National reports:

French experience and plans

Demonstration is central to a multi-faceted R&D programme

by André Crégut

Forty years of nuclear activities have demonstrated that the industry is able to design, operate, and maintain nuclear facilities of all types. Experience has involved numerous operations in hostile environments — for emergency repairs, modifications, overhauling after accidents, and dismantling of some facilities or putting them in a safe standby state.

This record, together with theoretical studies done, suggests that it will be possible, without major difficulties and undue risks, to carry out future decommissioning or to maintain shutdown facilities in a safe condition over a period of years.

Without minimizing the extent and value of the knowledge gained so far, or of the quality of equipment available, several points must be emphasized, however:

- It does not yet appear possible to lay down general rules for defining, in an industrial context, the tactics to be applied for each type of facility, even though dismantling certain large units (power reactors and plants) after final shutdown can be used to evaluate the quality of available means, tools, and equipment.
- Operations already carried out show that more suitable techniques have to be created and developed.
- It is necessary to co-ordinate decommissioning policy with such interrelated activities as robotics and waste management, for example.

Actions needed for future

In short, with the experience already gained, thinking on the subject of future requirements identifies some necessary actions. These include:

- Carrying out a programme of research and development (R&D) that will lead to adoption of certain existing

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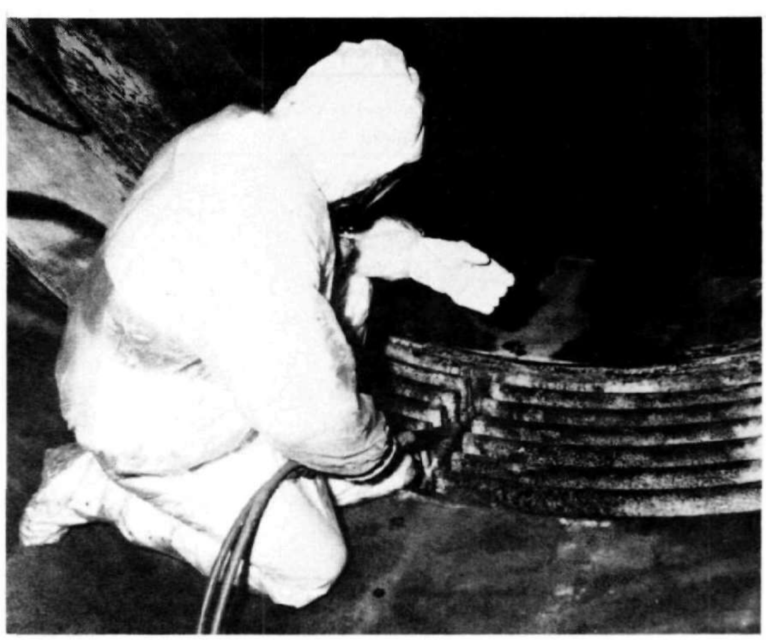


Cutting of the primary circuit at Marcoule G-1, which was shut down in 1975 and will be decommissioned in 1986. (Credit: CEA)

techniques or to development of new ones so that dismantling requirements can be met

- Testing these techniques to determine their area of application and to confirm their validity from the point of view of safety, so that they can be rated for decommissioning purposes
- Modifying or supplementing certain programmes that cover activities touching upon decommissioning (robotics and waste management, for example)
- Preparing for future activities (establishment of a suitable structure and appropriate financing requirements; management of decommissioning operations with a view to identifying specific policies and technical requirements, among other things).

Activities in France

As shown in accompanying tables, a number of reactors and facilities in France have been shut down for good, decommissioned, or are in the process of being decommissioned. Each case is viewed as an experiment from which certain lessons can be drawn, specifically:

- To gain a better understanding of dismantling costs and, therefore, to improve with suitable computation programs those evaluations relating to future decommissioning projects
- To limit radiation doses to personnel through improved management and better programming of tasks
- To arrive at a policy for different types of facilities to be decommissioned – reactors, fuel cycle plants, laboratories, etc. – and to enable formulation of suitable regulations for the various types of cases encountered
- To provide guidance for the R&D programme, adapting it to scientific requirements of decommissioning.

In France, there is a certain homogeneity in the choices that have been made regarding decommissioning of facilities. Currently, it is planned that fuel cycle facilities, laboratories, and experimental pool-type reactors should be decommissioned to Stage-3. This choice was dictated by economic considerations (cost of maintenance at shutdown) and safety factors.

For reactors other than those of the pool-type, or for certain other facilities, the presence of containment barriers (primary circuits and enclosure) enables decommissioning to Stage-2. Total dismantlement can be postponed to allow for radioactive decay.

R&D work

Research and development activities in France are concerned with general studies and the following specific subjects:

- Safety evaluation of nuclear facilities in a final shutdown state and during decommissioning
- Remote operation and remote manipulation; robotics techniques
- Cutting tools and techniques for materials
- Decontamination and waste treatment
- Processing and management of radioactive waste.

Safety evaluations

The strategy and tactics of decommissioning are governed by evaluation of potential radioactive hazards from residual activity in a nuclear facility. The R&D programme focusses on this area. It is sought to improve knowledge on the nature of contamination deposition mechanisms in facility circuits during operation, and on the distribution of induced radioactivity in metallic and protective concrete structures of reactors.

Additionally, the programme is directed at development of methods and equipment for *in situ* measurement and sampling means. This involves, for example, equipment for introduction into hot cells to localize and

Decommissioning of reactors in France

Station name	Reactor type	Power output (megawatts)	Initial operation	Shutdown	Decommissioning	Current/ planned stage
Zoé	HWR	0	1948	1975	1977	Stage-2
EL-2	HWR	2.2 (thermal)	1952	1965	1968	Stage-2
EL-3	HWR	18 (thermal)	1957	1979	1985	Stage-2
EL-4	HWR	70 (electric)	1966	1984	Not yet planned	
G-1	GCR	46 (thermal)	1956	1975	1986	Stage-2
G-2	GCR	40 (electric)	1958	1980	1990	Stage-2
G-3	GCR	40 (electric)	1959	1984	1995	Stage-2
César	GCR	0	1964	1974	1978	Stage-3
Peggy	MTR-LW	0	1961	1975	1977	Stage-3
Pégase	MTR-LW	35 (thermal)	1962	1975	1978	Stage-3
Néréide	MTR-LW	0.5 (thermal)	1959	1982	1986	Stage-3
Triton	MTR-LW	6.5 (thermal)	1959	1982	1986	Stage-3
Minerve	MTR-LW	1 (thermal)	1954	1976	1977	Stage-3
Chinon-1	GCR	80 (electric)	1963	1973	1980	Stage-1
Chinon-2	GCR	230 (electric)	1964	1985	Not yet planned	

HWR = Heavy-water reactor   MTR-LW = Materials test reactor, light water   GCR = Gas-cooled reactor   Source: CEA identify radiation sources and to estimate their radioactivity levels. This is necessary to determine conditions when action should be taken and to supply essential information for forecasting the type of waste management application.

The long-term ageing of structures constituting safety barriers and equipment is another area of study. The purpose is to assess conditions for containment of radioactivity inside the shutdown facility, and to determine permissible waiting periods for complete dismantling.

Another programme element covers studies and validation tests (from the safety viewpoint) of dismantling and decontamination methods and for waste treatment. This includes, for example, the safe use of cutting tools such as electron torches.

Finally in this area, R&D is being directed at design of new facilities that allow for decommissioning constraints.

Robotics and remote systems

R&D in this area concerns the development of devices designed for penetrating containment barriers, for remote manipulation of cutting equipment, and for handling and transporting wastes, among other functions.

The technology of remote-controlled devices and remote-handling equipment has to be developed to meet specific requirements for long-distance operations or procedures in, for example, hot cells and reprocessing plants, or in reactor pools and vessels.

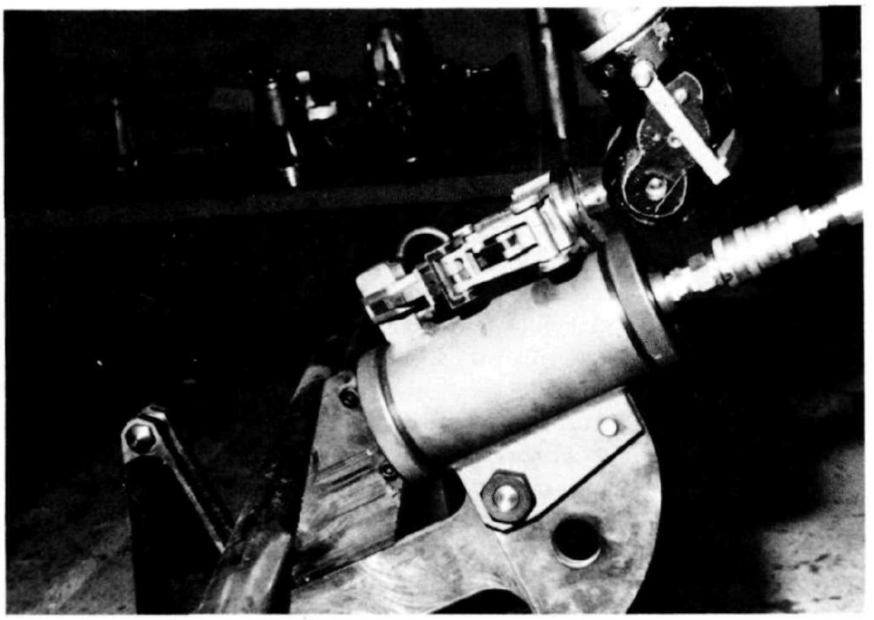
Careful analysis of dismantling tasks indicates that certain particular functions, or characteristics, stem from limited access or load capacity, for instance. This calls for special development of various items, among them:

- *Carrying and penetration devices.* The emphasis is on designs that enable tools to be introduced into, and withdrawn from, a radioactive zone without jeopardizing the integrity of the barriers; they should also be able to "carry" advanced remote-handling devices.
- *Master-slave devices.* The aim is to increase the lifting and manipulation capacities (to 75 kilograms and 40–50 kilograms, respectively) of master-slave, remote-handling devices (with feedback capabilities and advanced technology) to make them completely compatible primarily with powerful cutting tools. Precision, strength, and manageability would be maintained. Adaptation for underwater work is another area of focus.
- *Heavy remote-handling devices.* The aim is to increase their capacity (to 500 kilograms) and to improve diversity of their gripping parts.
- *Compatible remote-handling devices.* This concerns adaptation of transfer equipment (horizontal and vertical) to nuclear environments, making them compatible with the heavy weights and large dimensions of dismantled components.
- *Devices for remote-controlled procedures.* This is directed at improvement of devices for remote-controlled movement so they can be introduced into radioactivity zones to carry out simple operations (sampling, supporting measurements, decontamination procedures). Improvements should be concerned with making them easier to handle to be useful in encumbered areas that are difficult to access. Internal parts of the devices also must be protected against contamination.
- *Tele-information.* This involves development of equipment for receiving and interpreting information by electric, sonic, or optical means that is adapted to conditions when dismantling tools are used in a radioactive and contaminated environment.
- *Connection technology.* This centers around transfer links (adapted to remote operations) that are flexible, reliable, strong, and can be disconnected at a distance. Requirements include the transfer of energy in pneumatic,

Decommissioning of facilities and laboratories in France

Station name	Type of facility	Initial operation	Final shutdown	Decommissioning	Current/ planned stage
Le Bouchet	Ore treatment		1970	1982	Stage-3
Attila	Reprocessing pilot plant	1966	1975	1985	Stage-3
Piver	Vitrification pilot plant	1969	1982	1987	Stage-3
Gulliver	Vitrification pilot plant	1965	1967	1981	Stage-3
Elan-II-A	Pilot for Elan-II-B	1968	1970	1984	Stage-3
Elan-II-B	Caesium-137 sources fabrication	1970	1973	1988	Stage-3
AT-1	Fast breeder reactor fuel reprocessing	1969	1979	1990	Stage-3
Gueugnon	Ore treatment		1980	1981	Stage-3
Hot cells	Radionuclides for medical and other use			1983	Stage-3
Bâtiment-19	Plutonium metallurgy		1984	1988	Stage-3
Bâtiment-18	Plutonium metallurgy		Progressive shutdown since 1982		

Source: CEA



This hydraulic shear for pipe cutting is handled by a master-slave manipulator. (Credit: CEA)

hydraulic, and electrical form; and the transfer of data in electrical, optical, or sonic form in air and underwater.

- *Validation testing station.* The purpose here is to simulate operating conditions in a hostile environment in a cell and underwater.

Cutting tools and techniques

In this area, work calls for development of remote-controlled techniques for cutting metallic or concrete structures by mechanical, thermal, electrothermal, or pyrotechnical means. Also covered is development of associated equipment for observing the cutting.

Decontamination and waste treatment

The large volume of contaminated wastes in connection with decommissioning warrants perfecting decontamination methods in several respects. These cover efficiency (to permit recycling of materials and to reduce the volume of radioactive waste for storage); *in situ* operations (to avoid the transfer of heavy and bulky components to special workshops); and handling of effluents (to reduce the volume of effluents from the decontamination process).

The French R&D programme includes the improvement of basic information on the nature of contamination and its mechanisms; the study of chemical, electrochemical, and physical methods of decontamination and their application *in situ*; the study of the treatment of effluents and the development of mobile stations; and the conduct of full-scale tests for validating the processes.

Waste management and processing

The management of decommissioning waste is not essentially different from management of operations waste. However, procedures have to be adapted to some special concerns.

One concern is the large amount of low- and medium-level wastes to be stored, and the low-level materials to be recycled or placed in public dumps. Another concern is the search for a final storage place (to avoid the necessity of a subsequent decommissioning; i.e., decommissioning of waste storage facilities).

This process implies that careful thought be given to the estimation of the quantity and nature of decommissioning waste; the acceptable limits on the waste placed in the public domain; the acceptable radioactivity limits for final storage (taking into account the nature of the radionuclides and the inherent characteristics of the waste processing method and storage facility); the possible solutions regarding future handling of this waste, and the procedures for obtaining agreement of authorities concerned.

From the technical point of view, it would be desirable for R&D efforts in this connection to emphasize some points to meet decommissioning requirements. These points include the development of activity measurement procedures that are suited to waste monitoring (both *a priori* for forecasting how to manage it, and *a posteriori* for controlling it); and devising techniques for volume reduction, processing, and the design of special large containers and storage facilities.

General studies in field

The general study programme of French R&D efforts involves three elements:

- Development of a methodology for evaluating the costs of decommissioning and the formulation of computation codes that take accumulated experience into account
- Analysis of physical operations from the viewpoint of safety to optimize the progress of decommissioning
- Compilation (in the form of codes, guidelines, or technical recommendations) of data that will lead to the formulation of decommissioning policies.

Engineering: A vital role

In France, the role of engineering in decommissioning operations is apparent right from the start of nuclear facility design — exactly when engineers are in charge of planning and construction. Recommendations based on experience with decommissioning must be taken into account to the fullest possible extent.

Generally, there is no justification at the construction stage for making provision for additional investment costs related to all arrangements that would be advantageous for later dismantling. However, there are many constructive steps that can easily be taken — and are being taken more and more — to facilitate these later operations. For example, a suitable means of access can be set aside to hot cells; hooks or maintenance rails can be installed; floor loads can be forecasted to allow for subsequent installation of mobile shields. All these provisions will, of course, also be of use for emergency or maintenance operations, not only dismantling.

Engineering also has a role in the use, on an industrial scale, of special remote-control and remote-handling devices adapted to dismantling requirements. In this area, engineers must apply great rigour in preparing specifications and in ensuring compliance with them, seeing to it that the devices are precisely suited to their task and that they meet expected performance standards — despite initial difficulties associated with the multi-disciplinary nature of the work and particular constraints involved in work with nuclear energy.

Also in the province of engineering is the reinforcement of facilities for effluent treatment and waste processing made necessary by decontamination and dismantling operations. This job requires employment of the entire arsenal of existing techniques, depending on specific constraints at each site and within the context of national waste policy. Of fundamental importance in the selection of the best decontamination and dismantling tactics is the integration of costs associated with waste processing and storage.

Overall, the involvement of engineering in large-scale decommissioning operations is a natural consequence of the range of studies that have to be carried out, of the scope of organizational and co-ordinating tasks, and of the vital importance of proper preparation and compliance with planning. All this is to ensure that work remains within a given financial framework and is carried out under the most satisfactory safety conditions.

Taking Canada's Gentilly-1 to a "static state"

by Balarko Gupta

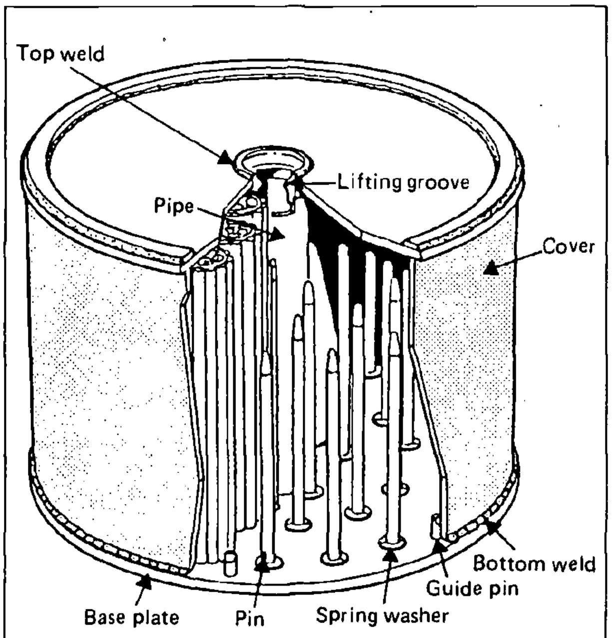
In 1971, Canada's 250-megawatt Gentilly-1 went into service in the province of Quebec and produced power intermittently until 1979. Today, the station is the focus of a two-year decommissioning project that will take it to a "static state" by March 1986: Some radioactive materials and components will be removed, parts of the plant will be decontaminated and released for alternate uses, and the reactor building will be sealed off. Final dismantlement is expected in about 50 years, which allows time for radioactivity levels to fall significantly.

Mr Gupta is project and station manager at Gentilly-1, Atomic Energy of Canada Ltd., Candu Operations, Montreal. References for the article include "Gentilly-1 nears 'static state' ", by Paul Denault and Pabrita L. De, *Nuclear Engineering International* (August 1985), and IAEA Technical Reports Series No. 230 (1983).

The decision to take this route was based on several factors. After the plant was shut down for repair work in 1979, the Canadian regulatory authority demanded extensive modifications before re-start to bring the plant in line with existing safety requirements. The station was mothballed for three years, and in 1983 it was decided to retire it because rehabilitation would not be economically worthwhile. Subsequent engineering and economic studies were the basis for the decommissioning project.

Project objectives and scope

The project's four major objectives are to significantly reduce the station's operating and maintenance costs; to confine radioactivity into clearly identified sealed areas (for example, the reactor building); to release parts of the station for alternate use; and to



Schematic of fuel basket used during spent-fuel storage operations at Gentilly-1. (Credit: AECL)

gain "hands-on" experience in decommissioning a nuclear station on a commercial scale. (A prototype, Gentilly-1 is a CANDU boiling light-water reactor that is fuelled with natural uranium, moderated with heavy water, and cooled with light water.)

The project's scope identifies specific tasks:

- Retrieving all spent fuel from the spent-fuel bay in the service building and placing it in dry storage in specially designed concrete canisters. This will eliminate most of the maintenance cost and release the service building for other purposes.
- Putting the reactor building into a static state condition.
- Removing all components (equipment, piping, cabling, control panels, etc.) from the service building and parts of the turbine building so that these areas can be transferred to Hydro Quebec, which owns and operates the adjacent Gentilly-2 nuclear station.* Administration areas will be transferred in "as-is" condition.
- Decontaminating the spent-fuel bay, fuel trays, and various other contaminated components.
- Developing and implementing radiological, and health and safety, policies and procedures that are consistent with the ALARA principle (as low as reasonably achievable, economic and social factors being taken into account) of radiation protection.

* Before transfer, the areas must meet Zone-1 criteria, which include no loose contamination, no beta fields above 10 micro-sieverts per hour, and no gamma fields above 2.5 micro-sieverts per hour at one centimeter.

Dry storage of spent fuel

Some 3213 bundles of irradiated fuel and fuel hardware have been stored in eleven cylindrical concrete canisters that were specially designed for the purpose. Each canister (6 metres high with an outside diameter of 2.6 metres) has a steel liner that serves as the storage cavity for eight specially designed stainless steel baskets. Each basket contains 38 fuel bundles, each of which is placed over one basket pin. (The bundles had been stored in the spent-fuel bay for a minimum of 7 years and the decay heat emitted averages approximately 1.4 watts per bundle.) Irradiated fuel is contained in 85 baskets, while two baskets contain flux suppressors and keys that are parts of the fuel string.

Typical storage operation

A typical storage operation starts by unstringing the bundles and removing the central structural tubes (CST) that contain cobalt-60. Each bundle number is then identified and individually loaded into a numbered basket. Both the basket and bundle numbers are permanently recorded in keeping with IAEA safeguards requirements. Once a basket is filled, a cover is put on and the basket assembly is raised into a shielded station by a grapple that engages inside a central opening. All these operations are done underwater for shielding purposes.

Inside the shielded station, the basket cover is removed, the fuel assembly is dried, and the basket assembly is seal-welded at top and bottom by remote semi-automatic welding. The basket is then moved laterally inside the shielded station to a position directly below the shipping flask. Flask doors are then opened, a grapple inside the flask is lowered to raise the basket from the shielded station into the flask, and the flask doors are closed. The flask is now ready for transfer to the canister area.

Inside the shielded station, radiation of up to 3500 rem has been measured.* However, outside the station (and the flask) radiation always has been less than one millirem on contact.

To transport the flask to the canister site, a specially designed trailer is used. The flask is raised to the top of a canister by a 15-ton crane. The grapple assembly and a 3-ton crane lower the basket from the flask into the canister. The top plug is then welded to the canister, and an IAEA safeguards seal is installed by Agency inspectors.

From start to finish, this operation took a crew of six an average of three hours. Since the process must be repeated for all 11 canisters and the eight baskets each contains, the entire fuel-storage operation took six weeks, not including five weeks for construction of the canisters themselves.

The radiation level outside a loaded canister is about 0.6 millirem on contact.

* In international usage, the rem has been replaced by the sievert, which is equal to 100 rem.

The reactor building

Most common pipes, cables, ducts, etc., between the reactor, turbine, and service buildings have been cut and sealed to prevent the spread of radioactivity. All components in the reactor building have been drained and dried, including oil and other inflammable agents that have been removed. Systems inside the reactor building have been isolated and tagged.

Access to the building has been permanently shut off, except for one airlock that can be made operable for periodic inspection. This static state will be maintained for the reactor building for at least the next 40 or 50 years, with periodic inspection to ensure structural integrity. The delay will mean a significant reduction of radioactivity of benefit to final dismantling.

Other uses for buildings

In the service and turbine buildings, Hydro Quebec, the local utility, will install a full-scope training simulator for the adjacent 600-megawatt-electric Gentilly-2 reactor; a training centre; and some offices. Currently under way are removal of components, radiological surveys, and decontamination around areas to be transferred to Hydro Quebec, including the spent-fuel bay inside the service building. Once the bay is decontaminated, a new concrete slab will be built on top of it and the area will be a part of the simulator's headquarters complex.

Decontamination work

Engineering and economic studies, and initial site experience, have shown that large-scale system decontamination to release components for unrestricted use is neither time nor cost effective. Nonetheless, a significant decontamination programme has been set up at the site to meet the criteria (Zone-1) to transfer areas for other uses, and to gain "hands-on" experience for determining future methods and estimating manpower and cost requirements.

Major experience has been gained through decontamination of the feedwater and hydrazine dosing system, feedwater sampling system, various sizes of piping, fuel trays, new fuel inside the spent-fuel bay, and several ventilating ducts and fans.*

* A Butterworth hydrolaser model 110-ET has been used extensively in this programme at a pressure of up to 2000 pounds per square inch (psi), or 40 mega-Pascals (MPa), although it can operate at up to 10 000 psi, or 68 MPa. Regarding loose surface contamination, 170 bundles of new fuel had up to 1.7 megabecquerels per square metre (MBq/m^2), whereas the fuel trays had up to 2.2 MBq/m^2 loose contamination. Frequently, mixing the water jet with a foam cleaner was found adequate for cleaning in most cases. A stainless steel cabinet has been designed to work with the hydrolaser to hold small pieces to be cleaned and to contain the water spray. This combination has been very effective, and it has eliminated the need for protective clothing. Fixed contaminations up to 500 kBq/m^2 on concrete floors have been reduced to Zone-1 level by using a scarifier coupled with a vacuum take-off.

Radiation protection

All aspects of the Gentilly-1 decommissioning are regulated by a license from the AECB, which has insisted on the maximum health and safety protection for workers and the public. To satisfy these requirements, and the ALARA principle, documents have been developed, specifically health guidelines and radiation protection standards; a health and safety manual; and radiation protection procedures.

The health and safety group produces and distributes a computerized report that shows biweekly dose exposure of everyone working on the project. So far, the individual dose has been much lower than allowable (5 rem per year, 3 rem per quarter), and it is very unlikely that anyone will even approach the limit on this project. The maximum recorded dose for a 12-month period for an individual has been 225 millirem. However, the individual dose for most workers has been less than 110 millirem.

Project management, cost

Currently, the site organization consists of about 40 professionals/technicians and 50 craftsmen from AECL. Additionally, 15 to 25 workers are available from outside contractors.

Site organization is headed by a station and project manager, and there are seven managers/supervisors responsible for resident engineering, decontamination, radiological protection, fuel handling, operations, plant services, and security. To preserve their independence, the heads of health and safety and of quality assurance do not report to the station/project manager.

During the study stage, the cost estimates for various decommissioning scenarios for Gentilly-1 were prepared using a programme that has the capability to estimate manpower, man-rem exposure of workers, radioactive waste volume, and cost.* During the decommissioning, the programme code has been validated with actual costs and compared against estimated amounts. This data base would be a good source of cost data for future decommissioning.

The estimated cost of the Gentilly-1 two-year decommissioning programme is $25 million (Canadian), and the project is expected to be completed on time (by April 1986) and within the cost estimate.

Due to the critical nature of the project, cost and project management schedules are computerized at site. Once a week, they are reviewed and updated so that actions can be taken to avoid potential delays.

* The programme, called DECOM, is more fully discussed in a paper, "Methodology of a computerized cost model for decommissioning of nuclear power plants", which was prepared in November 1984 by the author and John Saroudis as part of the IAEA Co-ordinated Research Programme on Decommissioning.

Decommissioning US DOE nuclear facilities

by Edward G. Delaney

"You will be interested to know that the Italian navigator has just landed in the new world."

This is the coded message that Karl Compton telephoned James Conant on the day Enrico Fermi achieved the first self-sustaining chain nuclear reaction in the graphite pile at Stagg Field, Chicago, on 2 December 1942.

For the next 25 years or so, a large number of facilities were built to carry out experiments and demonstrations, including test reactors, power demonstration reactors, fuel fabrication facilities, radioisotope separation and fabrication facilities, and nuclear propulsion test facilities. In addition, facilities were constructed to produce nuclear fissile and fusion materials, including those for uranium mining and milling, uranium enrichment, uranium processing, plutonium production, and tritium production.

The radioactive wastes from all these activities were disposed of in shallow land disposal facilities for the most part, except for some intermediate-level waste, which was injected into deep subsurface formations that had been hydrofractured.

Past decommissioning activities

During the 1960s, the US Government agency responsible for nuclear energy activities – the Atomic Energy Commission (AEC) – recognized the need to eventually decommission facilities so that they could be either re-used for other nuclear work, could be safely stored in a manner which caused essentially no risk to the public, or could be decontaminated sufficiently to release the facility for unrestricted use (that is, with no concern for remaining radioactivity).

The AEC began to develop techniques for decontaminating some facilities for re-use or for unrestricted use, as well as methods for safe storage of the facilities when decontamination was not a preferred option. A summary of some of the facilities decommissioned during this initial period appears in the table on page 32.

Techniques were developed (1) to safely store facilities for long periods with moderate surveillance and maintenance (the end condition of the facility is given the name SAFSTOR by the US Nuclear Regulatory Commission (NRC) and Stage-1 by the IAEA); (2) for safe storage of facilities for hundreds of years with very little surveillance and maintenance (termed ENTOMB and Stage-2); and (3) for decontamination and dismantling of facilities so that they can be released for unrestricted use (termed DECON and Stage-3).

Substantial development of technology was completed in accomplishing these early decommissioning projects. The technology developed by AEC projects, as well as some important projects in other countries, provides a foundation for decommissioning work today.

Current and planned programme

In 1977, the Energy Research and Development Administration (ERDA), the successor to the AEC, made an inventory of unused radioactively contaminated facilities and established a programme for an orderly decommissioning of these "surplus" facilities. About 500 facilities were included in the Surplus Facilities Management Program (SFMP). The SFMP is being continued under the US Department of Energy (DOE), the successor to ERDA. The 348 facilities now in the SFMP are divided into "civilian" (114 facilities) and "defense" (234 facilities) categories.

The objectives of the SFMP are to:

- Safely manage and dispose of the inventory of surplus facilities in accordance with priorities
- Maximize re-use of facilities
- Optimize use of state-of-the-art decommissioning techniques
- Transfer the decommissioning technology to US industry and collaborate with international and other national decommissioning programmes.

The safe management of DOE surplus facilities is accomplished by the removal of fuel, radioactive liquids, flammable and pressurized liquids, and other materials with potential for leakage or energy release; provision of necessary maintenance to assure facility integrity; and monitoring of the facility and the surrounding environment.

The priorities for disposal of the surplus facilities are determined by considering facility factors and assigning a ranking, generally according to the following hierarchy:

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Part of the reactor from the SRE facility in California being shipped for burial. SRE was dismantled, with the job completed in 1982. (Credit: Rockwell International)

DOE legal and contractual requirements; health risks of delayed disposition; economic impact of immediate versus delayed disposition; future plans for the facility site; cost-effective programme management (for example, maintaining continuity of decommissioning work at a location); other special factors such as potential for re-use of a facility.

The state-of-the-art technology for decommissioning generally is adequate for disposition of these DOE facilities. Techniques and equipment available from industry and DOE laboratories are being used. These techniques and equipment are adapted from other uses such as nuclear power plant maintenance operations and hazardous materials handling. Only a small amount of research and development is conducted, generally on an *ad hoc* basis for the particular project.

The transfer of technology to industry is accomplished by contracting with industry to conduct the facility disposition projects, by preparing and publishing technical reports on the projects, and by participating in and initiating technical meetings with industry. International and national collaboration is accomplished by participating in the international decommissioning activities and by exchanges with other national decommissioning projects, generally through bilateral exchange agreements.

The 348 facilities in the SFMP have been grouped into 74 projects for planning and implementation. Details of some of these major projects are shown in the accompanying tables. The overall planning for the SFMP anticipates completion of the projects during the first decade of the next century at a total cost of more than US $1.5 billion.

Following are brief descriptions of three projects.

Shippingport station project

The Shippingport Atomic Power Station is a pressurized-water reactor of 72 megawatts-electric (MWe) that started up in 1957 and was shut down in 1982. It had produced more than 7.2 terawatt-hours of electricity from three cores. DOE is preparing to dismantle the nuclear portions of the plant beginning in September 1985, with completion in January 1990. The estimated total cost for the project is US $98.3 million, and about US $19 million has been spent through September 1985.

The decommissioning operations contractor, General Electric, took possession of the site from the operations contractor in September 1984, after removal of all fuel from the site. During the past year, the decommissioning operations contractor has been performing surveillance and maintenance of the plant, mobilization and training of personnel, bid package preparation for subcontractor awards, development of detailed work plans and procedures, and site modifications needed prior to start of dismantling.

Work has started on removal of all asbestos from piping and equipment. During the next year, work will be started for removal of piping, decontamination and removal of equipment, removal of primary system components, and removal of the power and control systems. In 1987, removal of concrete and structures will begin. Removal of the containment chambers will begin in 1988, and the reactor vessel will be removed in 1989.

Some technical features of the project include:

• Removal of the reactor vessel and surrounding neutron shield tank as a single unit weighing over 770 tonnes with

Selected US experience from decommissioning projects

Facility name and location	Facility type	Capacity	Type of D/D	Date	Experience
Reactors					
Carolina/Virginia Tube Reactor (CVTR) (Parr, South Carolina)	HWR	65 MW(th)	Stage-1	1968	Basic Stage-1 procedures developed; periodic surveillance.
Pathfinder (Sioux Falls, South Dakota)	BWR with nuclear superheat	190 MW(th)	Stage-1 for BWR with conversion of facility to other use	1972	Isolation of steam plant and replacement of nuclear reactor with fossil-fired boiler; continuous surveillance.
Saxton (Saxton, Pennsylvania)	PWR	23.5 MW(th)	Stage-1	1973	Remote intrusion alarms for security to minimize work force.
Fermi I (Monroe County, Michigan)	FBR	200 MW(th)	Stage-1	1975	Sodium handling experience for Stage-1.
Peach Bottom I (York County, Pennsylvania)	GCR	115 MW(th)	Stage-1	1978	Core graphite fuel handling and disposal.
Hallam, (Hallam, Nebraska)	Graphite-moderated, sodium-cooled	256 MW(th)	Stage-2	1968	Basic Stage-2 procedures developed; no continuous surveillance.
Piqua Reactor (Piqua, Ohio)	Organic-cooled and -moderated	45 MW(th)	Stage-2	1970	Entombment with conversion of reactor building to warehouse; reactor vessel entombed in sand; no continuous surveillance.
Boiling Nuclear Superheat Reactor (BONUS) (Rincon, Puerto Rico)	BWR	50 MW(th)	Stage-2	1970	Concrete entombment of vessel; decontamination of systems; release of site as exhibition center; no continuous surveillance.
Elk River Reactor (ERR) (Elk River, Minnesota)	BWR, fossil-fuelled superheater	58 MW(th)	Stage-3	1974	Remote segmentation of vessel & internals; explosive demolition of concrete; survey and release of site for unrestricted use.
Fuel cycle facilities					
Redox (Hanford, Washington)	Reprocessing facility	Production size	Stage-1	1967	Plutonium recovery programme using various flushes; system drained and air dried; external flushing of equipment, cells, and deck; entrances locked.

Notes: MW(th) = megawatts-thermal; HWR = heavy-water reactor; BWR = boiling-water reactor; PWR = pressurized-water reactor; GCR = gas-cooled, graphite-moderated reactor; D/D = decontamination and decommissioning

concrete shielding and lifting fixture. The reactor vessel will be shipped by barge from Shippingport to Hanford, Washington, for shallow land burial.

• The four steam generators will be shipped as units without other packaging on the barge to Hanford. Other radioactive components also will be included in the barge shipment.

• No primary system decontamination will be conducted. Some materials will be decontaminated for disposal as ordinary waste or scrap.

• Underground concrete structures below three feet (0.9 metres) will not be removed. The site will be backfilled with clean rubble and soil and levelled to grade.

Selected decommissioning projects completed under the SFMP

Facility name and location	Facility type	Type of decommissioning	Year completed
Reactors			
Los Alamos Molten Plutonium Reactor Experiment, New Mexico	Molten plutonium reactor	Dismantlement Stage-3	1980
Organic-Moderated Reactor Experiment, Ohio	Organic-moderated reactor	Dismantlement Stage-3	1980
Special Power Excursion Reactor Test II, III, IV; Idaho	Safety test reactors	Dismantlement Stage-3	1980
Sodium Reactor Experiment Facility, California	Sodium-graphite reactor	Dismantlement Stage-3	1982
Fuel cycle facilities			
Monticello Mill Site, Utah	Uranium ore mill	Dismantlement (restricted site)	1979
Advanced Fuel Laboratory, California	Plutonium fuel fabrication	Dismantlement Stage-3	1982
Plutonium Fuel Fabrication Facility, Pennsylvania	Plutonium fuel fabrication	Dismantlement Stage-3	1982
Building 350, ANL, Illinois	Plutonium fuel fabrication	Dismantlement Stage-3	1982

Note: SMFP = Surplus Facilities Management Program.

Mound laboratory project

The fabrication of radioisotope heat sources fuelled with plutonium-238 was conducted in several buildings at the Mound Laboratory at Miamisburg, Ohio, from the late 1960s through the late 1970s. These heat sources were used to supply power in many outer space applications.

DOE decided to decommission the facilities because they do not meet current design standards for processing plutonium. A project was initiated for this purpose by the Monsanto Research Corporation, the operator of the facilities, in 1978 and is expected to be completed in September 1988 at a total estimated cost of US $69 million.

Plutonium fabrication and waste handling facilities in three buildings consisting of about 1100 linear feet (335.3 metres) of gloveboxes, 900 feet (274.3 metres) of conveyor housing, and associated piping equipment and structures are being removed. The rooms are being decontaminated sufficiently for personnel occupancy without protective clothing.

In addition, about 2600 feet (792.5 metres) of dual underground liquid waste lines and contaminated soil around these lines are being removed. Approximately 30 000 curies of plutonium-238 have been removed in waste and scrap residues. These wastes have been sent to the Idaho National Engineering Laboratory for storage.

As a result of this work, much valuable experience has been gained in the techniques for worker exposure control, contamination control, decontamination, equipment removal, structural decontamination, and waste packaging. This experience can be applied to decommissioning of other fuel cycle facilities.

Weldon Spring project

During 1955 through 1957, the AEC constructed a large chemical plant at Weldon Spring, Missouri, to process uranium ore concentrates into intermediate uranium chemicals and finally into metallic uranium. Thorium ore concentrates also were processed into other chemical forms. The residues from this processing were disposed of in four large open pits. The plant extends over about 70 hectares and the disposal pits over about 21 hectares.

During operations of the plant, the buildings, equipment, immediate terrain, process sewer system, and a drainage area became contaminated with uranium, thorium, and their decay products. In addition, a nearby formerly used quarry was contaminated from scrap and rubble that was dumped into it.

DOE has established a project to conduct cleanup of the quarry, the contaminated properties surrounding the chemical plant, and the chemical plant. The plant will be decontaminated and demolished. The radioactive wastes from these operations are estimated to exceed 600 000 cubic metres, and more than 80 million gallons (about 302 million litres) of contaminated water must be treated and released. The project is scheduled to start in 1987 and be completed in 1996 at a cost of US $357 million.

Experience to prove valuable

In summary, many hundreds of radioactively contaminated facilities have resulted from the nuclear research, development, and production activities of the US Government agencies. These facilities will be

Selected major projects in the DOE Surplus Facilities Management Program

Project/location	Type of facilities	Decommissioning plan*	Timetable	Cost**
Mound Lab Advanced Nuclear and Space Power Facilities (Miamisburg, Ohio)	Plutonium-238 fabrication facilities, waste transfer and handling facilities.	Removal of plutonium fabrication equipment, decontamination of structures to permit occupancy and re-use; removal of waste transfer and handling facilities; shipment of all decommissioning wastes to Idaho National Engineering Laboratory.	1978–1988	69
Niagara Falls Storage Site (Lewiston, New York)	Storage facility for uranium processing residues and radium-containing wastes.	Cleanup of contaminated areas surrounding the storage site; cleanup and consolidation of residues and wastes onsite into near-surface entombment facility.	1981–1986 (Stage-1), 1995–1996 (Stage-2)	51
Monticello Mill Site (Monticello, Utah)	Storage site for tailings from uranium mill processing.	Cleanup of contaminated areas surrounding the storage site; surface and groundwater drainage modifications; entombment of the tailings onsite.	1987–1994	35
Shippingport Atomic Power Station (Shippingport, Pennsylvania)	Pressurized-water reactor with power capability of 72 MWe.	Dismantlement of nuclear portions of the plant; shipment of intact reactor vessel and other major components to Hanford, Washington for near-surface burial.	1985–1990	98
Weldon Spring Site Remedial Action Project (Weldon Spring, Missouri)	Uranium and thorium processing facility to convert mill concentrates to metallic form.	Cleanup of contaminated areas near the plant, including a quarry; dismantlement of a large uranium processing plant; entombment of the wastes onsite.	1987–1996	357
Experimental Boiling Water Reactor (Argonne, Illinois)	Boiling-water reactor with power capability of 100 MW(th).	Decontamination and removal of all radioactive material from the containment to permit its unrestricted use for other purposes.	1987–1995	22
Heavy-Water Components Test Reactor (Savannah River, South Carolina)	Heavy-water moderated, uranium-fueled reactor.	Dismantlement of reactor and near-surface burial of the components and wastes.	1988–1993	15
Homogeneous Reactor Experiment (Oak Ridge, Tennessee)	Light-water uranium solution reactor.	Dismantlement of reactor and near-surface burial of the components and wastes.	1989–1997	25
Molten-Salt Reactor Experiment (Oak Ridge, Tennessee)	Uranium-233 fuel in fluoride salts reactor.	Processing of fuel salts into a stable form, disposing of the stabilized fuel; dismantling the reactor and disposing of the waste.	1992–2001	68

* Subject to completion of environmental review process for each project.
** Estimated in millions of US dollars.

very expensive to decommission. DOE has a vigorous programme underway to maintain these facilities in a safe condition and to decommission them in a manner to provide for the long-term protection of the public and the environment. Valuable experience is being gained from this programme that is expected to be of use in the eventual decommissioning of commercial nuclear facilities.

Remote-controlled equipment for decommissioning

Improved robots and manipulators offer practical advantages

For some decades now, automation and robots have been used with success in various forms for industrial handling, assembly, and manipulation jobs. In the nuclear industry, a wide range of specialized manipulators and equipment have been, and continue to be, developed to perform remote tasks such as inspection, maintenance, repair, and refurbishment.

The use of such devices is one important way of reducing human exposure to radiation during decommissioning and decontamination operations at nuclear facilities. Consequently, decommissioning costs also may be reduced.

What is meant by the terms "robot" and "manipulator"? Within the context described here, a robot is a programmable handling machine that has a memory, can be trained, and can be retrained easily when changed to a new job. This latter capability is the characteristic difference between robots and other pieces of automated equipment, although the flexibility of numerically controlled equipment is also high. Robots basically consist of mechanical components, actuators, controls, and sensors, and generally have many degrees of freedom.

A manipulator, on the other hand, has many features of a robot, but it is usually operated directly under some form of manual control, which may be remote. Programmed control of a manipulator can be accomplished (producing a form of robot), just as manual control of a robot is possible through an appropriate control system.

For decommissioning and decontamination work, the following components are important for both robot and manipulator applications:

- Task analysis
- Remote control technology
- Advanced mechanical engineering
- Simulation technology
- Remote sensing equipment
- Man-machine interface.

Programmes in the nuclear industry

In the nuclear industry, remotely operated equipment has been used for handling, inspection, dismantling, assembly, repair, replacement, and fabrication tasks in reactors, shielded cell facilities, underwater bays, reprocessing plants, fuel fabrication plants, and radioisotope production facilities, for example.

Of most interest from a decommissioning viewpoint are the remotely operated manipulators, robots (stationary and mobile), the visual and sensor technology, and the computer hardware and software associated with the equipment.

The types of manipulators in use include relatively simple master/slave manipulators, sophisticated bilateral force-reflecting electric manipulators (in which the master and slave can be connected by direct wire, radio, or laser beam) and the most advanced and dexterous computer-aided master/slave servomanipulators. In addition, industrial manipulators can be equipped with environmentally conditioned and shielded cab enclosures and mounted on vehicles if necessary.

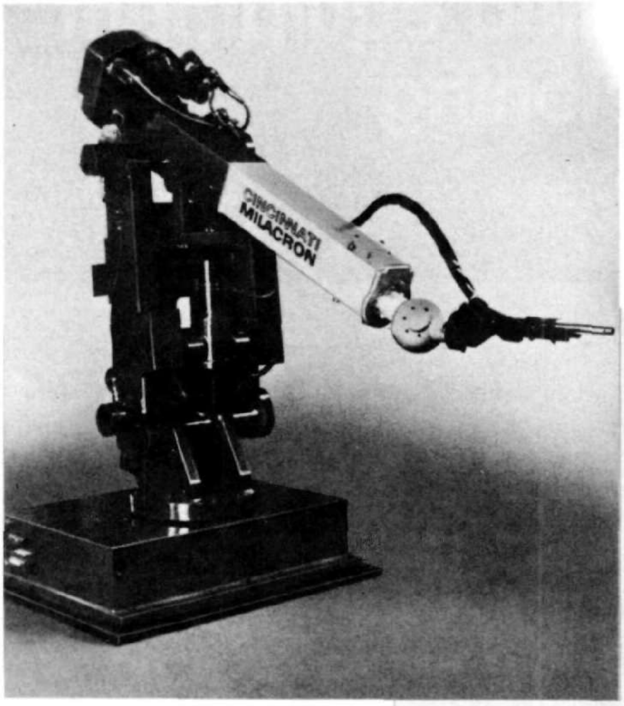
Automatically guided vehicle systems have been used in industry for many years for a variety of tasks. Some are free-ranging with optical or radio-controlled guidance systems while others follow guidance wires installed under the floor. Specialized track and wheel vehicles have been developed for the nuclear industry as well. For decommissioning, such vehicles may be used as mobile bases for carrying manipulator arms and equipment to do work in areas having high radiation fields. A study detailing the options for decommissioning has been completed for the Commission of the European Communities (CEC).*

These general purpose mobile robots can advantageously replace man for multiple tasks such as surveying and monitoring. Physical measurements are possible (for example, of radiation levels, temperature, humidity) as well as scabbling and decontaminating walls and floors. The load capacity of the vehicle-borne manipulators determines the extent to which small compacts can be disassembled and other tasks, such as building shielding walls, can be achieved.

The remote technique can be extended to larger vehicles such as bulldozers, backhoes, and excavators required for mass concrete demolition. Radio-controlled systems that operate control levers on these machines are commercially available.

This article has been adapted from *The Methodology and Technology of Decommissioning Nuclear Facilities,* IAEA Technical Report (in press). For related articles, see the *IAEA Bulletin,* Vol.27, No.3 (Autumn 1985).

* See "Review of Systems for Remotely Controlled Decommissioning Operations", by L. Da Costa et al., Commission of the European Communities (in press 1985).



Robotic arm for use in decommissioning activities. (*Credit: Cincinnati Milacron*)

At TMI-2, workers check "Rover", a robot that made the first extensive post-accident examination of the reactor building basement. (Credit: GPU Nuclear)

For underwater use, manipulators mounted on submersibles are available, and similar ones can be envisaged for underwater nuclear decommissioning applications. However, this would require significant development.

In France, a sophisticated servomanipulator equipped with television and telescopic supports with computer control has been developed and is being used for remote maintenance and decommissioning tasks. The combination of options permits the arm to be operated either as a manually controlled maintenance manipulator or as a computer-controlled robot.

In Canada, a sophisticated remote manipulator subsystem (RMS) is being developed by SPAR Aerospace for Ontario Hydro for possible use in the retubing of Pickering reactors. It uses technology developed by SPAR for the arm used on the US space shuttle vehicles. The RMS is one part of a co-ordinated Remote Manipulator and Control System that will be used for a variety of handling, inspection, support, and transport activities, as well as maneuvering containers in the fuelling machine vault. In another project, Atomic Energy of Canada Limited has developed a complex remotely controlled arm with a viewing system and a remote welding machine to repair leaking pipes located in a vault below the Douglas Point nuclear reactor.

In Japan, a comprehensive programme is in progress to develop a robotic remote handling system for the decommissioning of the 90 megawatt (thermal) power