electrochemical Processes		
• Phosphoric acid		•
• Nitric acid		•
• Nitric acid – Electrodeplating		•
• Sodium-sulfate ELDECON process		•
• Oxalic acid		•
• Citric acid		•
• Sulfuric acid		•
• Other electrolytes		•

Metal decontamination	Closed systems	Open systems
Physical processes		
• Ultrasonic cleaning		•
• High-pressure water		•
• CO_2 ice blasting		•
• Ice water		•
• Freon substitutes		•
• Abrasives wet	•	•
• Abrasives dry		•
• Grinding/planing		•
Combined mechanical/ chemical processes		
• Pastes + HP cleaning		•
• Foams/Gels/HP cleaning		•
• Vacuum cleaning (Dry/Wet)		•

Concrete decontamination	Surface decontam	Concrete decontam
•Kelly process	•	
• Scabbling	•	
• Sand blasting	•	
• Wet abrasives	•	
• Milling	•	
• Explosives		•
• Microwaves	•	
• Drill/Spalling		•
• Drill/Lime expansion		•
• Jack hammer		•

•= Decontamination technique applied for open or closed systems

Annex V

REPORT FROM THE TASK GROUP ON RECYCLING AND REUSE

Introduction

Significant volumes of waste will be generated from decommissioning nuclear facilities throughout the world. Existing regulations throughout the world currently require most of this waste to be classified as "low-level" nuclear waste and will be directed to regulated disposal facilities. However, currently operating waste facilities have limited capacities and are insufficient to accommodate the large volumes of waste that will be generated from decommissioning the world's nuclear facilities. Public opposition to the siting and licensing of new radioactive waste facilities makes the expansion of available waste capacity difficult and serves to increase already high disposal costs.

Concrete, steel and other valuable materials comprise a large portion of the waste generated by decommissioning activities. The inherent value of these materials and the need to reduce waste directed to radioactive disposal facilities makes recovery through some form of decontamination, a prudent, if not necessary undertaking. Furthermore, recyclable materials sent to waste facilities must ultimately be replaced with new materials. Adverse health and environmental impacts from mining and milling processes associated with the replacement of these materials are significant considerations which should not be ignored by those who intend to adequately assess the merits of recycling metal, concrete and other recoverable materials.

The OECD/NEA Co-operative Programme on Decommissioning is a forum established in 1985 for sharing valuable scientific and technical information, and for enhancing international co-operation among experts directly involved in decommissioning projects throughout the world. In 1992, the Co-operative Programme on Decommissioning chartered a Task Group on Recycling and Reuse to conduct an examination of the current state of the nuclear industry so that it might identify obstacles to recovering scrap metals and concrete generated from decommissioning nuclear facilities. The Task Group, focusing on metals, also was to identify and determine the effectiveness of methods for overcoming these obstacles. Its findings and conclusions, which are contained in the following report, are intended to provide information and insights into the practicality and usefulness of release criteria form the perspective of organisations currently engaged in actual decommissioning activities.

In accordance with this mission, the Task Group examined existing and proposed standards and regulations to determine whether the current regulatory environment is conducive to recovering these materials. The Task Group also examined the health, environmental, and socio-economic impacts associated with disposal and replacement of scrap metals, and compared these impacts with those associated with a proposed "tiered" regulatory regime that would allow large portions of these materials to be recycled and reused. Finally, the Task Group examined the technical adequacy and cost-effectiveness of available decontamination techniques.

Current Practices

One component of the Task Group's examination was a survey of 25 completed and ongoing decommissioning projects. This survey suggested that, in some cases, efforts to recycle and reuse materials generated by the projects had been limited by regulatory requirements.

Specifically, most recycling initiatives continue to be governed by case-specific release cirteria, or licenses, which vary from country to country or project to project. Consequently, shipment of material between countries, and even to other facilities within the same country, have been made extremely difficult by the absence of uniform criteria which would allow facilities to release or accept the material. Recycling and reuse initiatives were found to have been further complicated by variations in the quality assurance requirements, sampling protocols, required instrumentation, and documenting practices used by the surveyed projects.

The information compiled by the Task Group indicated that approximately 362,000 t of materials had been released from the projects since 1979 under varying criteria. Significantly, conditional or restricted release criteria had been applied to large quantities of scrap metals and other waste products, providing valuable insight as to the effectiveness of these alternative waste management practices. These case studies indicate that recycle can be effectively performed and regulated as an attractive alternative to storage and disposal as low-level waste.

International Standards and Release Criteria

The absence of consistent, internationally accepted release criteria remains a significant impediment to the recovery of large portions of radioactive scrap metals. A number of international "clearance" levels have been proposed by various international organisations to address this deficiency. "Clearance" is here distinguished from "exemption" based on the extent to which subject material has entered practices or facilities governed by radiological regulatory regimes. Clearance levels apply to materials that previously were subject to regulation (*e.g.*, components of a nuclear reactor or fuel facility). Exemption levels establish thresholds below which radiological restriction is deemed unnecessary. Accordingly, a clearance standard defines an activity level below which previously regulated materials no longer warrant regulation. Exemption criteria are used to determine which materials or practices initially require or do not require regulation. Although exemption levels are not directly related to the Task Group's examination, the great disparity between existing exemption levels and proposed clearance levels is a subject that warrants considerable attention.

Currently proposed clearance levels focus almost entirely on "unconditional" clearance, or unrestricted release of the material in question. The proposals are intended to form the bases for release criteria so trivial and comprehensive in scope that they will be readily accepted. However, a variety of alternatives, in addition to unconditional clearance, are available that are not addressed by these proposals. As previously mentioned, material has been released from facilities for transport to melting facilities. Following melting, remaining radionuclides are allowed to decay to the point that the material can be released. This approach would not be available under an "unconditional" release standard.

The absence of international "conditional" release criteria would unnecessarily hinder the transport and melting of scrap metal; particularly if implementing such an option requires transhipment of the material across national boundaries.

Moreover, existing international guidance, particularly ICRP 60, suggests that analyses of standards to govern radiological practices should include assessments of non-radiological impacts associated with the practices. Current proposals are based almost entirely on radiological considerations.

The Task Group's examination found that non-radiological health, environmental, and socio-economic considerations associated with directing large volumes of radioactive scrap metals to disposal facilities and replacing them with new material significantly exceed any radiological assessment of adverse impacts.

Finally, despite the availability of data from operating melting facilities, proposed international clearance levels have tended to use models that make use of largely conservative assumptions as a safeguard against uncertainty. These models incorporate data and assumptions that multiply the conservatism of the basic assumptions. Resulting criteria, already subject to pressures for general acceptability, are so conservative that non-radiological risks associated with related processes exceed by orders of magnitude the reductions to radiological risks. Consequently, the perceived radiological benefit gained by overly-conservative assumptions are negated by demonstratable increases in non-radiological risks where metals are subsequently replaced.

Health, Environmental and Socio-economic Impacts

Two fundamental options are available for managing the disposition of radioactive scrap metal; disposal and replacement, and recycling and reuse. In order to more effectively evaluate the health, environmental, and socio-economic impacts of these two management alternatives, the Task Group compared disposal and replacement, with a "tiered" system of release criteria. This "tiered" system would establish residual radioactive contamination levels applicable to end-use or final destination options for material generated by decommissioning operations. This is intended to optimise the materials to be recycled with the available options for reuse.

Physical risks to workers from workplace accidents and to the public from transportation accidents exceed the risks attributable to either alternative from radioactive materials or chemicals. Radiological risks to the public from both alternatives would be kept to very low levels (approximately 10^{-5} fatalities per year of practice). In contrast, non-radiological health risks associated with disposal and replacement are much higher than those associated with recycling and reuse. This disparity results primarily from accident risks to workers associated with steel mill and blast furnace operations, and increased transportation risks consequential to new materials production. For example, the risk of a worker fatality associated with the replacement of 50 000 t of radioactive scrap metal is approximately 15 fatal or serious injuries to workers in steel mill and blast furnace operations, nearly twice the risk for steel smelting and milling operations for recycling.

Moreover, environmental and socio-economic impacts attributable to disposal and replacement exceed those for recycling and reuse. Land use, disruption and environmental damages from mining operations and environmental impacts associated with the additional energy requirements of replacement processes are but two of the many contributing factors documented in greater detail in the Task Group's Report that lead one to this conclusion. Environmental impacts associated solely with the disposal and replacement alternative also include increased leaching of heavy metals from soils and mining wastes into surface and ground water, and sedimentation of streams and rivers.

With regard to adverse socio-economic impacts, both alternatives likely will confront some form of public opposition. Recycling and reuse must overcome the negative stigma associated with the nuclear industries of most countries.

However, the disposal option must overcome public opposition to the siting and licensing of new disposal facilities necessary to accommodate the needs of the decommissioning community. Other economic factors, including affects of recycling on scrap metal markets, also tend to favor recycling and reuse management alternatives. Even if recycling radioactive scrap metal is deemed unacceptable today, consideration of benefits from recycling the material still should be examined over an extended period of time.

Technological Capabilities

A variety of decontamination techniques exist that provide means to recycle and reuse radioactive scrap metals. A particularly important methodology is melting. During the melting process, caesium 137 volatilises from the metal. In most reactor scrap metal, the remaining radioactive elements have short half-lives (*e.g.*, cobalt 60), permitting material to be reused at some predetermined time in the future. Melting also results in considerable volume reduction and permits far more accurate measurements of radioactivity.

Although melting represents a major component of recycling practices, other decontamination techniques are available that are less intensive and would still permit items to be reused. These include wet and dry blasting techniques, as well as chemical processes. The decommissioning industry currently is in a state of transition, evolving from techniques for use in maintenance applications, to those for use in decommissioning nuclear facilities. Moreover, a single technology may not be capable of decontaminating to below required clearance levels. Consequently, decontamination frequently is implemented in stages, ultimately decontaminating the material to the required activity levels.

The current state of characterisation methodologies constitutes what should be a significant consideration in the process of developing release. In order to effectively apply release standards based on specific activity or surface contamination, means must be available to demonstrate or verify compliance. A number of practical constraints significantly influence instrument capability, including the geometrical complexity of materials and the sensitivity of available instruments relative to the prescribed criteria. Some of the proposed clearance levels will challenge state-of-the-art and practicality of measurement technologies and instrumentation.

Case Studies

The Task Group also reviewed a number of case studies to determine the cost-effectiveness of pursuing recycling and reuse options. In many of these cases, implementation of available technologies resulted in significant cost-savings compared to direct disposal alternatives. The techniques available to the decommissioning community routinely yield savings in excess of 50 percent. Savings generally result from either volume reduction, reuse of the material, or sale of decontaminated materials. One noteworthy example was a pilot project conducted by Belgoprocess which used a dry abrasive blasting system to decontaminate and unconditionally release steel scrap metal from a Eurochemic reprocessing facility. Cost savings approached 70 per cent over supercompaction and disposal. This conclusion is heavily influenced by the cost of local or national waste disposal.

Conclusions

The Task Group's examination indicates that recycling and reusing materials generated from decommissioning nuclear facilities is both practicable and cost-effective. The most significant impediment to pursuing this waste management alternative is the absence of consistent, internationally accepted release criteria.

Current proposals to remedy this deficiency remain extremely conservative, do not address a variety of conditional release alternatives, and consequently may not promote efforts to most effectively use available technologies. The OECD/NEA Task Group report documents evidence of the need to establish clearance criteria for different kinds of accepted practices. In this context, the Task Group has proposed a "tiered" system of release criteria to facilitate discussion of appropriate conditional international release criteria.

The establishment of unconditional release criteria is a critical step to filling the need for a consistent, internationally accepted standard. However, such criteria should be established in a manner that will encourage, rather than preclude, the future establishment of conditional release criteria. The group hopes that the debate on recycle will be benefited by the analysis conducted and that the discussion of the various proposals for release standards be considerate of the points identified in this work. Most importantly, this work provides some unique insight into the state of the recycle world from nuclear decommissioning perspective.

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