A REVIEW OF VARIOUS APPROACHES BEING UNDERTAKEN BY INDUSTRIALIZED NATIONS FOR THE MANAGEMENT AND DISPOSAL OF HIGH-LEVEL NUCLEAR WASTE

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Federal Environmental Assessment
Review Office, Ottawa

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PURPOSE OF STUDY

The high-level nuclear waste (HLW) disposal concept proposed by Atomic Energy of Canada Limited (AECL) has been submitted for review by the federal Environmental Assessment and Review Process (EARP). The purpose of this report is to provide a reference document to the EARP Review Panel and other interested parties which summarizes the status of high-level nuclear waste management programs in other countries.

COMPARISON BETWEEN CANADA'S HLW PROGRAM AND OTHER COUNTRIES

A brief review of the Canadian HLW program is made so that comparisons can be made with other countries' progress. Canada is focussing on the burial of spent nuclear fuel deep into the crystalline rocks of the Canadian Shield. The HLW disposal programs of particular interest or relevance to Canada are those of Belgium, France, Federal Republic of Germany, Sweden, Switzerland, and the United States. Their programs are described in detail. The programs of a number of other countries are also covered, but in less detail.

HLW DISPOSAL PROGRAM DETAILS

Where information is available, the following topics are described for each major country:

- key organizations
- disposal facility schedules
- waste quantities
- interim storage and transportation
- site investigations
- repository design
- impact analysis
- monitoring
- licensing and other regulatory requirements
- disposal concept assessment
- public participation process.

Canada, Finland, Spain and Sweden are planning no reprocessing of their spent fuel prior to disposal. Most other countries are planning to dispose of reprocessed spent fuel which has been solidified into a glass matrix and then encapsulated into a metal container (vitrified waste), or to dispose of a combination of vitrified waste and spent fuel.

Reprocessing removes some of the long-lived radionuclides that generate heat. However, in all cases, the waste container is intended to play a major role in isolating the waste and preventing its release into the groundwater. A thick metal wall of either titanium (Canada), copper or steel is used to resist leaching and corrosion. For spent fuel, the void spaces inside the container are filled with glass beads (Canada) or lead to withstand the rock and groundwater pressures.

CANADA'S STATUS IN HLW DISPOSAL

A summary section and summary tables are provided which allow the various programs to be compared. For each country, key features are listed including the following

- lead organizations and progress
- installed nuclear capacity, waste type and packaging
- repository design.

It is noteworthy that all countries have selected burial deep in a stable geologic formation although many different rock types are under consideration including crystalline rock, salt, clay and tuff. Underground research laboratories form a central part of most national programs both for developing basic concept assessment data and for ultimate site characterization and licensing. Although Canada has an active and focussed research and development program, in terms of site selection for a final disposal facility, Canada lags behind many major nuclear nations including the Federal Republic of Germany, France, Sweden, the USA, Belgium, and Switzerland.

CONCEPT ASSESSMENT AND PUBLIC PARTICIPATION

Canada, Sweden, Switzerland and the USA have well-developed concept assessment programs. In addition, Canada, France, Switzerland and the United States have comprehensive public participation programs. Little information is available regarding the concept assessment and public participation programs of other countries.

1 - INTRODUCTION

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Nuclear power is a major component of the energy programs of most industrial countries as witnessed by the approximately 300,000 MW of nuclear electrical generation capacity in the world today (Nuclear News, 1989). Research and development programs for managing the wastes from these nuclear programs are in various stages of progress. In particular, the ultimate disposal of high-level radioactive wastes (HLW) is a key concern (Rippon, 1987).

HLW can take one of two forms. It can be either used, or spent, uranium fuel as discharged from the reactors, or it can be reprocessed waste, that is, a chemical treatment is used to remove some of the useful chemical elements from the used fuel. In the latter, the waste is solidified into glass blocks (vitrified). In the former, the HLW is in the form of fuel bundles or rods.

Canada has a major research program for developing methods for nuclear waste disposal. Headed by Atomic Energy of Canada Limited, the Nuclear Fuel Waste Management Program centers on encapsulation of used nuclear fuel with subsequent deep burial into stable geologic formations of the Canadian Shield.

At the time of preparation of this report, AECL's disposal concept has been submitted for review by the federal Environmental Assessment and Review Process. The purpose of this report is to provide a reference document to the Environmental Assessment and Review Panel, as well as to other interested Canadians, which summarizes information concerning the status of high-level nuclear waste disposal programs in other countries. This report focuses on the disposal aspects of the various national waste management programs including issues associated with transportation and interim storage. In particular, the technical components of every program are summarized. Available information regarding public involvement and hearings processes is also included.

A companion report reviewing the issues associated with high-level nuclear waste management is also being prepared (LURA Group, 1989).

A brief review of the Canadian program is also given so that comparisons can readily be made to the other national programs. The countries selected for review have been divided into two groups. The disposal programs of the countries included in the first group are dealt with in considerable detail; the programs of the second group are described only briefly. The disposal programs of the first group are of particular interest or relevance to the Canadian program because they are in a similar or greater degree of advancement. The countries in the first group consist of:

- Belgium
- France
- Federal Republic of Germany
- Sweden
- Switzerland
- United States of America.

A brief summary of various national programs is presented in Section 11, where tables provide a comparative reference of key features of each country. Discussion is also presented on the different approaches that are being taken by various countries in their disposal programs. Although all countries are focussing on deep geological disposal, there are many variations in the methodologies including the waste form itself, the role of central/interim storage, the choice of geologic medium, repository design features and in the relative progress being made. In addition, the cooperation which is taking place at international levels is summarized.

Obviously, it is not possible to comprehensively review such large and sophisticated programs in a single report. Thus, an extensive reference list and bibliography is included. The interested reader may

also contact the responsible organizations in each country directly using the list of addresses which is included in Appendix A. A list of acronyms and terms is presented in Appendix B.

2 - OVERVIEW OF CANADIAN HLW PROGRAM

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A brief summary of the Canadian high-level nuclear waste program is presented here so that comparisons to other national programs can be made. To facilitate such a comparison process, this section will follow the same format as subsequent sections (Sections 3 to 9) which describe the programs of other countries.

2.1 - Key Organizations

There are three main groups in the Canadian nuclear waste management scene.

- Since 1978, as directed by the Government of Canada, Atomic Energy of Canada Limited (AECL) has been pursuing a research and development program for the immobilization and disposal of nuclear fuel waste in Canada. The Canadian program is called the Nuclear Fuel Waste Management Program (NFWMP).

- The spent fuel which is to be disposed is the property of the provincial utilities which generate nuclear power: New Brunswick Power, Hydro Quebec and Ontario Hydro. The latter is the senior nuclear utility as it generates the major share of used nuclear fuel. Under the 1978 agreement, Ontario Hydro was given the responsibility of developing and demonstrating the technologies for interim storage and transportation of spent fuel.

- The Atomic Energy Control Board (AECB) regulates all facets of the nuclear industry in Canada.

It should be noted that at the present time, no formal policies, responsibilities or schedules have been developed for the postconcept assessment period. No agency has been given the responsibility for finding a site, constructing and operating a repository, or for developing plans for these activities.

2.2 - Schedules

Although Canada has no schedule for repository siting or construction at this time, AECL has assumed that a repository will begin receiving HLW in 2025 (Baumgartner, 1986) to provide a basis for their concept assessment documentation.

2.3 - Waste Quantities and Packaging

Currently Canada is operating 18 nuclear reactors with a total electrical capacity of about 12,000 MW. It is estimated that a total of 191,133 Mg of spent fuel will be generated by the year 2035 (Baumgartner, 1986). CANDU fuel consists of natural uranium which has not been enriched in uranium-235.

At present, there are no plans to reprocess spent fuel in Canada. For this reason, used CANDU fuel bundles would be placed into a corrosion-resistant package (Teper, 1985), as shown in Figure 2.1. The shell material would be made of titanium and the container would be filled with a particulate material such as soda-lime glass beads (Baumgartner, 1986). The waste package would contain 72 used fuel bundles.

2.4 - Interim Storage and Transportation

Currently spent fuel is being stored primarily at reactor sites in large water-filled pools. In addition, a small fraction of spent fuel is stored in large concrete canisters.

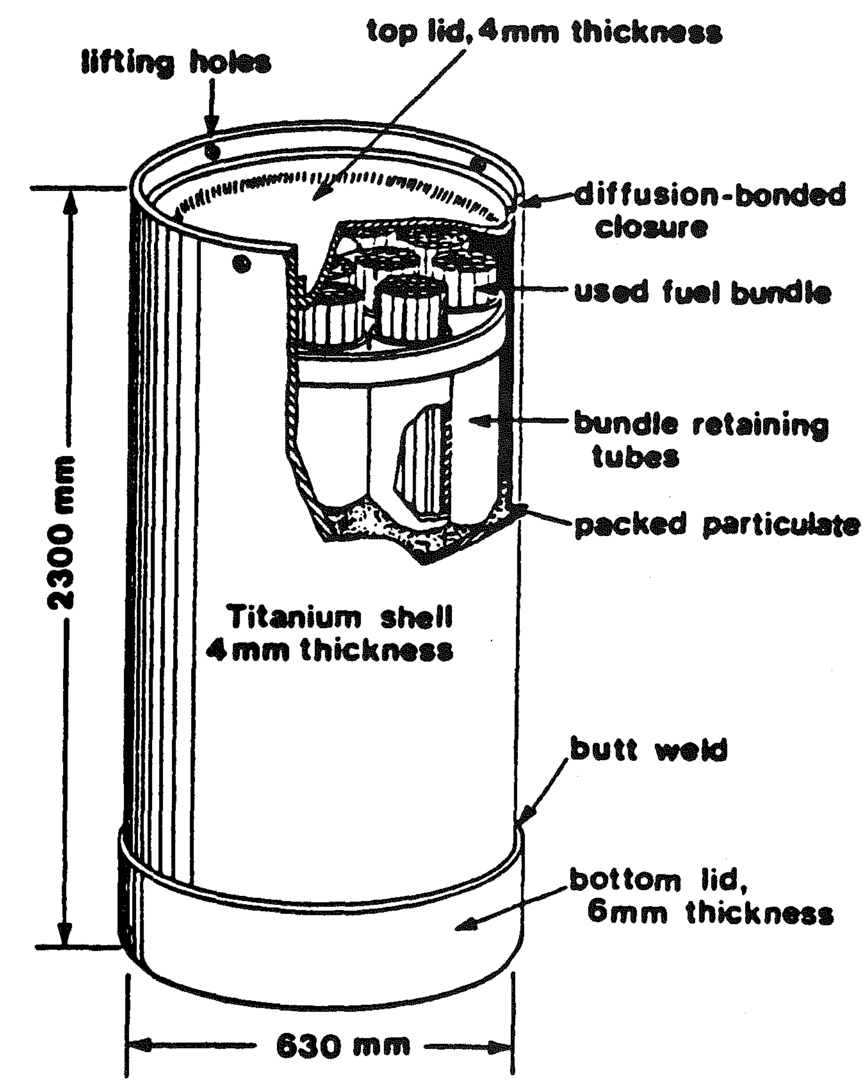

Fig. 2.1

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The Canadian Reference Waste Package (Teper, 1985)

Because of an international shift towards long-term storage and uncertainty in the disposal schedules, Ontario Hydro is assessing a number of alternatives for increasing storage capacity (McEachran, 1986). These include a more compact means of storing used fuel bundles in the water-filled pools; concrete cylindrical canisters which are approximately 6 m high and 2.6 m in diameter; metallic casks; and concrete integrated casks. The latter is an innovative concept in which one cask would serve the multiple function of storage, transport as well as disposal, thus, reducing handling/loading operations.

Of these options, the concrete canister has become the method of choice. Eleven canisters are in use at Gentilly-1, Quebec, and 46 canisters store 22,000 fuel bundles at the decommissioned Douglas Point generating station, Ontario. New Brunswick Power has recently announced that it will use concrete canisters for long-term storage for the used fuel from its Point Lepreau reactor (Intercomm, 1989).

Ontario Hydro has implemented a program for development of the technology for large scale transportation of used fuel (McEachran, 1986). A major part of this program is to design, license and construct a cask for road transportation. The cask, which is shown in Figure 2.2, is expected to be ready for full-scale use by mid-1989. The cask would hold 192 used-fuel bundles, weighs 35 Mg and has dimensions of 2.13 m high, 2.13 m long and 1.82 m wide. A dedicated four-axle, flat-bed trailer has been designed to transport the cask. Scale models of the cask have undergone a series of tests for seal leakage and response to accidents including drop and fire tests. AECB certification was received in July 1987 (Ribbans, 1988). The full-scale cask has been constructed and is undergoing trial runs in early 1989. There are currently no definite schedules for constructing further casks (T. Kempe, Ontario Hydro, personal communication).

In addition, appropriate computer software has been acquired and simulations made to assess radiation doses to the public and the operators from various transportation scenarios.

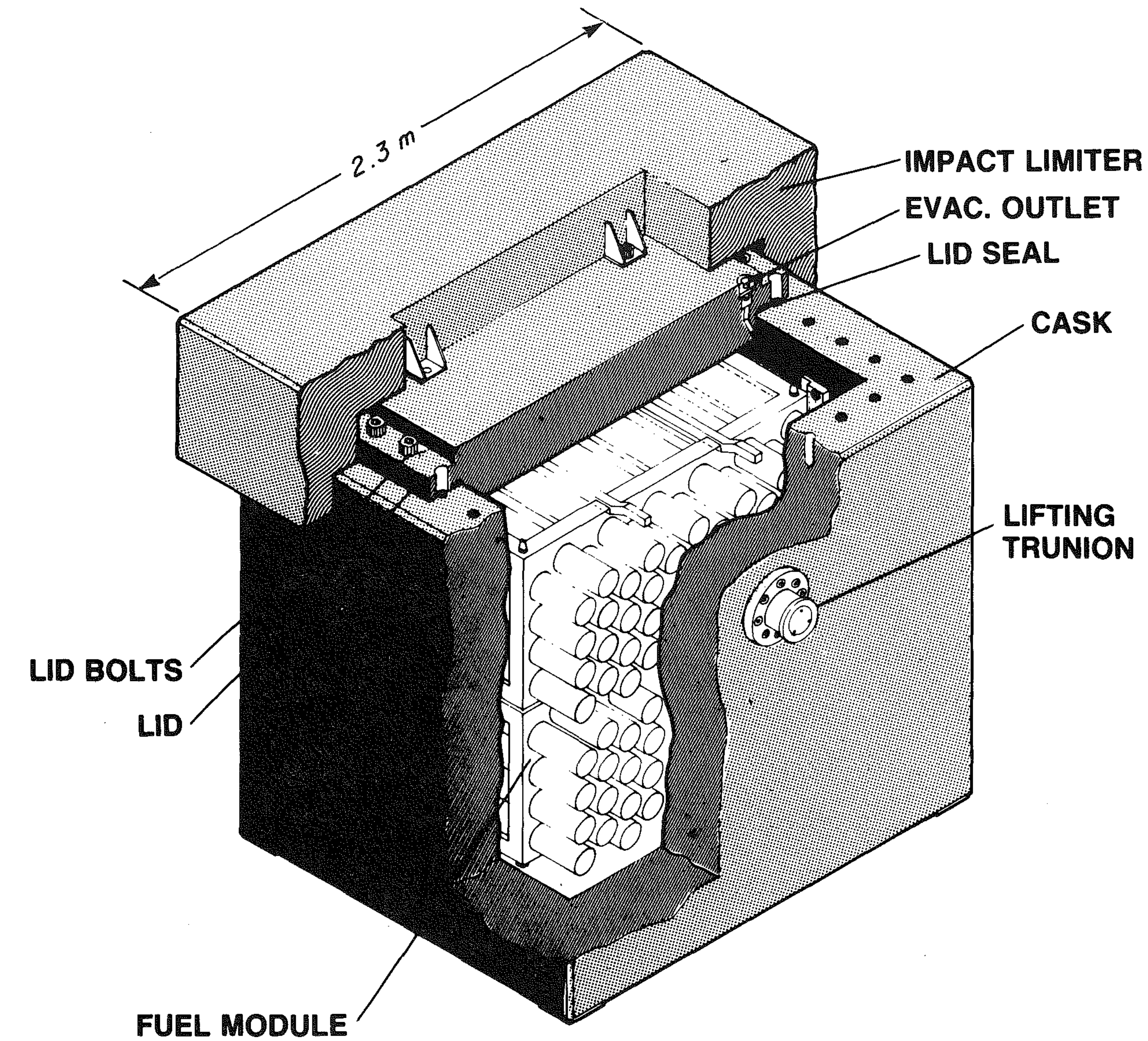

Fig. 2.2

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Candu Spent Fuel Road Cask (McEachran, 1986)

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2.5 - Site Investigations

AECL has selected the crystalline rocks of the Canadian Shield as the host medium for a Canadian repository since the Canadian Shield is the most stable part of Canada, the rocks are strong and relatively uniform, and relatively little groundwater is found at depth.

Only minor effort has been placed into studies of other rock types. For example, an inventory of salt deposits has been developed. However, for all other aspects of repository technology related to salt, reliance has been placed entirely on cooperation and information exchange with other countries. Canada has participated in the international seabed disposal working group sponsored by OECD Nuclear Energy Agency (NEA). Occasional studies have been done on other rock types such as limestone and shale (Heystee, 1982).

Several geological research areas have been and are under investigation, i.e., East Bull Lake, Atikokan, and Chalk River in Ontario as well as the Whiteshell Research area in Manitoba. These sites are being used to develop the information for concept assessment and are not part of a repository site selection process. Investigations have included geological field mapping, airborne and ground geophysics, and borehole studies. The primary objectives have been: to gain an understanding of groundwater flow in fractured crystalline rock; to develop tools that will predict subsurface conditions from the surface; and to develop a database of rock mass properties.

The Underground Research Laboratory (URL) at the Whiteshell Research area plays a central role in AECL's program by developing site investigation methods for characterizing subsurface conditions; in assessing how an underground facility will affect the rock mass and groundwater regime and in performing in-situ experiments relevant to assessing repository performance. Many of the research activities are being done as cooperative programs with Sweden and the USA (Wright, 1988, pg 108).

Recently the US has withdrawn from the URL but Japan has joined the cooperative programs. In addition, an international comparison has been made of groundwater computer programs in simulating the groundwater drawdown at the URL site (Guvanasen et al, 1985).

2.6 - Repository Design

The repository design being developed assumes that 191 133 Mg of fuel-wastes are to be disposed in a single-level vault which is proposed for a granitic plutonic rock body at a depth of 1,000 m (Baumgartner 1986). Based on initial thermal calculations, the vault perimeter dimensions are limited to 2,000 m by 2,000 m. It is proposed that the grid of parallel disposal vault rooms be excavated using a controlled drill and blast method. The boreholes would be bored or core drilled to a depth of 5 m and would have a diameter of approximately 1.2 to 1.3 m.

Ventilation and mine drainage would pass through the nonradioactive excavation areas before passing through the waste emplacement areas. Access tunnels and haulage ways would be designed at a grade of 0.5% for drainage and development/emplacement operations would retreat towards the main shafts to minimize the working time that operators would spend in or adjacent to radioactive areas.

Constraints have been placed on the design of the repository. For example, the maximum container-surface temperature cannot exceed 100°C, to prevent the onset of crevice corrosion. The maximum buffer/backfill temperature cannot exceed 100°C, to minimize the potential for clay alteration.

The barrier materials used and method of placement in the proposed Canadian disposal facility are described by Baumgartner (1986). The borehole would be filled with compacted buffer of bentonite clay and well-graded silica sand (Dixon and Gray, 1985). This buffer mass will be centrally augered to accept the spent fuel container. A minimum buffer annulus of 250 mm is required (Gray and Cheung, 1986) for insert moisture and radionuclide transport retardation. When the emplacement boreholes in the room are filled, room and access tunnel backfilling would begin. The reference backfill (Yong et al, 1986) is a mixture of Lake Agassiz clay (a montmorillonite-rich clay) and crushed granite mixed in a 1:3 ratio. It would be compacted in place in layers to achieve a near homogeneous mass.

Final sealing would be achieved by installing permanent concrete bulkheads immediately following room backfilling. These bulkheads would be placed in the entrance to the emplacement room, and at key locations in the access drifts.

No special provisions are currently included in the repository design to facilitate retrieval of waste containers.

2.7 - Impact Analysis

Canada's disposal vault concept assessment is divided into two areas of investigation: preclosure assessment and postclosure assessment.

2.7.1 - Preclosure Assessment

In the preclosure assessment the following impact factors are considered

- impact on resources
- capital and operating costs
- radiological effects of normal and abnormal operation as well as accidents
- nonradiological effects on the natural environment
- socioeconomic effects
- occupational safety.

A preliminary assessment (Wuschke et al, 1985) found that normal disposal facility operation would result in no radiological dose to the public greater than that from natural background radiation (about 1.8 milliSievert). Analysis of 'worst case' accidents at the facility indicate that radiological doses to the public would be within regulatory limits established by AECB. It was also determined that the total occupational risk (radiological plus conventional) associated with disposal facility construction, operation and decommissioning would be no greater than the risk in comparable industries.

The socioeconomic impacts of Canada's disposal facility have also been analyzed (Stevenson, 1983; Gee et al, 1983; Nathwani, 1983). The total direct employment from construction, operations and decommissioning is estimated at 25,800 man-years. In addition, indirect employment in service and support industries would add up to 122,000 additional man-years.

The socioeconomic effects of used-fuel transportation have also been investigated in terms of traffic volumes, noise and perceived risks to the public (Rogers and Hardy, 1983).

Generally the preclosure assessment showed that no unacceptable risks or effects would be experienced (Wuschke et al, 1985).

2.7.2 - Postclosure Assessment

The postclosure assessment considered the potential long-term effects of the disposal facility on man and the environment after the facility has been closed. The assessment was based on the Systems Variability Analysis Code developed by Dormuth and Sherman (1981). The computer program predicts the transport of radionuclides through the system to determine their effect on man.

Based on this model, the postclosure assessment showed that no radiation dose would be received for at least tens of thousands of years, and probably for hundreds of thousands of years, and that any doses eventually received would likely be only a small fraction of the dose from natural background radiation (Wuschke et al, 1985).

2.8 - Monitoring

Currently there are no plans to monitor the repository once it is decommissioned and sealed.

2.9 - Canadian Regulatory Requirements

The Atomic Energy Control Board (AECB) is the federal agency responsible for regulating nuclear waste management in Canada.

In addition to the AECB regulations, certain other requirements must be met, i.e.,

- generic license conditions

- adherence to regulatory guides e.g., AECB (1987).

- adherence to regulatory policy statements, e.g., AECB (1987).

2.10 - Canada's Concept Assessment Review Process and Public Participation

A Technical Advisory Committee (TAC) currently consisting of 13 members was formed by AECL in 1980 and provides detailed technical review of the scientific and technical progress made within the Canadian program.

Although funded by AECL, the TAC operates as an independent review group with its members nominated by learned societies. They have issued a series of annual reports (Shemilt, 1987).

Canada is very active in international cooperation and information exchange in the area of nuclear waste management. Agreements between AECL and the USA, the Commission of European Communities, Sweden, the UK, the Federal Republic of Germany, the IAEA and the OECD are described by Rosinger et al (1983). In addition, Sweden and Japan are actively involved in the URL project. The US has recently withdrawn from participating in URL activities.

Canada's "concept assessment" phase was jointly agreed upon by the governments of Canada and Ontario in 1981. The concept assessment phase included a review process which required both a technical and public assessment of all aspects of the disposal concept. The review process was undertaken by the Interagency Review Committee consisting of the AECB (lead organization), Environment Canada and the Ontario Ministry of the Environment, and is comprised of the following activities (AECB, 1985)

- public announcement of the "concept assessment" process (August 1981)

- interim concept assessment document for review by the Interagency Review Committee and the public

- regulatory review and assessment of the disposal concept by AECB

- updated concept assessment document

- review of updated concept assessment document by AECB, Interagency Review Committee and the public.

The "concept assessment" was referred for public review under the Federal Environmental Assessment and Review Process (EARP) by the Minister of Energy, Mines and Resources on September 28, 1988 and will include public hearings.

AECL provides information to the public through a variety of means, including displays, computer facilities, information pamphlets, booklets, films and public speakers.

Regional information programs for those living in the vicinity of research areas (i.e., Manitoba, as well as northwestern and north-eastern Ontario) are also held to keep the public informed of activities and to address any concerns.

A public consultation program with public and special interest groups was initiated with a national newsletter in 1984 and invitations to approximately 50 groups. The objectives were to identify, analyze and attempt to address public concerns about nuclear waste disposal. As a result of meetings held with some of these groups, it was determined that the key issues relate to risk assessment, costs, benefits, post-closure monitoring, retrievability, and health and safety provisions (Anderson et al, 1986; Delbridge Associates, 1988).

The result of recent public opinion surveys and focus group discussions in Ontario indicate that general awareness of the waste management program has increased but that knowledge about specific aspects of the program is limited. Over half of the respondents surveyed are in favor of geological disposal and support is increasing when the alternative of continued onsite storage is considered (Gerber, 1986).

3 - BELGIUM

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3.1 - Key Organizations

Radioactive waste management in Belgium is the responsibility of the National Agency for Radioactive Waste and Fissile Materials (Organisme Nationale des Dechets Radioactifs et des Matieres Fissiles/Nationale Instelling voor Radioactief Afval en Splijtsoffen, ONDRAF/NIRAS). Its responsibilities include the following

- transport of radioactive wastes

- conditioning and surface storage of radioactive wastes for generators without suitable facilities

- storage of spent fuel away from the power station or reprocessing plant

- final disposal of radioactive wastes.

ONDRAF/NIRAS is also responsible for research and development programs in radioactive waste management. The actual R & D programs, however, are carried out at Belgium's Research Centre for Nuclear Energy at Mol-Dessel.

3.2 - Schedules

The schedule for HLW investigations in Belgium is as follows:

1974 - 1987: Investigation of the Mol-Dessel site; construction of underground laboratory; beginning of site confirmation work

1988: Completion of first Safety Assessment and Feasibility Interim Report

1988 - 2015: Continuation of site confirmation studies

1995: Presentation of second Safety Assessment and Feasibility Report

1995 - 2015: Demonstration operations

2015: Final conceptual design and beginning of licensing procedure

2020: Invitation to tender and final design

2025: Repository construction

2030: Emplacement of reprocessing wastes

3.3 - Waste Quantities and Packaging

As of 1988, the installed nuclear power capacity in Belgium was 5540 MW. Spent fuel is shipped to the Cogema plant at Pointe La Hague in France for reprocessing into vitrified wastes and is then returned to Belgium for interim storage and final disposal. The first reprocessed waste packages are scheduled to be shipped back from France starting in 1993. There is also an inventory of waste from the activities of the former reprocessing company Eurochemic.

Assuming that decommissioning of the existing nuclear facilities will occur around the year 2050, it is estimated that 4000 - 5000 cubic metres of vitrified wastes will accumulate for final disposal.

The reprocessed wastes will be returned to Belgium in 120 litre canisters as a vitrified product. A number of candidate canister materials for high-level vitrified wastes have been evaluated. Carbon steel, chromized steel, aluminum and its alloys showed the lowest corrosion resistance in a humid atmosphere while titanium and its alloys showed the highest resistance (Bonne and Heremans, 1985).

3.4 - Interim Storage and Transportation

Spent fuel is presently stored in water-filled pools at the power plant sites. Vitrified wastes from former reprocessing facilities in Belgium are stored in the air-cooled storage pits of a bunker building.

A central storage facility will be built in Dessel on the former Eurochemic reprocessing facility site for wastes from reprocessing at the La Hague plant in France. It is scheduled to be completed by the end of 1992 so that it is ready to start receiving shipments in 1993.

Spent fuel is transported by road to the reprocessing plant in France. Specially designed casks are used which comply with the requirements of international transport regulations. All shipments must be authorized in advance and, in general, the requirements of the IAEA regulations for the transport of radioactive materials must be followed.

3.5 - Site Investigations

Based on a survey of the geology of Belgium, it appeared that only clay formations were suitable for HLW disposal (Bonne and Heremans, 1985). In particular, the Boom clay formation in northeastern Belgium is considered the most favorable host medium for siting a repository. Boom clay is attractive in terms of its impermeability, its capacity to retain radionuclides and its proximity to the Mol-Dessel research site and Belgium's nuclear power plants. The clay formation under consideration has a thickness of about 100 m and is free of faults. These favorable characteristics led to a decision in 1975 to start research in the Boom clays at the Mol-Dessel nuclear site. However, the decision was not without some concerns, i.e., the soft clay formation is sandwiched between two aquifers and excavations have never been made in soft clay at depths greater than 100 m (Bonne and Heremans, 1985).

Results have been sufficiently promising that the HADES underground research laboratory was approved at the Mol-Dessel site. Construction commenced in 1978 and was completed in 1984. The first phase of investigation (1986 - 1992) will demonstrate construction capability in nonfrozen clay and involve pilot experiments on heat transfer, radiolysis and gamma source handling. The second phase (1988 - 1994) involves construction of a second shaft with connecting tunnels to the existing laboratory. A schematic of the HADES underground research laboratory is shown in Figure 3.1. A horizontal gallery of 35 m length with a 3.5 m diameter has been constructed and is lined with galvanized cast iron vaults in which numerous ports have been installed. At the end of the gallery a 20+ m deep shaft (1.4 m diameter) has been dug into nonfrozen clay and lined with concrete blocks. At the base of this shaft, an 8 m horizontal drift at 246 m ends up in an open clay wall. A 63 m long test drift has also been constructed to perform experiments with radioactive sources.

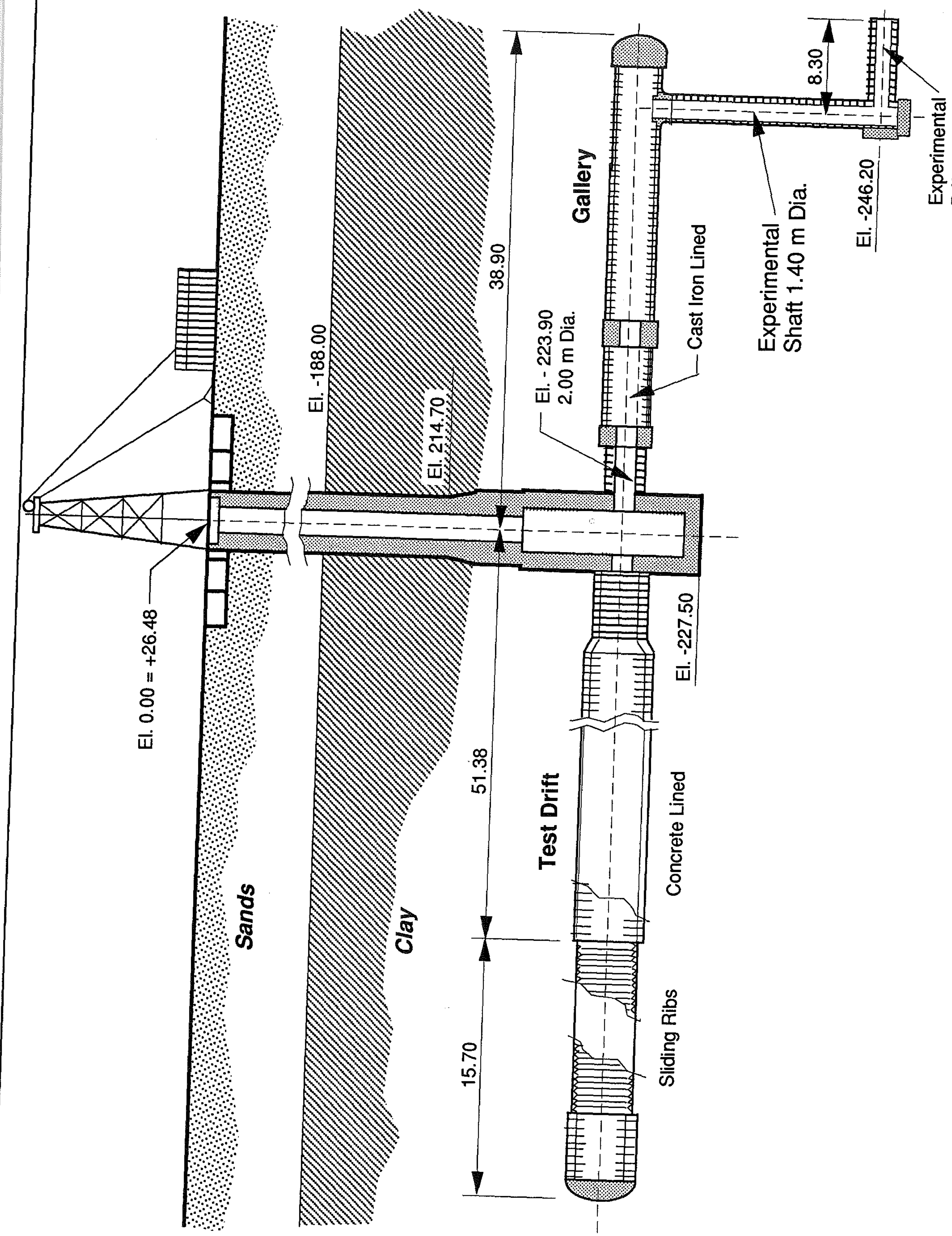

Fig. 3.1

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Belgium's Underground Research Laboratory at Mol (After Baetsle et al, 1986)

Present plans envisage that a larger underground facility will be constructed eventually to provide full-scale demonstration of HLW disposal technology.

3.6 - Repository Design

It is intended that the Hades research and demonstration facility will be expanded into a full-scale repository. The geotechnical properties of Boom clay limit the design to lined circular tunnels of 3 - 4 m diameter. The underground facility will therefore be a network of interconnected galleries. It is envisaged that the vitrified waste canisters will be set in small boreholes drilled at an angle of 45° to the horizontal in the low part of the main galleries as shown in Figure 3.2. The concept of dipping, long boreholes for multiple waste package emplacement is quite unusual. Other emplacement concepts such as horizontal placement inside the tunnels are also under consideration.

Numerous backfilling materials have been evaluated and good results have been obtained from bentonite, cement and Boom clay epoxy resin mixtures (Bonne and Heremans, 1985). However, studies of backfill materials are still underway and Belgium is presently undertaking research jointly with France on Boom clay and a mixture of smectite clay, quartz sand and graphite (NEA, 1988a).

3.7 - Impact Analysis

The impact analysis is presently centered on the HADES underground research laboratory. Experiments have examined the corrosion of waste containers, the integrity of engineered barriers, the geochemistry and migration of radionuclides, the geomechanical stability of excavations in clay, backfilling and sealing technology, and the near-field effects of heat and radiation on clay.

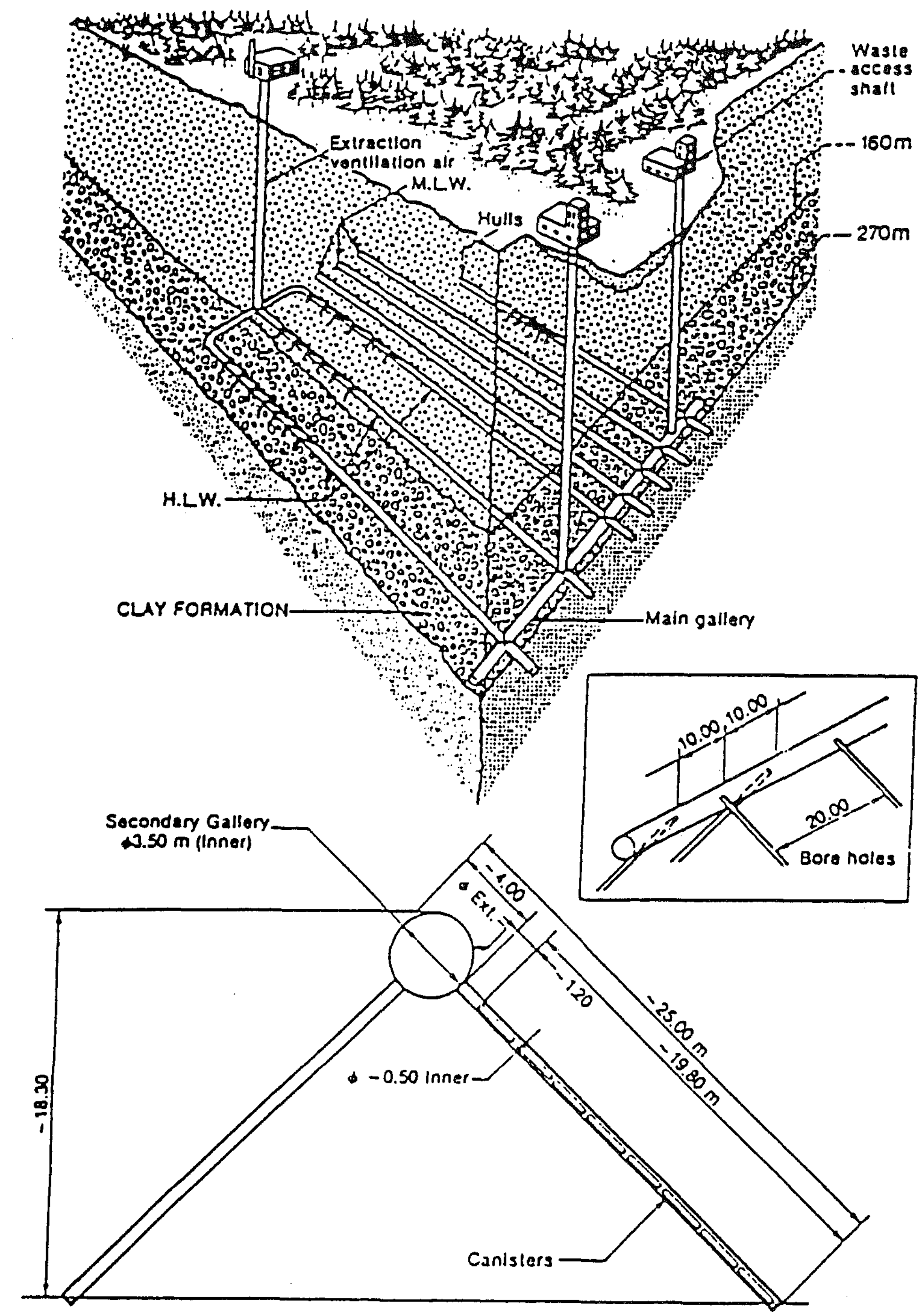

Fig. 3.2

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Reference Concept of Repository in a Clay Formation (from Heystee, Personal Communication)

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In addition, Belgium's Mol site was selected as the reference clay disposal site case study by the Commission of European Communities (CEC) for their performance assessment investigations. When natural pathways were considered, it was found that the calculated dose rate never exceeded 10^{-10} Sieverts per year for all scenarios. The maximum calculated dose rate for the water well interception scenario in the aquifer just above the repository area was approximately 3×10^{-7} Sieverts per year (NEA, 1988).

3.8 - Monitoring

Belgium's repository design is insufficiently developed at the present time to enable monitoring programs to be designed for the construction and operational phases of the program.

No postclosure long-term monitoring of the repository is presently anticipated.

3.9 - Licensing and Regulatory Requirements

Licensing procedures for nuclear installations are outlined in the "General Regulation for the Protection of the Population and Workers Against the Hazards of Ionizing Radiation". Since there are no specific requirements for radioactive waste disposal at the present time, ONDRAF/NIRAS is charged with the responsibility for developing regulations for approval by the appropriate government authority.

As it now stands, each nuclear facility project is subject to a safety analysis which must be submitted to the Belgian Safety Authorities in order to obtain an operating license. Items which must be covered in this safety analysis include

- conventional accidents (handling, loss of coolant, etc)
- nuclear accidents (criticality, contamination, irradiation)
- other events (earthquakes, tornados, airplane crashes, etc).

In the safety analysis the International Commission on Radiological Protection (ICRP) recommendations are presently used to assess the adequacy of radiation protection measures.

3.10 - Performance Assessment Review Process

ONDRAF/NIRAS has a quality assurance program which is applied during the development phase of projects as well as during construction and testing of facilities.

In addition, Belgium is a member of the Commission of European Communities which has initiated project PAGIS (Performance Assessment of Geological Isolation Systems). Scientists from member countries work together to assess the general capability of a waste disposal system to confine (or severely restrict) the release of radionuclides after the closure of underground HLW repositories.

4 - FEDERAL REPUBLIC OF GERMANY

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4.1 - Key Organizations

The Federal Institute for Science and Technology (Physikalisch-Technische Bundesanstalt, PTB) is the central organization with responsibility for disposal of radioactive waste in Germany. The PTB reports to the Federal Ministry of Environment, Nature Protection and Nuclear Safety (Bundesminister für Umwelt, Naturschutz und Reaktor Sicherheit). The German Company for Construction and Operation of Repositories (Deutsche Gesellschaft für Bau und Betrieb von Endlagern fur Abfallstoffe mBH) is constructing both the low-level and high-level waste repositories on behalf of PTB.

All other aspects of HLW management such as transportation, interim storage and reprocessing are the responsibility of the waste producers. The German Company for Reprocessing of Spent Fuel (Deutsche Gesellschaft für Wiederaufarbeitung von Kernbrennstoffen mbH), a subsidiary of the twelve utilities using nuclear power, manages these responsibilities.

4.2 - Schedules

The schedule for West Germany's HLW repository and associated facilities is as follows

1977 - Site selection (Gorleben salt dome)

1979 - Commencement of field investigations from the surface

1983 - Commencement of underground exploration

1986 - License application for a pilot conditioning and encapsulation plant at Gorleben for spent fuel

1988 - Commence operation of interim storage facility for spent fuel at Gorleben

1992-1994 - Commence operation of pilot conditioning and encapsulation plant for spent fuel

1995 - Commence construction of repository

2000+ Operation of repository.

4.3 - Waste Quantities and Packaging

West Germany has 22 power reactors totalling 18,900 MW of generating capacity (Sparrow, 1988). By the year 2000 it is estimated that this generating capacity will increase to 27,500 MW. Given this capacity about 600 to 700 Mg of spent fuel will be discharged annually by the turn of the century. Up to 500 Mg of this spent fuel (with a minimum cooling time of 7 years) will be reprocessed each year leaving 100-200 Mg potentially for direct disposal unless the capacity at the reprocessing plant is increased (Closs and Einfeld, 1986).

Present plans are that spent fuel will be reprocessed. However, since 1985 programs have been initiated to develop the technology for disposing of spent fuel.

The German reference disposal cask system for spent fuel contains eight fuel elements and weighs about 65 Mg. It has a length of about 5.5 m and a diameter of 1.5 m. The cask system is comprised of a pressure-

resistent disposal canister, a corrosion-resistent layer and a shielding container which allows direct handling. The cask can also be used for transportation and long-term interim storage with an option of reopening the cask in case reprocessing is desirable (Closs and Papp, 1988; Closs and Einfeld, 1986).

4.4 - Interim Storage and Transportation

West Germany's nuclear power plants have water-filled pools for the interim storage of spent fuel. However, dry storage using modular cast-iron casks is now the direction for central interim storage facilities. One of these facilities has been completed at Gorleben, one is under construction at Ahaus/Northrine-Westfalia and a third will be built at the Wackersdorf reprocessing plant. Each has a capacity of 1500 Mg uranium (Closs and Einfeld, 1986).

Spent fuel is transported primarily by rail in West Germany, and occasionally in truck shipments. The thick-walled transport casks are made of cast-iron in compliance with existing international recommendations.

4.5 - Site Investigations

The Federal Republic of Germany was the first European country to commence research into radioactive waste disposal and has progressed the farthest to date. Research began in the Asse salt mine in 1965. In 1977 the Gorleben salt dome was selected to host a repository. Selection of the Gorleben salt dome repository site near the north-eastern border with East Germany, was based primarily on studies which have been ongoing for over 10 years at the nearby Asse salt mine. The selection does not appear to have been based on a national survey of sites, and was undoubtedly heavily influenced by the fact that the site was volunteered by Lower Saxony.

The Asse mine site, Lower Saxony, was transformed into an underground research laboratory by the German Company for Radiological and Environmental Research. In addition to providing an in-situ laboratory, the Asse salt mine was used for disposal of low-level and intermediate-level wastes from 1967 to 1978. Located at depth of about 850 m in a dome-shaped salt formation, the Asse mine is a showpiece of the German program. Currently research at Asse is concentrating on the inter-relation of waste and rock salt and its consequences for the long-term safety of a repository. Technologies are also being developed to demonstrate the construction, operation, backfilling and sealing of a repository.

Surface exploration commenced at the Gorleben site in Lower Saxony near Asse in 1979 and concentrated on the type and thickness of the strata overlying the salt dome and the related hydrogeological situation. The overlying strata consists of sand, gravel and clay. Two exploratory shafts of depths of 940 and 840 m respectively are planned (Closs and Papp, 1988).

4.6 - Repository Design

A one-level repository at a depth of about 870 m is proposed although a final layout for the repository will not be available until completion of the underground investigations. It is envisaged that an area of only a few square kilometers will be required to dispose of 50 years of nuclear waste (Bechtold et al, 1988).

The repository will be accessed by two shafts located about 500 m apart. No waste packages will be disposed within a 300-m distance

around the shafts. It is proposed that underground exploration of the salt dome's interior take place approximately 30 m above the later emplacement level. The exploration drifts will subsequently be used for ventilation purposes.

Present plans are to dispose of the high-level reprocessed wastes in vertical boreholes 300 m to 600 m deep below the main galleries (Closs and Papp, 1988). In the case of spent fuel, this type of waste may be placed in the galleries at 870-m depth or in vertical boreholes encased in thick-walled, self-shielding casks.

Backfilling (crushed salt), plugging and sealing techniques are presently under investigation at the Asse mine site.

No plans for retrievability are currently envisaged since this capability could have deleterious effects on safe performance of the repository. Retrievability would mean that encapsulation of the waste by the surrounding host medium would have to be delayed and rooms kept open for some time, increasing the probability of potential brine inflow (Bechtold et al, 1988).

4.7 - Impact Analysis

To date, West Germany's impact analysis for a HLW repository has primarily concentrated on research investigations at the Asse salt mine. Particular attention has been given to the following areas of concern

- the thermo-mechanical behavior of the host rock

- the water and gases present in rock salt and their release mechanisms in a temperature field which is above ambient levels.

- the transport and handling system for high-level vitrified wastes.

In addition, a radiological performance assessment has been conducted by the Commission of European Communities since the Gorleben site was selected as the reference salt repository for their PAGIS project. The Commission found that under a normal evaluation scenario, no radioactivity would escape. More pessimistic scenarios were also considered including water intrusion from the anhydrite vein (with or without an undetected brine intrusion in the vicinity of the repository), and a human intrusion scenario (salt mining). Maximum dose rates in the order of 10^{-5} Sieverts/year have been computed to occur at 20,000 years assuming unlimited water intrusion immediately after repository closure. Dose rates in the order of 10^{-5} Sieverts/year have been computed to occur at 700,000 years for the human intrusion scenario. As a result of the above analysis the Commission of European Communities concluded that the safe disposal of vitrified HLW in salt can be achieved provided sites are appropriately selected and repositories are designed and built according to sound engineering practices (CEC, 1988).

4.8 - Monitoring

No details on West Germany's monitoring programs for a HLW repository are presently available.

4.9 - Licensing and Regulatory Requirements

The disposal of radioactive waste in West Germany is governed by the following acts and regulations

- Atomic Energy Act (1976)
- Radiation Protection Ordinance (1976)

- Federal Mining Act (1980)
- Safety Criteria (1983).

The initial step in the licensing procedure is to obtain plan approval which requires the participation of all authorities concerned and public consultation. The legal requirements for the licensing of a repository are contained in regulations under both the Atomic Energy Act and the Federal Mining Act. In the long term, the repository must not lead to individual dose rates in excess of 0.3 milliSieverts per year.

4.10 - Performance Assessment Review and Public Participation

Public consultation is of major importance for the licensing of a repository facility. Specific details are not available.

5 - FRANCE

5 - FRANCE

5.1 - Key Organizations

The National Agency for the Management of Radioactive Wastes (Agence Nationale pour la Gestion des Dechets Radioactifs, ANDRA) was created within the Commission on Atomic Energy in 1979. ANDRA is responsible mainly for the design, siting, construction and operation of the disposal centers for every kind of radioactive waste produced in the country (Marque and Andre-Jehan, 1988).

Waste management policy and the regulations and licensing of nuclear installations are the responsibility of the Central Service for Nuclear Installation Safety under the Ministry of Industry.

In addition, the Central Service for Protection Against Ionizing Radiation under the Ministry of Health and Labor plays a specialized role. This agency is responsible for monitoring and controlling releases to the environment from radioactive sources.

5.2 - Schedules

The present program in France for a HLW repository is as follows.

1987 - 1990: Field investigation of four potential sites for an underground site validation laboratory (USVL)

1990 - 1991: Selection of one site and construction of USVL

1994: Decision on site validation

2010: Commence operations of the HLW repository

5.3 - Waste Quantities and Packaging

The current nuclear capacity in France is 44,000 MW which is expected to increase to 57,000 MW in 1990 and 71,000 MW by the year 2000. Nuclear power's share of electricity in France is about 70%, the highest in the world.

The spent fuel will be reprocessed at either the Marcoule or La Hague reprocessing plants in France prior to final disposal. It is estimated that by the year 2000, France will have accumulated approximately 60 000 cubic metres of reprocessed waste (Sparrow, 1988).

Currently the reference waste container is made of corrosion-resistant stainless steel and is 1.5 m long and 0.3 m in. diameter. It contains 350 kg of vitrified waste. The container design may be modified to suit the specific conditions of the final site.

5.4 - Interim Storage and Transportation

Presently the light-water reactor spent fuel is held in pool storage while the smaller quantities of fast breeder reactor spent fuel is contained in dry storage. Vitrified wastes are stored in air-cooled vaults at the Marcoule and La Hague reprocessing facilities.

France's regulations on transportation of spent fuel and radioactive waste are modeled largely upon IAEA recommendations. Many different transport casks, mostly of French design, are used which incorporate the following features: dry containment, steel body, double containment, large capacity, standard sizes.

Transport is made preferably by rail with road transport limited to short distances.

5.5 - Site Investigations

There is a broad choice of possible host media in France for a HLW waste repository, i.e., clay, salt, granite and schist. Thirty zones were initially identified which were subsequently reduced to four sites as follows.

- AISNE (clay) The host medium has two layers of clay 100 m thick and is located 400 - 750 m deep.

- DEUX-SEVRES (granite) This area covers approximately 250 square kilometres with a granite thickness of more than 3,000 m.

- MAINE-ET-LOIRE (schist) This potential site is located in the center of a 10-km anticline. The schist formation is more than 600 m thick.

- AIN (salt) This area of bedded salt is protected above and below by thick layers of clay.

Field investigations of the four sites commenced in 1987 and a decision for location of the underground site validation laboratory at one of these sites is scheduled for late 1989. The plan is to eventually construct the repository on the laboratory site, assuming that underground experiments prove the site to be favorable.

In addition to the above, in-situ investigations are being conducted in a former uranium mine located in granitic rocks at Fanay-Augeres (Limoges). Also, one of the reference sites for international cooperation on performance assessment (see Section 10) is in a French granite formation (Auriat).

A similar public information program is underway for the repository. In 1987, at the beginning of field investigations at each of the four potential sites, ANDRA installed local 'missions' to be responsible for both the technical and public information programs.

6 - SWEDEN

6 - SWEDEN

6.1 - Key Organizations

The key organizations in Sweden responsible for nuclear waste management and radiation protection are listed in Table 6.1. The prime responsibility for demonstrating/developing technology, and disposing of nuclear waste lies with the utilities, who have formed a company, the Swedish Nuclear Fuel and Waste Management Company (Svensk Karnbranslehantering AB, SKB) to perform these duties.

6.2 - Schedules

A schedule for development and implementation of the HLW repository for spent fuel in Sweden is shown in Figure 6.1. The Swedish parliament has declared that no more reactors are to be built in Sweden and the existing ones are not to be operated beyond the year 2010 (Forsstrom, 1986). The repository for the final disposal of spent fuel is presently scheduled to be in operation by the year 2020.

It should be noted that the disposal of low-level wastes is a priority issue in Sweden and is integrated with the HLW programs. For example, the organizations who have responsibility for HLW (Table 6.1) also have responsibility for LLW. In April 1988, an underground repository for LLW was opened, which is located 50 m below the Baltic Sea and is accessed by tunnels from land.

TABLE 6.1

AGENCIES IN SWEDEN RESPONSIBLE FOR NUCLEAR WASTE MANAGEMENT AND RADIATION PROTECTION

Agency	Responsibility
Svensk Karnbranslehantering AB (SKB) (Swedish Nuclear Fuel and Waste Management Company)	Management and disposal of spent nuclear fuel and other radioactive wastes (this company is owned by the four Swedish electric utilities operating power reactors).
Statens Stralskyddinstitut (The National Institute of Radiation Protection) Ministry of Environment and Energy	Administers the Radiation Protection Act and the Radiation Protection Ordinance; monitors people working with ionizing radiation; regulates the release of radioactivity at nuclear power stations; reviews radiation protection requirements at nuclear power stations, etc.
Statens Karnkraftinspektion (Swedish Nuclear Power Inspectorate)	Responsible for the licensing of nuclear facilities under the Atomic Energy Act. Also responsible for safety regulations associated with operation of a repository under the Act on Nuclear Activities.
Statens Karnbranslenamnd (Swedish National Board for Spent Nuclear Fuel)	Supervisory and financial authority for the management and disposal of spent nuclear fuel and nuclear plant decommissioning; recommends fee to be paid by utilities annually to cover disposal and decommissioning costs.

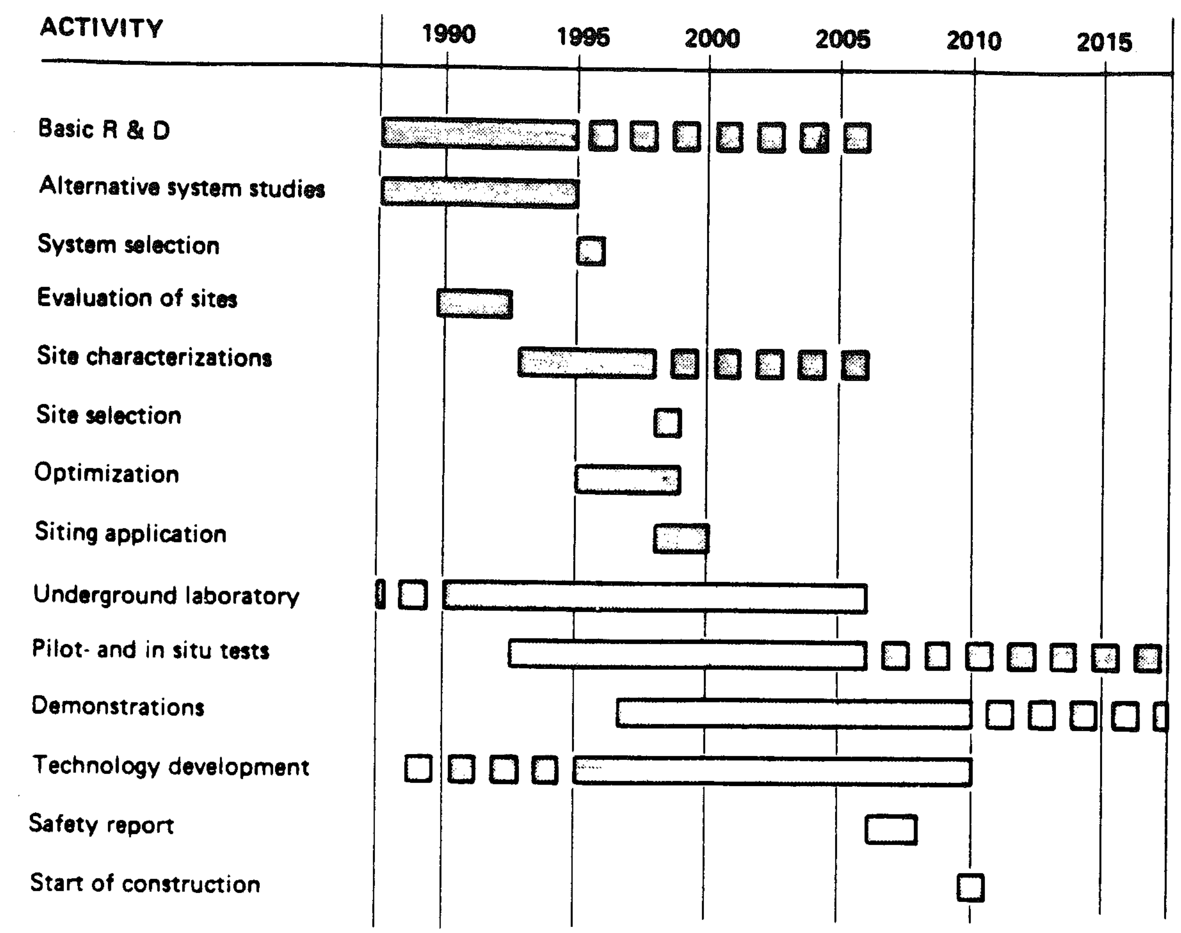

Fig. 6.1

FEARO

Schedule for Sweden's HLW Repository (Bjurstrom, 1988)

6.3 - Waste Quantities and Packaging

It is estimated that Sweden will have 7,800 Mg of spent fuel from the operation of 12 reactors until the year 2010 (Forsstrom, 1986), as well as 19,000 cubic metres of long-lived wastes from reactor decommissioning and 6,000 cubic metres from other activities. Sweden's original disposal concept, developed in 1977, envisaged that spent fuel would be reprocessed. However, that decision has been reversed and it is now planned to dispose of spent fuel only. Sweden's light-water reactors use enriched-uranium fuel.

Present plans are to encapsulate the spent fuel in corrosion-resistant copper canisters (Bjurstrom, 1988). Fuel rods are embedded in lead inside the copper canisters as shown in Figure 6.2.

The canisters have a minimum wall thickness of 20 cm. It was calculated that after one million years of exposure to oxygen and sulphide in a worst case situation involving 'pitting' of the canister the maximum corrosion depth would be 60 mm (30% of the wall thickness). It was also found that there were no mechanical stresses that would limit the life of the copper canister design to less than one million years (KBS, 1978). Thus, the copper canister forms a major barrier to prevent release of radionuclides.

6.4 - Interim Storage and Transportation

A central facility for the interim storage of spent fuel has been in operation since July 1985. This facility comprising underground storage pools in a rock cavern, is located on the east coast of Sweden adjacent to the Oskarshamn power plant. When fully expanded, it will have the capacity to store all 7,800 Mg of spent fuel for 30 to 40 years until final direct disposal in crystalline rock formations becomes available (Bjurstrom, 1988).

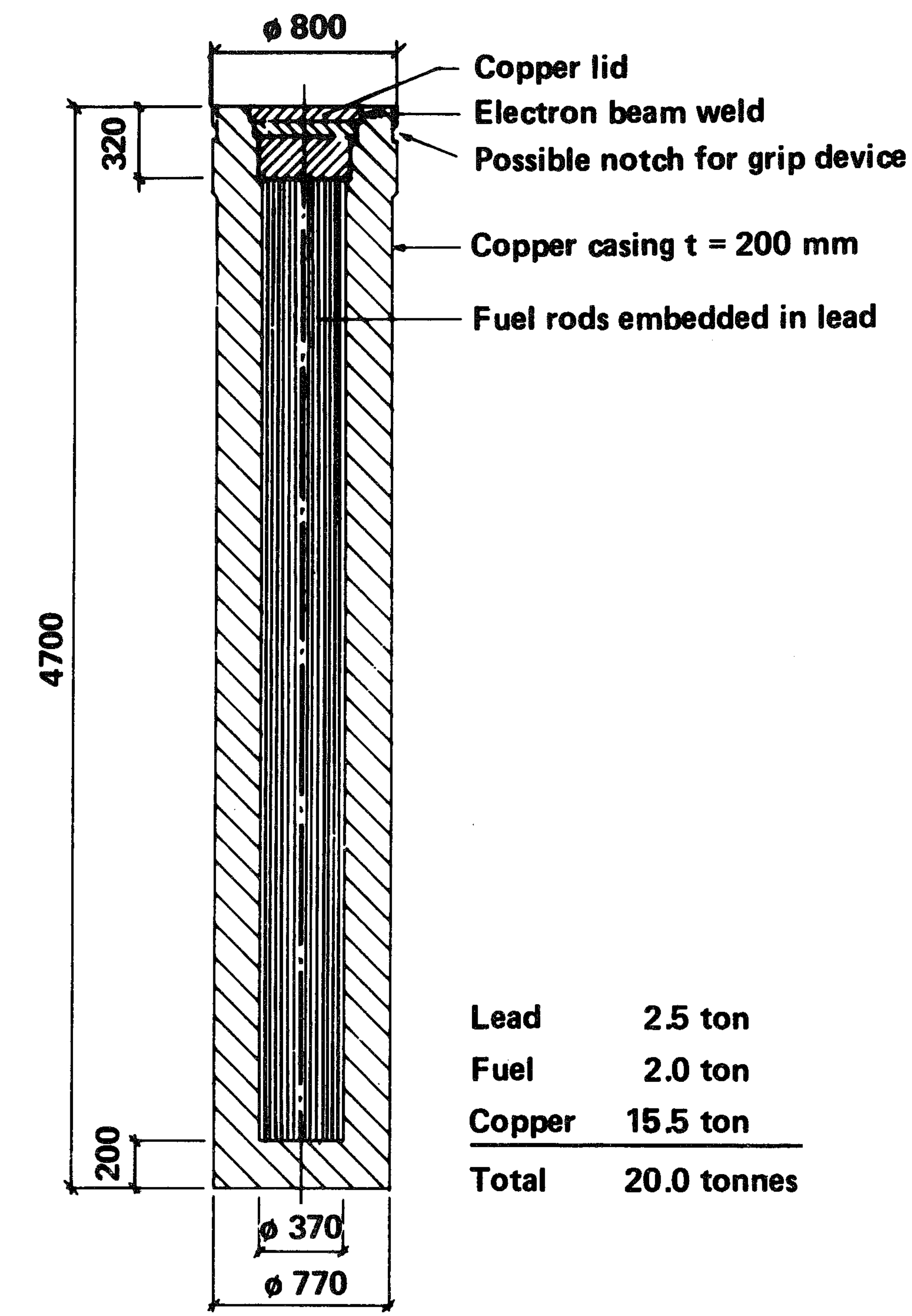

Fig. 6.2

FEARO ACRES

Sweden's Copper Canister with Fuel Rods Embedded in Lead (KBS, 1978)

Since all of Sweden's nuclear power stations and storage facilities are located on the coast, a sea transportation system has been developed to transfer spent fuel to a final repository site. A specially designed ship was launched in 1982 which can take 10 fuel casks each with a weight of about 80 Mg. The fuel is transported dry and cooled by natural air convection (Forsstrom, 1986).

6.5 - Site Investigations

Sweden's geology consists solely of crystalline rocks of the Precambrian Shield. For this reason, Sweden has had no alternative but to concentrate on crystalline rocks.

Fourteen sites have been investigated in Sweden since 1977. Detailed investigations have been carried out on eight of these sites including boreholes drilled to a depth of 500 - 1000 m. Geological, hydrological and geochemical measurements were made on the surface and in the boreholes. The results confirm that Swedish crystalline bedrock, dominated by granite and gneissic formations of old age, provide acceptable conditions for safe disposal at many locations (Forsstrom, 1986). The schedule for further site investigations is as follows (Bjurstrom, 1988)

- 1987 - 1990 Supplementary non site-specific geological investigations aiming at deeper and broader knowledge of the Swedish bedrock. Reexamination of possible sites and development of selection criteria for final sites.

- 1990 - 1992 Evaluation of existing site-specific data. Supplementary geological site specific investigation of interesting sites. Selection of two sites for detailed characterization and a decision by the government.

- 1993 - 1998 Detailed characterization of two sites including shaft-sinking etc.

- 1998 - 2000 Selection of proposed final repository site and siting applications.

- 2000 - 2003 Review of siting application and final approval by local and national authorities and confirmation by the government.

Sweden has been participating with several OECD countries in an underground research laboratory called the "Stripa project" since 1977. Stripa is a former iron ore mine located in the granitic bedrock of central Sweden, 360 - 400 m below ground. Investigations have centered on groundwater flow, radionuclide transport in rock fractures and the sealing of groundwater flow paths. The Stripa project will be completed in 1991.

Construction of the Swedish Hard Rock Laboratory, located in granite near Oskarshamn, is expected to start in 1990. The objectives are to test and demonstrate site characterization methods, repository construction techniques and engineered barriers, and to further develop, validate and demonstrate the models and assumptions to be used in safety analyses. Experiments and demonstrations will be conducted at a depth of about 500 m (NEA, 1988).

6.6 - Repository Design

Sweden's KBS-3 repository design concept consists of a grid of tunnels at 500 m depth (Figure 6.3). Each canister would be placed in a borehole at the bottom of tunnels. The borehole would then be filled with a bentonite clay barrier and sealed with a copper plate as shown in Figure 6.4. When the repository is full, all shafts and tunnels would be backfilled and sealed (Forsstrom, 1986).

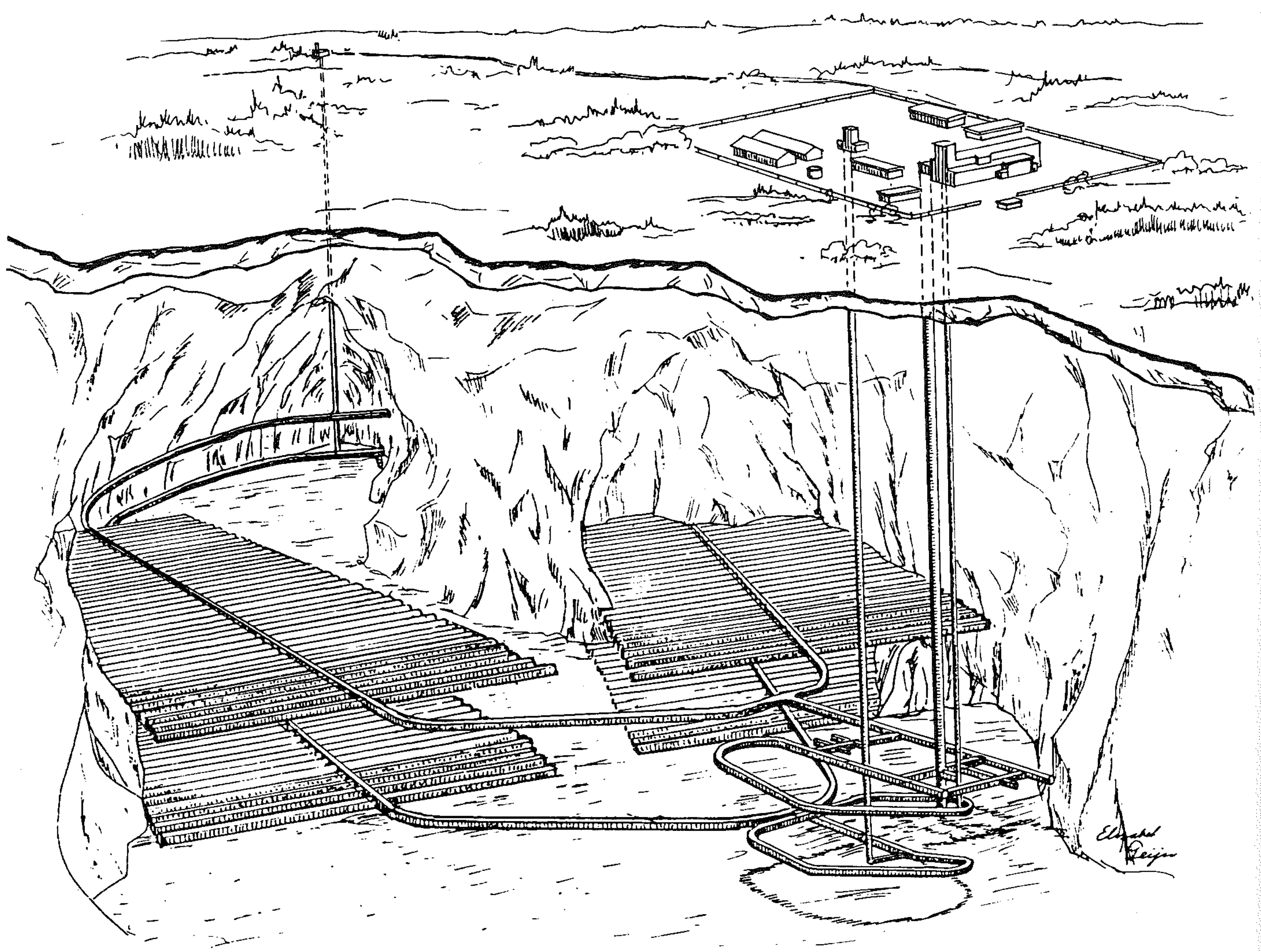

Fig. 6.3

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Schematic Perspective View of Sweden's Repository Design (SKBF, 1983)

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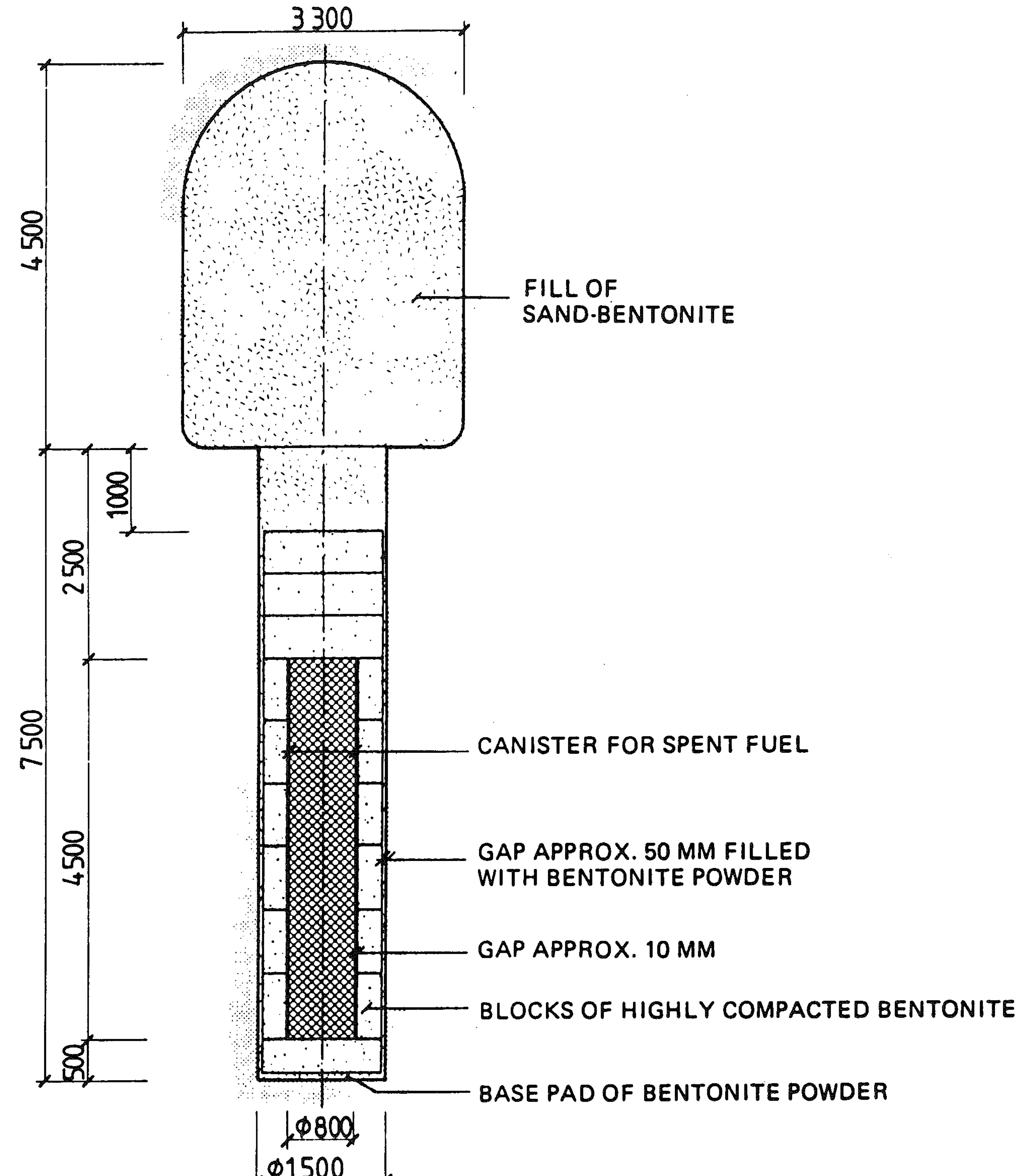

Fig. 6.4

FEARO

Sweden's HLW Canister Sealed in Repository Room (SKBF, 1983)

ACRES

The repository would be backfilled with a mixture of quartz sand (80-90%) and bentonite (10 - 20%). When the mixture is used as tunnel fill 0.5% ferrophosphate would be added to serve as an "oxygen-getter". One or more sections of the vertical shafts would be filled with "plugs" of pure highly compacted bentonite to provide extra security against water flow in the rock (KBS, 1978).

The distance between the tunnels and between the storage holes have been determined on the basis of rock mechanics and the heat flux of the fuel in the canisters (approximately 0.8 kilowatts per canister at the time of deposition). This results in an areal heat load of 5.25 watts per square metre (KBS, 1978), which ensures that temperatures remain within the rock/barrier material temperature limit of 80°C.

At this stage, both a two-level (as shown in Figure 6.3) and a single-level repository are under consideration.

No provisions are included in the repository design for retrieval of the waste containers.

6.7 - Impact Analysis

Early research by KBS (1978) on impact analyses has covered the following areas

- integrity of the canister material (corrosion and mechanical stresses)
- integrity of the barrier material
- impacts of temperature on integrity of the repository
- transport of radionuclides by groundwater

- radiation exposure pathways (e.g., soil, grain, crops, milk, meat, drinking water, bathing, beach activities, fishing, etc)
- radiation doses
- fracture movements in the bedrock
- uplift and glaciation
- earthquakes
- meteorite impacts
- extreme climatic changes
- repository construction impacts
- operational impacts (including transport of canisters).

In particular, Swedish researchers have been concentrating on radionuclide transport in groundwater. Work in this area includes modeling groundwater travel in granite (Brotzen, 1988) and numerous other hydrogeological investigations in fractured crystalline rock (Andersson and Klockars, 1985; Gustafsson and Klockars, 1984; Klockars and Persson, 1982).

Further research on groundwater flow and how it is affected by shaft-sinking and tunneling will soon be possible when Sweden's new Oskarshamn underground research laboratory becomes available in the early 1990s (Bjurstrom, 1988).

Studies on social impacts have primarily centered on health risks associated with radiation levels emitted from the repository site, although acts of war, sabotage and the potential for future disturbance by man have also been considered (KBS, 1978). An example of the potential for future disturbance by man might involve drilling by future generations if knowledge of the final repository location becomes lost in the distant future.

6.8 - Monitoring

The tunnels in which the canisters are deposited can be inspected and measurements taken of rock stresses, temperatures, groundwater, ventilation systems, etc. until the final repository is sealed. Monitoring is not expected to be needed for long-term safety once the repository is sealed.

6.9 - Licensing and Other Regulatory Requirements

Regulatory guidelines and radiation protection criteria are being developed with the philosophy that the contribution to the most highly exposed public group shall constitute only an insignificant portion of the dose from natural background and shall be within the range of natural variation.

A distinction is being made between radiation dose criteria for the first few thousands of years, and for more distant times. Conventional dose calculations are appropriate for the former period with the requirement that doses to the most exposed group shall not exceed 0.1 milliSieverts/year. For the latter period, new policies are being developed. For example, criteria may be based on comparisons to natural releases of radionuclides from weathering of bedrock.

Occupational exposure limits are in accordance with IAEA and ICRP limits (50 milliSieverts/year).

6.10 - Concept Assessment Review Process and Public Participation

Sweden's research and development program for the final disposal of radioactive waste must be revised and presented to the government every third year. In addition to outlining results and measures that are needed until final disposal of the waste has been completed, a detailed research and development program for the next six years is required.

The latest safety report was presented in September 1986 to the government. An extensive review of the program was arranged including 50 domestic reviewers and 10 foreign expert groups, including the Canadian Technical Advisory Committee. The review and evaluation resulted in a generally favorable statement in May 1987 (NEA, 1988).

More than 50% of the Swedish general public believe that high level radioactive waste cannot be disposed in a safe manner at the present time. Therefore it is acknowledged that in order to achieve acceptance of a final repository site at the end of the 1990s, extensive information must be furnished both locally and at the national level (Bjurstrom, 1988). Also, it is apparent that public opinion in Sweden on the nuclear issue has hardened since the Chernobyl accident in May 1986 (Sparrow, 1988).

7 - SWITZERLAND

7 - SWITZERLAND

7.1 - Key Organizations

Switzerland has five principal agencies with responsibilities for nuclear waste management and disposal as listed in Table 7.1.

The National Cooperative for the Storage of Radioactive Waste (Nationale Genossenschaft für die Lagerung Radioaktiver Abfalle, NAGRA) is the key agency which has responsibility for the design, construction and operation of repositories for radioactive waste and related facilities. As part of this responsibility NAGRA initiated Project Gewähr in 1985 to study the feasibility of HLW disposal in Switzerland. The partners in NAGRA are the Swiss Confederation (represented by the Federal Office of Public Health) and six utilities with nuclear power plant projects.

In 1978/79, the government announced that existing nuclear power plant operational licenses would not be renewed and no new operational licenses issued unless the safe disposal of nuclear wastes could be demonstrated. Ten years later, in June 1988, the Swiss federal government announced that existing nuclear power plants could continue to operate since the safe disposal of high-level wastes in Switzerland had now been demonstrated in crystalline rock formations (Intercomm, 1988).

7.2 - Schedules

In Switzerland, the first priority is low-level and intermediate-level waste; HLW is considered less urgent.

TABLE 7.1

AGENCIES IN SWITZERLAND RESPONSIBLE FOR NUCLEAR WASTE MANAGEMENT

Agency	Responsibility
NAGRA (Swiss National Cooperative for the Storage of Radioactive Waste)	Design, construction and operation of radioactive waste disposal facilities in Switzerland.
Federal Commission for Safety in Nuclear Installation	Jointly reviews disposal projects with the Federal Office of Energy, Nuclear Safety Department and will also undertake control and supervision measures.
Federal Office of Energy, Nuclear Safety Department	Jointly reviews disposal projects with the Federal Commission for Safety in Nuclear Installations
Arbeitsgruppe des Bundes fur die nukleare Entsorgung (Federal Interagency Working Group on Nuclear Waste Management)	Prepares technical support material for decisions by the Federal Council and the Federal Department of Transport, Communication and Energy; monitors nuclear waste disposal projects by third parties.
Paul Scherrer Institute	Nuclear waste disposal research; processing of radioactive wastes from medicine, research and industry.

The schedule outlined below for a high-level waste disposal facility assumes that reprocessed spent fuel will be returned to Switzerland commencing in 1992 at the earliest and will then go to interim storage for approximately 3 decades to allow for a decrease in heat production.

1985: Regional bedrock investigations; desk studies on sediment-sites

1993: Selection of one site (crystalline or sediment) for further investigation

1998: Application for an underground rock laboratory of the repository site

2010: Results of final site characterization

2010: Start engineering and construction of a Swiss repository (or participation in an international project)

2020: In service.

7.3 - Waste Quantities and Packaging

Waste quantities were calculated on the basis of 6,000 MW of installed electrical capacity at eight nuclear plants with an average lifetime of 40 years. This results in a total of 7,860 Mg of nuclear spent fuel. Present plans are to reprocess this waste outside Switzerland. It will eventually be returned, solidified in borosilicate glass, in 5,895 containers representing a total gross volume of 1,120 cubic metres (NAGRA, 1985).

However, this does not preclude the possibility of the direct disposal of spent fuel without reprocessing. Switzerland's high level waste repository is also being designed to accept transuranic intermediate level waste (NAGRA, 1985).

As of mid-1984, 480 Mg of spent fuel had been produced in Switzerland, of which 295 Mg had been shipped outside the country for reprocessing.

The cast steel repository canisters (Figure 7.1) selected for the encapsulation of high-level wastes in Switzerland are designed to withstand chemical, radiological and mechanical conditions for a minimum lifetime of 1,000 years. The design comprises a cylindrical body with hemispherical base and welded hemispherical lid with walls 250 mm thick. A corrosion allowance of 50 mm represents almost double the thickness necessary on the basis of empirical findings. The remaining 200 mm wall thickness for mechanical strength was derived from standard methods of pressure vessel construction, and safety factors including the possible influence of corrosion-produced hydrogen or radiation damage (NAGRA, 1985).

7.4 - Interim Storage and Transportation

Interim storage of spent fuel elements at all Swiss nuclear power plants is in water-filled storage pools. A centralized interim storage facility is also being considered for high-level waste from reprocessing as well as spent fuel elements.

Spent fuel elements are presently transported to reprocessing plants (mainly in France, partly U.K.) using standard transport containers on road vehicles. No details regarding HLW transport to a final repository have yet been considered.

7.5 - Site Investigations

The crystalline rock (Bottstein granite) of northern Switzerland was originally chosen as the host medium because it has remained stable

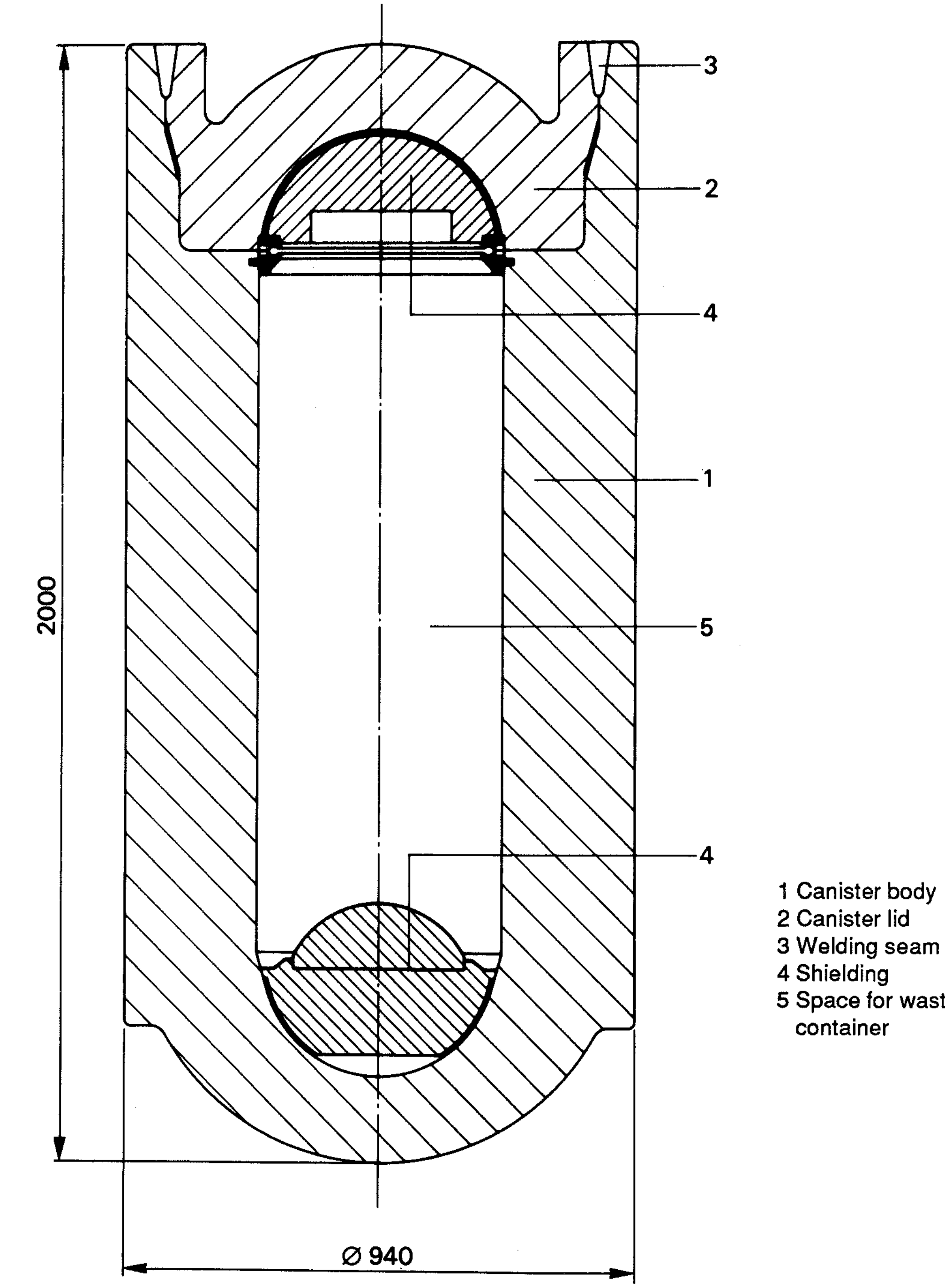

Fig. 7.1

FEARO

Switzerland's Steel Canister for Disposal of Vitrified High-Level Waste (Nagra,1985) over geological time periods, ensures a low water supply, and has favorable chemical conditions, i.e., reducing and near neutral ground-water (NAGRA, 1985). However the Swiss government now requires that site investigations include sedimentary as well as crystalline rock formations (NEA, 1988).

No specific sites have yet been selected for investigation. However, Switzerland does have an underground research laboratory in crystalline rock called the Grimsel Test Site (GTS) which was commissioned in 1984. Research activities are conducted in a tunnel system located 400-500 m below the surface and include geophysics, rock mechanics, thermal effects, hydrogeology and radionuclide migration (NEA, 1988a).

The final phase of the investigation program is scheduled for the period 1995 - 2010 and is expected to result in a final site choice and commencement of construction.

7.6 - Repository Design

The layout of Switzerland's nuclear waste repository is shown in Figures 7.2 and 7.3. It is designed on two levels for HLW disposal in horizontally mined tunnels and has provision for the disposal of intermediate level wastes in a separate area comprising vertical silos.

The repository consists of the following facilities as described by NAGRA (1985)

- the surface reception area where the waste is delivered, stored and encapsulated in thick-walled repository canisters;

- two independent vertical shafts;

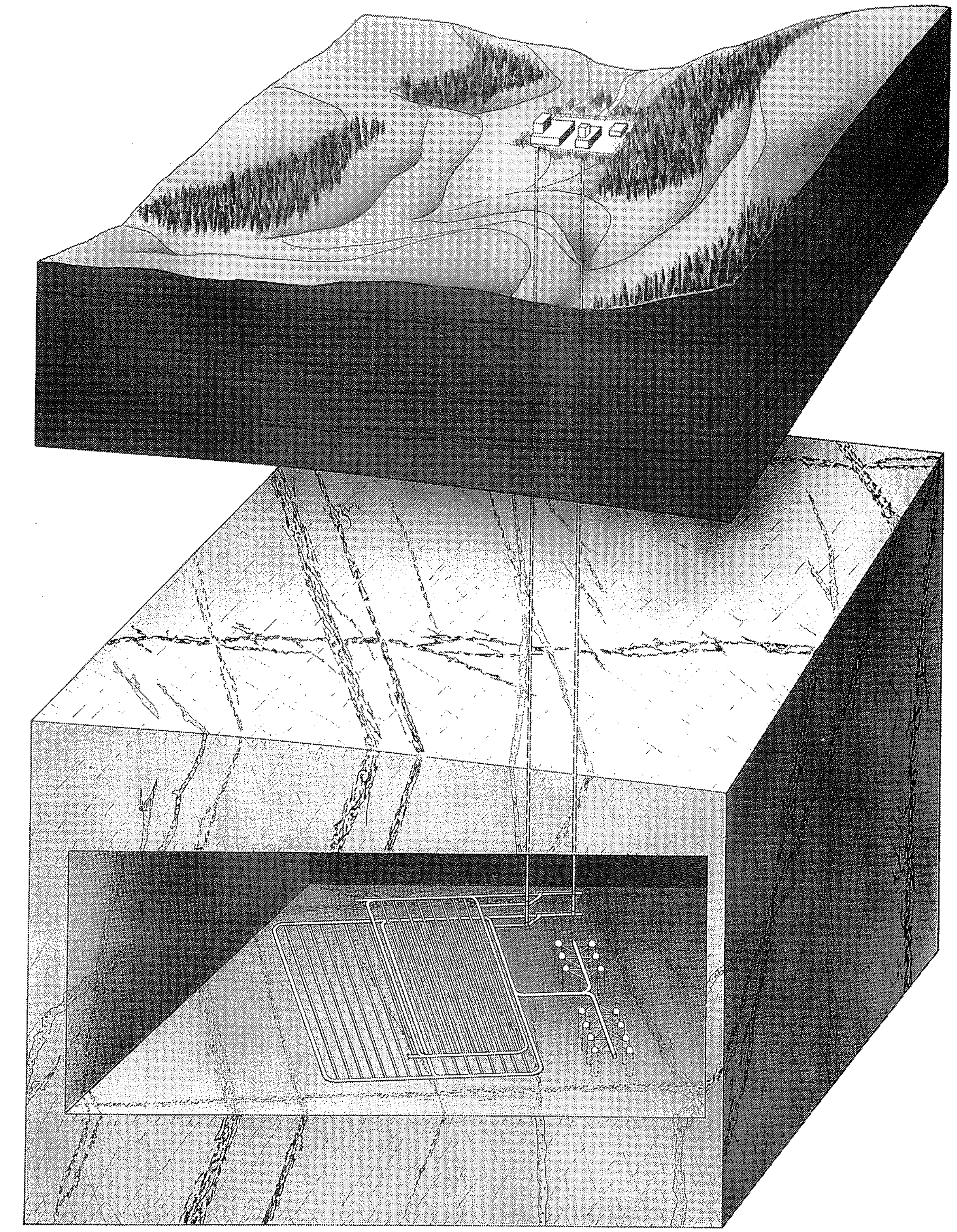

Fig. 7.2

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Overview Perspective of Switzerland's High-Level Waste Repository (Nagra, 1985)

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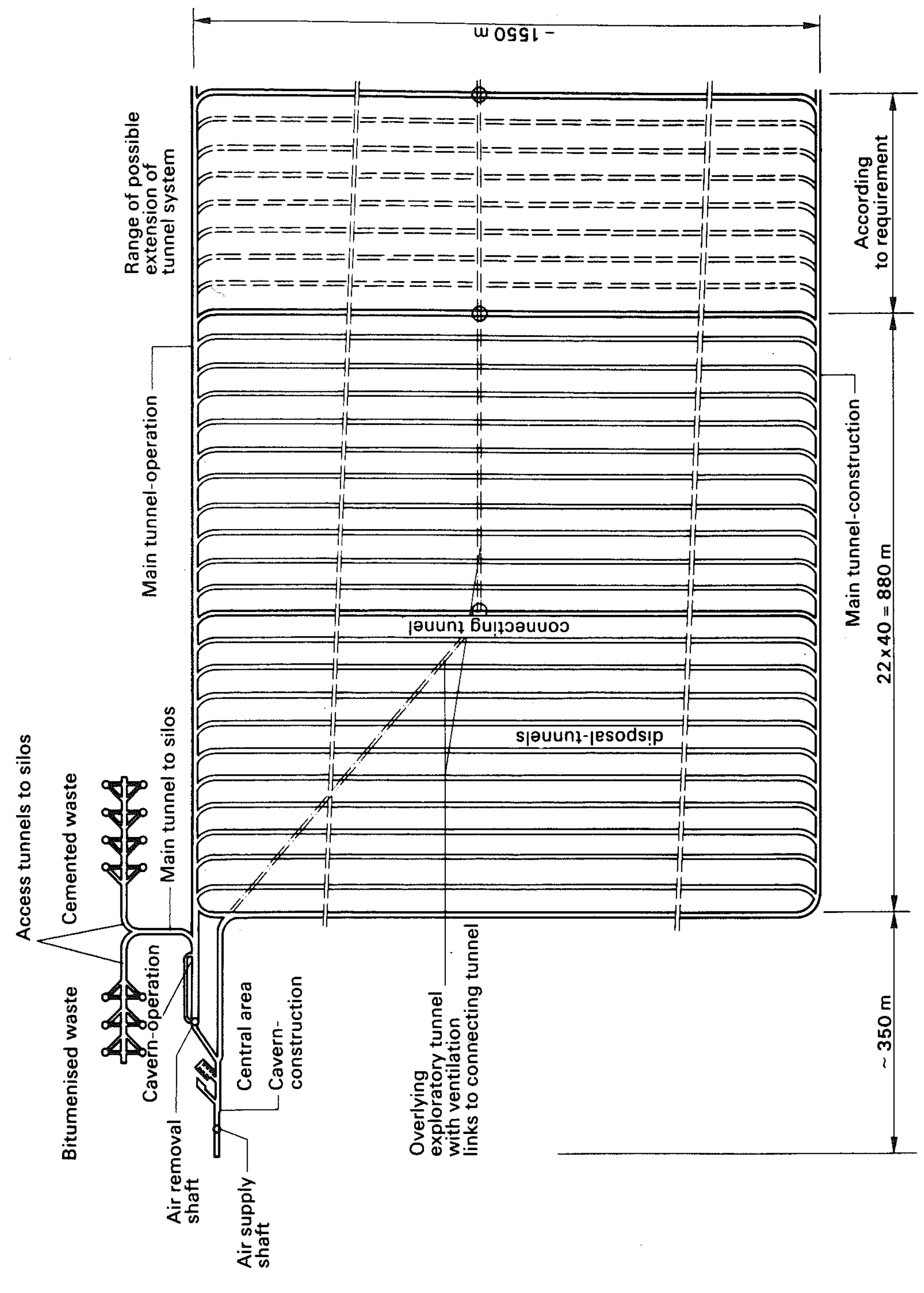


Fig. 7.3

FEARO

Schematic Lay-Out of Switzerland's High-Level Waste Repository (Nagra, 1985)

- the underground central area at a depth of around 1200 m, consisting of two large caverns, one for construction activities and the other for emplacement operations. A tunnel with a bulkhead connects the two caverns. The auxiliary installations required underground are also found in the central area;

- the two main tunnels which surround the repository area for high-level waste. They are sufficiently large to accommodate transport vehicles. These main tunnels are completed before the commencement of waste emplacement;

- the parallel repository tunnels which are mechanically excavated. These tunnels have a circular profile of 3.7 m diameter and lining is not envisaged. The high-level waste is placed in the tunnels at 5 m intervals and the remaining space is sealed with bentonite backfill;

- the repository silos in a separate area for the disposal of intermediate-level wastes.

The areal heat loading is assumed to be 2.5 watts/square metre based on emplacement of reprocessed high-level wastes.

The system of safety barriers for Switzerland's high-level wastes is graphically shown in Figure 7.4. If subsequent safety evaluations prior to final closure indicate that retrieval of the waste would be desirable, it is acknowledged that it would be technically rather difficult, but possible, and would involve high economic expense and significant radiation doses to operating personnel (NAGRA, 1985).

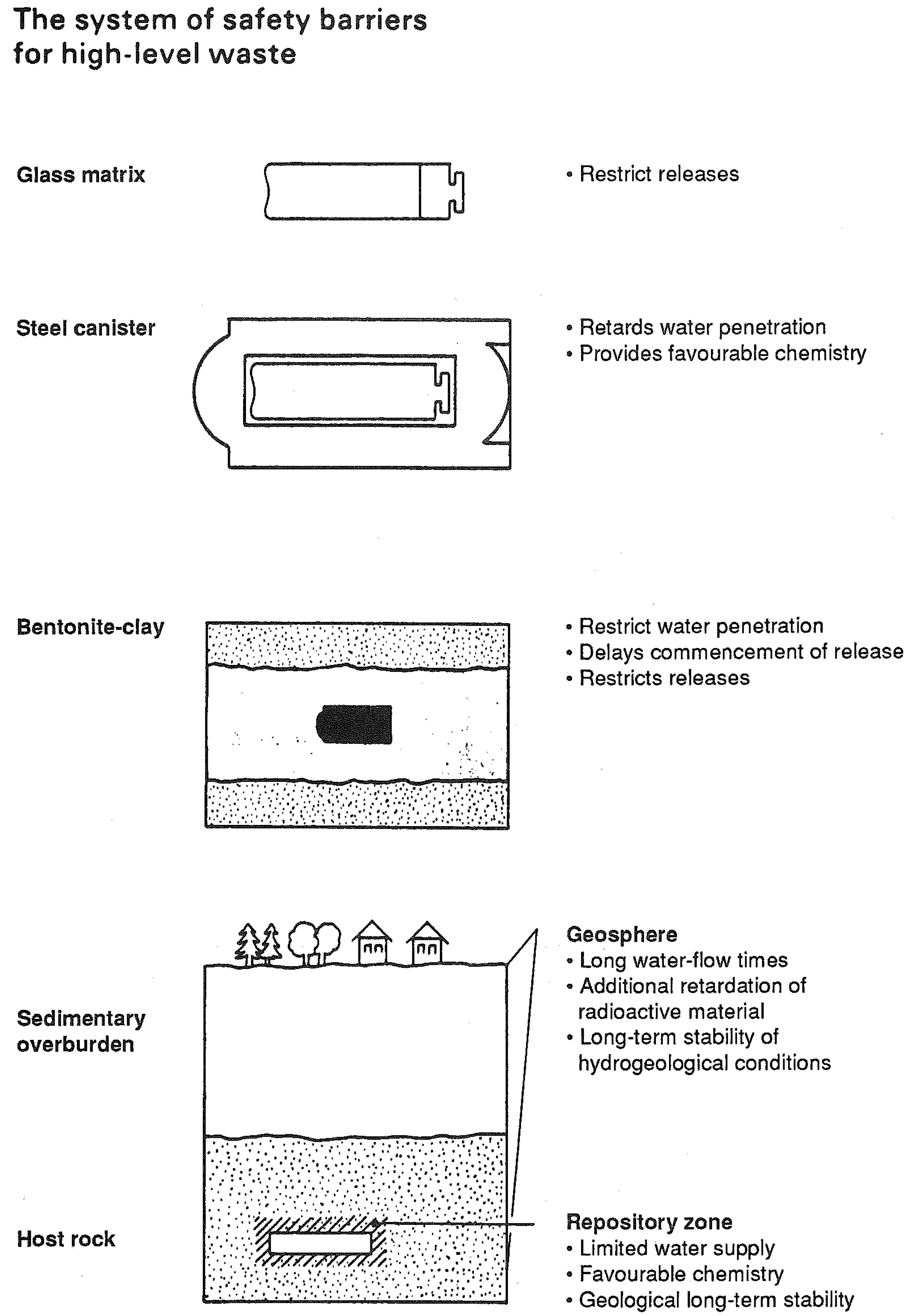


Fig. 7.4

FEARO

Switzerland's Safety Barrier System for High-Level Wastes (Nagra, 1985)

7.7 - **Impact Analysis**

Swiss scientists have carried out their own research and reviewed the international literature to determine specific effects on their proposed high-level waste repository. Investigations have centered on three main areas

- waste-induced impacts
- impacts from natural processes/events
- future disturbance of the repository by man.

With regard to waste-induced impacts, the integrity of their proposed steel canisters has been evaluated in terms of corrosion potential and mechanical stresses. The results of the impact analyses indicate that a steel canister with 250 mm thick walls will ensure safe containment for at least 1000 years.

Bentonite as a backfill was also evaluated and found to minimize waste-induced impacts due to numerous favorable properties (NAGRA, 1985). As a result of this analysis it is believed that bentonite properties will endure for the life of the repository (greater than one million years) (NAGRA, 1985).

The impacts of climatic changes, volcanic activity, tectonic movements, earthquakes, and meteorites have also been reviewed. None of these factors was considered to jeopardize the integrity of the Swiss repository (NAGRA, 1985).

The potential for radionuclide transport via groundwater to the biosphere has also been investigated. The resulting maximum radiation doses that might be expected are orders of magnitude lower than both natural radiation exposure and the official limit of 0.1 milliSieverts/year set by safety authorities. This can be compared

Switzerland has also reviewed the potential for exposure through the possible sinking of future wells for water supply. Using a worst case scenario with minimum dilution, the resultant radiation doses are considered insignificant. Deep drilling for drinking water into the repository is not realistic since even the permeable zones carry little water at depth (NAGRA, 1985).

The effects of construction and operation of the repository on surrounding communities are unknown at this time.

Future impact analyses will concentrate on additional corrosion tests, water uptake and gas transport in compacted bentonite, the integrity of bentonite-quartz sand mixtures, and hydrogeological and rock mechanical properties of the host rock.

7.8 - **Monitoring**

Monitoring of hydrogeological and rock mechanical properties are planned for a provisional site during the period 1995 - 2010. This will ultimately determine final site suitability. Once the repository becomes operational long-term monitoring over several decades is planned to observe the materials used in the repository prior to final closure. This includes monitoring the radioactive contents of the waste containers, and quality control monitoring, e.g., to replace defective canisters or to decontaminate container surfaces, etc (NAGRA, 1985).

A postclosure monitoring program is not presently envisaged since it is assumed that safety and surveillance measures will not be required once the repository is sealed.

7.9 - **Switzerland's Licensing and Regulatory Requirements**

The licensing procedure for nuclear installations (including radioactive waste repositories) is outlined in Switzerland's Atomic Energy Act (Egloff, 1987).

General License

The license application must include a site description, the main features of the project, storage capacity, waste categories, and the approximate form of underground or surface construction.

The license application documents are available for public review in the canton where the site is located, adjacent communities and the Federal Energy office. In addition to soliciting comments on the repository and site from cantons, the public and specialized services of government, the Swiss Federal Council invites opinions on the implications to national security, compliance with international law, protection of the population, other people's property and/or rights, including protection of the environment. All parties have 90 days to comment on the license application.

Once a general license has been granted or refused, there is no provision for appeal.

License to Construct a Nuclear Installation (Repository)

Following the granting of a general license, the applicant submits a technical (safety) report about the planned installation to the Federal Department of Transport, Communications and Energy.

The Department forwards this application, together with the safety report, to the Federal Commission for the Safety of Nuclear Installations. This Commission gives its opinion as to whether all the

the necessary and foreseeable safety measures, in the light of the current state of science and technology for the construction and operation of nuclear installations, have been taken for the protection of the population, property and important rights. The canton in which the site is located adds its opinion to that of the Commission. The Federal Council than takes the final decision.

Operating License

Construction of a repository proceeds under the permanent surveillance of the Swiss Confederation, until it is ready for trial operation, which requires a special license.

If the trial operation gives rise to no objections, the operating license can finally be granted. The repository remains under constant surveillance during operations.

In addition to the above, Swiss repositories are subject to a guideline which limits radiation doses to a maximum of 0.1 milliSieverts/year from radionuclides escaping from sealed repositories.

7.10 - Disposal Concept Assessment

Project Gewähr represents Switzerland's equivalent of Canada's concept assessment process. The most recent review of Project Gewähr was published in December 1986 and was carried out by three government bodies: the Nuclear Safety Inspectorate, the Nuclear Safety Commission and the Geological Subgroup of the Working Group for Waste Disposal. These authorities used Swiss and foreign experts in their review.

The reviews were generally positive and demonstrated that safe disposal of HLW is achievable. As a result the Swiss government, on June 3, 1988, confirmed that the feasibility of safe disposal of HLW had been demonstrated and authorized site selection investigations to proceed but requested sedimentary as well as crystalline rock formations be evaluated (NEA, 1988).

8 - UNITED STATES

8 - UNITED STATES

The United States has had an active and very well-funded research program to study nuclear waste disposal for over 30 years. Over this period a wide variety of disposal technologies and host media have been investigated. There are two distinct nuclear waste repository programs underway. The civilian HLW repository program is presently concentrating on the Yucca Mountain tuff site in Nevada, while the US Department of Defense Programs is completing construction of its Waste Isolation Pilot Plant (WIPP) in a salt formation near Carlsbad, New Mexico. The latter facility is intended only for defense transuranic wastes. Present plans are that all HLW from both civilian and defense programs will be disposed together in one or more permanent geologic repositories.

8.1 - Key Organizations

The Department of Energy (DOE) is responsible for storage and disposal of nuclear waste in the US. Within the DOE, there are two agencies responsible for civilian and defense nuclear waste programs: the Office of Civilian Radioactive Waste Management and the Office of Defense Waste and Transportation Management, respectively.

The US Nuclear Regulatory Commission (NRC) is responsible for licensing civilian HLW repositories. The US Environmental Protection Agency (EPA) also plays a key role through its regulatory requirements for nuclear waste management and disposal (see Section 8.9).

8.2 - Schedules

A schedule for site investigations and environmental studies at the Yucca Mountain (Nevada) site is outlined below (NEA, 1988a).

1989 - Construction and testing at Exploratory Shaft Facility

1993 - Draft Environmental Impact Statement

1994 - Site selection and Final Environmental Impact Statement

1995 - Repository Licence Application

1998 - Repository Construction

2003 - Repository Phase I Operations

Construction of the WIPP repository for transuranic defense waste in a salt formation near Carlsbad, New Mexico is underway. The first radioactive waste shipments were originally scheduled for October 1988 but are now due to be delivered in 1989 (NEA, 1988a).

The WIPP site will serve as a research and development facility for the first 5 years (1989 - 1993) of operations. A determination will then be made as to whether the site can be used for disposal of transuranic waste (Tillman and Hunt, 1988). Decommissioning of the WIPP site is presently scheduled for the year 2006 (Chaturvedi et al, 1988).

8.3 - Waste Quantities and Packaging

As of January 1, 1988, there were 109 nuclear reactors totalling 97,200 MW of generating capacity in the US. These units supplied approximately 18% of the electricity generated in the United States during 1987 (Sparrow, 1988).

It is projected that 106,000 Mg of civilian spent fuel and 8,000 Mg of defense high level wastes will be generated in the United States to the year 2020. The spent fuel from power reactors is presently placed in

interim storage at the reactor sites without commercial reprocessing. However, transuranic and HLW from the US defense program are being reprocessed at three facilities: the Savannah River Laboratory (South Carolina), the Hanford site (Washington), and the Idaho National Engineering Laboratory. Reprocessing involves vitrification into borosilicate glass followed by encapsulation in stainless steel canisters. Vitrification into a glass/ceramic is also being evaluated since the glass/ceramic waste form can contain two to three times higher waste loading than glass (Wodrich and Bracken, 1988).

8.4 - Interim Storage and Transportation

As in Canada, spent fuel in the US is primarily stored at the reactor sites in large water-filled pools. However, the existing pools are running out of space and the US Department of Energy has implemented a Federal Interim Storage program. Its objective is to maximize the use of existing at-reactor capacity. Prime responsibility rests with the owners and operators of the power plants; the federal government has the responsibility to encourage and expedite efficient use of, and additions to, such capacity. The government also must provide storage under certain limited circumstances (DOE, 1989).

Dry modular storage methods are currently considered to be the most flexible. Demonstration dry storage facilities are located primarily at the Idaho National Engineering Laboratory. In order to protect the fuel from oxidation, it is stored in large modular cast-iron or forged-steel storage casks in sealed inert atmospheres (usually helium).

A major, central storage site, named Monitored Retrievable Storage (MRS), is planned for civilian spent fuel. Originally recommended for Tennessee, site selection has now been broadened; conceptual design and site selection studies are currently underway. Spent fuel will be shipped from most nuclear power plants to the MRS for consolidation, uniform packaging and then reshipment, principally by dedicated trains, to the ultimate repository site (Barrett, 1987).

The OCRWM is developing a transportation system for shipping spent fuel and reprocessed HLW to storage and disposal facilities (Barrett, 1987). The primary equipment requirement is a fleet of up to 300 transportation casks. These fall into four categories: casks for moving used fuel from reactors to the MRS (or direct to a repository); casks for moving fuel from the MRS to the repository; casks for nonstandard fuel and components; casks for defense reprocessed HLW. The first prototype casks for the first category are scheduled for 1993.

For shipping wastes to the WIPP facility, the Transuranic Package Transporter was developed. It consists of three cylindrical containers on a lightweight trailer that can carry a maximum of 42 drums with a payload of 9.5 Mg. A composite stainless steel and solid foam envelope surrounds two stainless steel containment vessels (Tillman and Hunt, 1988).

8.5 - Site Investigations

8.5.1 - Civilian Program

Several host media have been investigated for a HLW repository in the United States including rock salt, basalt, granite, shale and tuff (solidified volcanic ash) (Hustrulid, 1982). At the present time tuff, basalt and salt are considered potentially suitable host rocks. Tuff has a high ion-exchange capacity and occurs in tectonically stable areas.

Nine potentially acceptable sites were identified in 1983 and subsequently evaluated. This exercise produced three candidate sites in 1986 for more detailed investigations: the Yucca Mountain tuff site (Nevada), the Deaf Smith salt site (Texas) and the Hanford basalt site (Washington).

In December 1987, the Yucca Mountain welded tuff site was selected for further investigations and the other two sites were closed in early 1988. This decision was largely influenced by the fact that Yucca Mountain is located in the Nevada Test Site, a federally-owned property, where considerable radioactivity occurs (elsewhere on the site) due to nuclear weapons testing. Important technical factors are the dry climate and extremely deep groundwater table (below the proposed repository location).

Surface-based evaluations have been carried out at Yucca Mountain for several years and underground testing in an Exploratory Shaft Facility is expected to commence in June, 1989 (Issacs, 1988).

Research is also underway in the United States on the potential for subseabed disposal of high-level radioactive waste and spent fuel (NEA, 1988).

The US has conducted considerable research in underground, in-situ laboratories. Some of these have involved the use of spent nuclear fuel. Project salt vault was conducted in the 1960s in bedded salt in the Lyon's Mine, Kansas (Bradshaw and McClain, 1971). The US was formally involved in Sweden's Stripa mine project (Rippon, 1987). A sophisticated research project was performed at the granitic Climax Stock, Nevada (Butkovich et al, 1982). Heater-tests and related geomechanics and hydrogeologic experiments have been performed at the Near-Surface Test Facility located in basaltic rocks in Washington State (Edwards et al, 1981). The US also contributed funding to, and actively participated in, Canada's underground research laboratory until mid-1988 when these activities were terminated due to congressional action.

8.5.2 - Defense Program

Rock salt was selected as the host medium for the WIPP defense repository for transuranic wastes because of its favorable characteristics and the long history of salt research in the US.

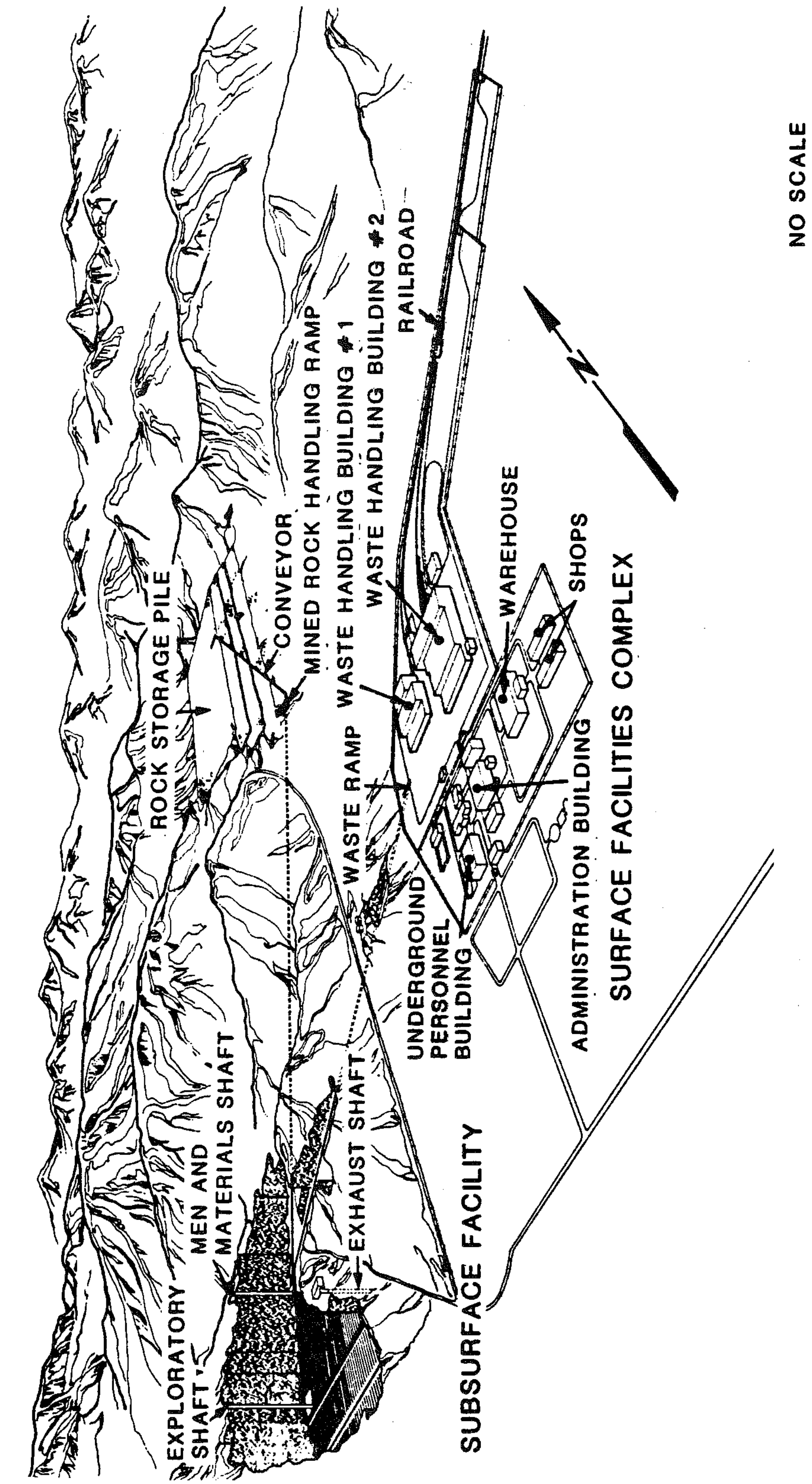
8.6 - Repository Design

8.6.1 - Yucca Mountain Repository

A repository design for the Yucca Mountain tuff site is shown in Figures 8.1 and 8.2. It is anticipated that it will have a capacity of 70,000 Mg of waste (spent fuel, vitrified reprocessing wastes and defense HLW) and is scheduled to commence in the year 2003. It is being designed to isolate radioactivity for at least 10,000 years. Located on one level at a depth of about 300 m the repository will be located above the water table. Four shafts and two ramps will connect the surface and underground facilities. Waste containers will be placed (singly) into vertical boreholes located in a grid of tunnels. An alternative concept of using long horizontal boreholes (for multiple container emplacement) drilled from the underground tunnels is also being considered (DOE, 1988).

8.6.2 - WIPP Defense Repository

The WIPP repository in southeastern New Mexico is located at a depth of 855 m in the lower part of a 600-m thick salt formation. The size of the repository is about 50 hectares and is located



FEARO Fig. 8.1 ACRES

Yucca Mountain HLW Repository Surface Facilities (US DOE,1986)

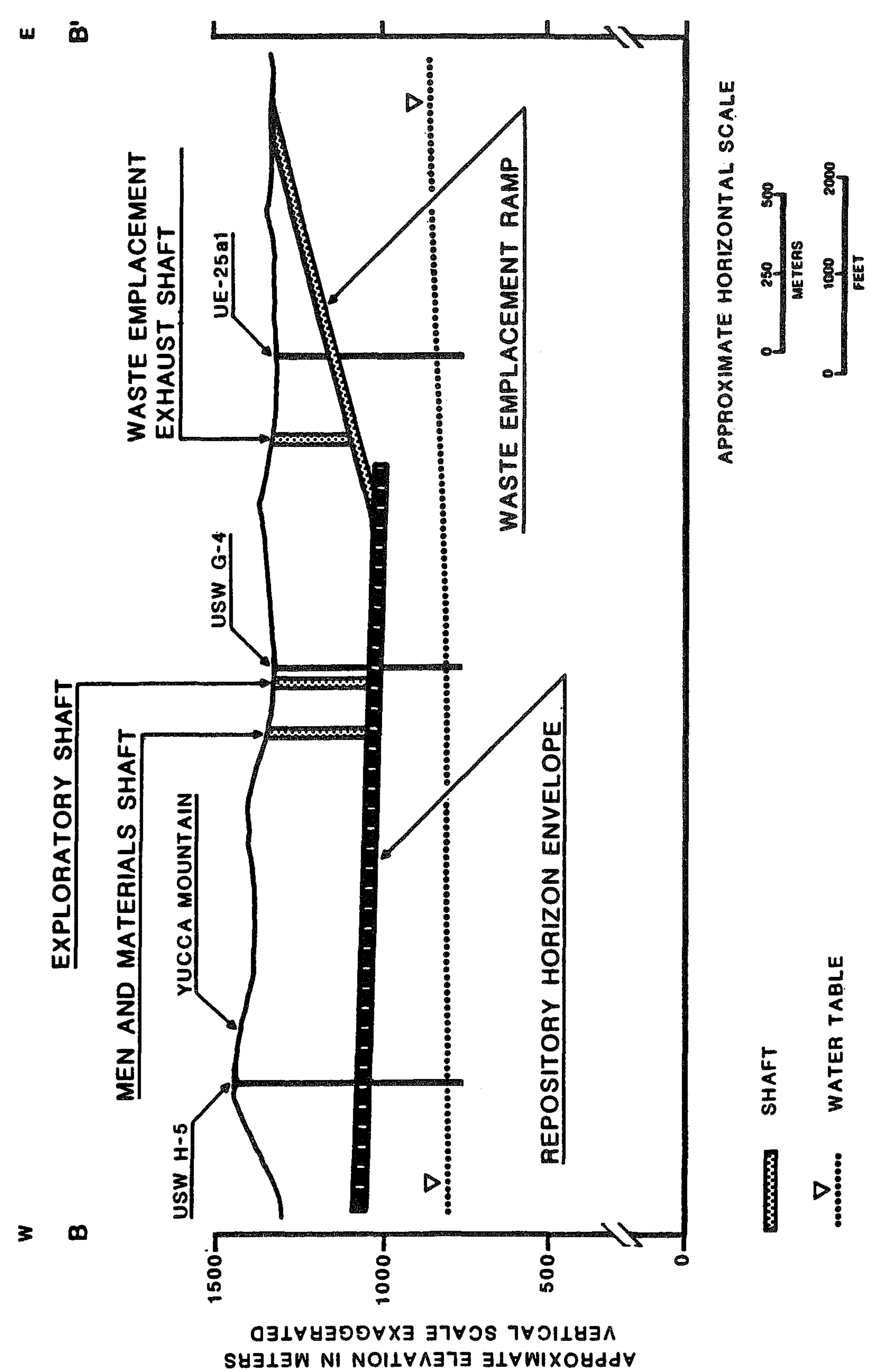


Fig. 8.2

FEARO

Yucca Mountain HLW Repository Subsurface Facilities (US DOE,1986)

within an 800-hectare area that has been reserved for further expansion. The repository consists of eight panels (91 m x 10 m x 4 m) with seven rooms in each panel (Figure 8.3). The contact-handled transuranic waste is stored in 208-litre drums stacked three high in the rooms and in the drifts connecting the rooms and in boxes.

The remote-handled transuranic waste will be disposed in 0.9 m diameter horizontal holes in the walls of most of the rooms (Chaturvedi et al, 1988).

The repository is designed to handle 156,000 cubic metres of contact-handled transuranic waste and 4,250 cubic metres of remote-handled waste.

In addition, 28 cubic metres of defense HLW will be placed in the repository for experimental purposes but will be retrieved prior to decommissioning (Chaturvedi et al, 1988).

All wastes in the WIPP repository are presently being retrievably stored until a decision is made on whether the facility can be used for permanent disposal of transuranic wastes. The wastes are being stored without backfill to allow easy retrieval for 5 years. The drum-filled rooms were initially going to be back-filled until it was found that salt deformation rates were actually 3 - 5 times larger than computed values. Therefore, to avoid the potential for crushing and breaching a decision was made to delay backfilling, thereby allowing easy retrieval of the drums (Chaturvedi et al, 1988).

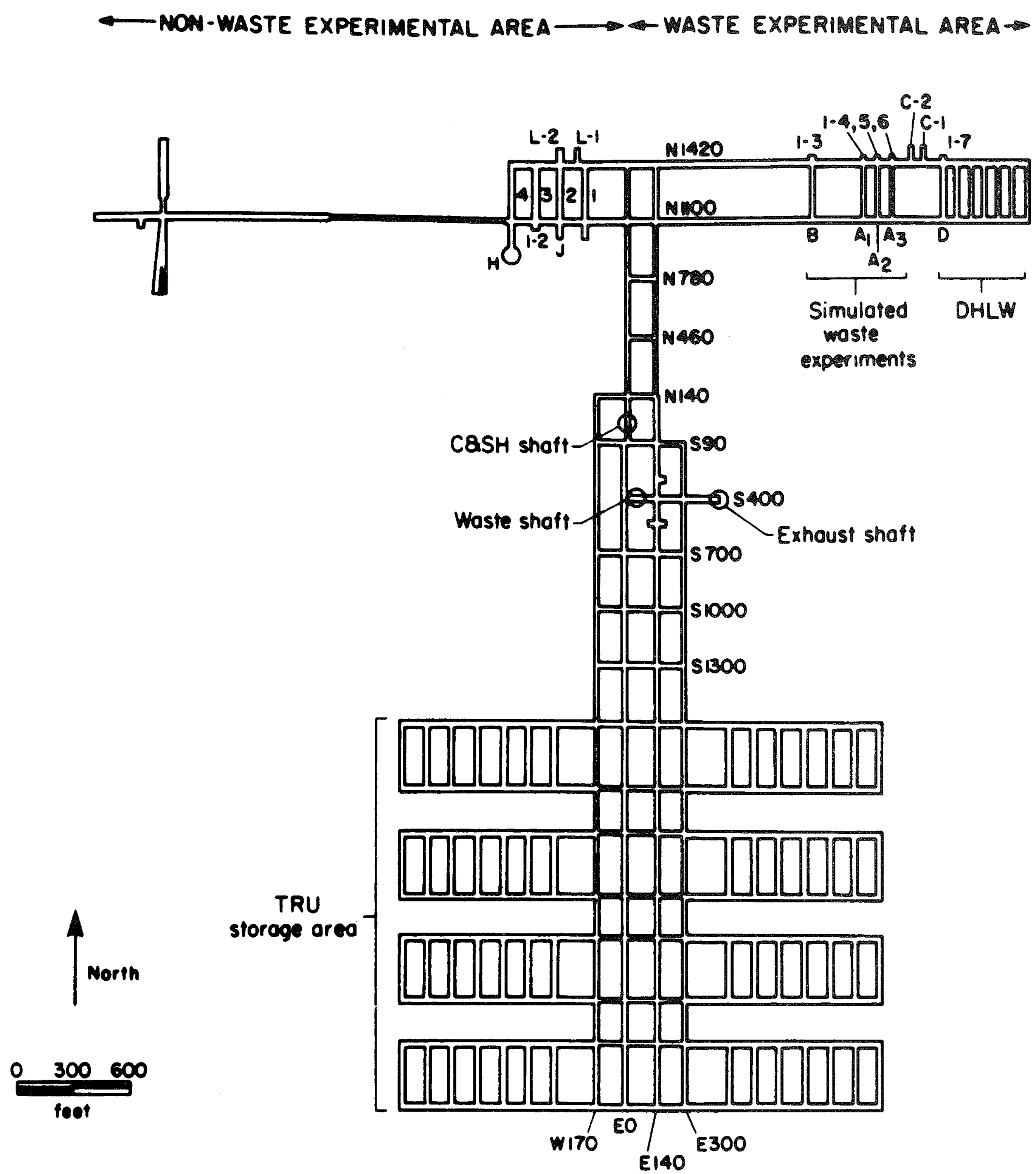


Fig. 8.3

FEARO

Underground Layout of the WIPP Repository and Experimental Area (Chaturvedi et al, 1988)

8.7 - Impact Analysis

8.7.1 - Civilian Program

Since the Site Characterization Plan for the proposed Yucca Mountain repository was only issued in 1988, the impact analysis is yet to be carried out. Investigations will centre on basic geological phenomena, rock mechanics, groundwater flow and waste package/barrier interactions. The prime focus will be on understanding the groundwater conditions. A draft Environmental Impact Statement is scheduled for 1993 which will include a socioeconomic assessment.

8.7.2 - Defense Program

An Environmental Evaluation Group was established in 1978 to independently evaluate the WIPP project for the state of New Mexico. The group has made numerous recommendations over the 10-year period including relocation of the repository when a brine reservoir estimated to be 5 to 17 million barrels was intercepted at the original planned location for the repository (Neill, 1988).

An Environmental Impact Statement was prepared and monitoring programs are on-going to continually assess environmental impacts. Recent observations of brine inflow from the salt rock into the repository excavations indicate that the repository may become saturated with brine in a few hundred years after closure. Since the waste containers are ordinary drums that will become corroded and breached within a few tens of years, the brine could form a slurry of waste in the repository rooms. Possible engineering solutions to prevent the problem include reprocessing each drum to reduce the void space and inclusion of cement or chemical grouts in the backfill (Chaturvedi et al, 1988).

With regard to socioeconomic impacts, the WIPP site currently provides approximately 620 jobs, 60% of which are filled with locally hired personnel. The US $22 million WIPP payroll significantly adds to the tax base supporting schools, roads, and other public services (Tillman and Hunt, 1988).

8.8 - Monitoring

The civilian HLW repository program is not sufficiently advanced for any monitoring programs to be in place at the present time. However, the WIPP defense repository has a Preoperational Environmental Monitoring Program that has been ongoing for several years. It includes both radiological and nonradiological environmental surveillance activities (Tillman and Hunt, 1988).

8.9 - US Repository Licensing and Regulatory Requirements

In licensing the US HLW repository, the NRC has four approval stages: site characterization, construction authorization, repository licensing and repository decommissioning.

The basic criteria to be met are summarized as follows:

- The geohydrologic setting and geochemical characteristics of a site shall be compatible with waste containment and isolation.

- The characteristics of the host rock shall be capable of accommodating the thermal, chemical, mechanical and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interaction among the waste, host rock, groundwater and engineering components.

- The site shall be located where future climatic conditions will not result in radionuclide releases greater than those allowed by regulation.

- The underground facility shall be placed at a depth such that erosional processes at the surface will not lead to radionuclide releases greater than those allowed by regulations.

- Any subsurface rock dissolution will not lead to radionuclide releases greater than those allowed by regulations.

- Future tectonic processes or events will not lead to radionuclide releases greater than those allowed by regulations.

- The site shall be located such that the natural resources, including groundwater, present at or near the site will not give rise to activities that would lead to radionuclides releases greater than those allowable under regulations.

- The site shall be located on land for which the DOE can obtain ownership, surface and subsurface rights and control of access. Potential surface and subsurface activities will not lead to radionuclide releases greater than those allowed under regulations.

In order to receive NRC licensing, the repository must also demonstrate compliance with other regulatory requirements, including the EPAs Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes.

The WIPP defense repository did not require NRC licensing (Hunter, 1988). In the absence of NRC regulatory authority, the State of New Mexico's Environmental Evaluation Group is providing full-time technical review and oversight of the project. The WIPP site is also subject to EPA legislation including the standard noted above.

8.10 - Performance Assessment and Public Participation

The major focus of performance assessment activities for the HLW repository to date has been on the preparation of site characterization plans for three repository sites. However, in 1988 only the Yucca Mountain Site Characterization Plan was released. It contains a discussion of the strategy for using performance assessment to demonstrate compliance with the regulations.

Environmental and socioeconomic plans for the Yucca Mountain site have also been prepared. All of these plans are subject to intensive technical and public review. Workshops are planned with the State of Nevada and NRC which will be open to the public. Public hearings are also planned prior to the proposed June 1989 commencement of exploration work at the Yucca Mountain site (Issacs, 1988).

At the WIPP defense repository site in New Mexico, the US Department of Energy does not plan to complete its performance assessment work to assess compliance with EPA standards until 1993 (Chaturvedi et al, 1988). There is also a comprehensive Public Information Program underway for the WIPP site which includes media contacts, site tours, public information presentations and displays (Tillman and Hunt, 1988).

The United States also participates as a member of the Performance Assessment Advisory Group of NEA which reviews recent developments in member countries.

9 - OTHER COUNTRIES

9 - OTHER COUNTRIES

9.1 - Australia

Australia has no nuclear power reactors and very limited production of nuclear wastes. Research at the present time is concentrated on the Koongarra uranium ore deposit in the Northern Territory. The object of the research is to investigate the long-term physical and chemical processes likely to influence the transport of radionuclides through rock masses. The project is proceeding under the auspices of NEA and is managed by the Australian Nuclear Science and Technology Organization. Project participants are the Japanese Atomic Energy Research Institute, the Swedish Nuclear Power Inspectorate, the United Kingdom Department of the Environment, the US Nuclear Regulatory Commission and the Power Reactor and Nuclear Fuel Development Corporation of Japan (NEA, 1988).

9.2 - Austria

As a result of a referendum in November, 1978 all activities related to nuclear energy have been discontinued.

9.3 - Denmark

The introduction of nuclear power in Denmark is conditional on the two major utility groups demonstrating that geological formations suitable for radioactive waste disposal exist in the country. The feasibility of nuclear waste disposal in salt domes has been considered and a preliminary safety assessment for a repository in a salt dome has been performed. The sorption of selected radionuclides by a variety of clay minerals has also been investigated.

9.4 - Finland

In Finland, the utilities have financial and operational responsibility for nuclear waste management. However, the Ministry of Trade and Industry controls the planning and implementation of nuclear waste management measures, and nuclear safety is the responsibility of the Finnish Centre for Radiation and Nuclear Safety.

Currently, approximately 100 potential sites are being investigated in Finland with the intention of selecting one by 2000 and commencing repository operations in 2020.

Finland has four light-water reactors with a capacity of 2300 MW. In 1987 37% of all electricity produced in Finland was generated by nuclear power. Spent fuel from two of the reactors will be returned to Russia, who supplied the reactors and fuel. Approximately 1270 Mg from the other two reactors will go into the Finnish repository. There are presently no plans for reprocessing of the enriched spent fuel.

Present plans are to construct a one-level repository in crystalline rock of the Precambrian Shield at a depth of about 500 m. Spent fuel will be encapsulated in copper canisters, and the spaces in the canisters will be filled with molten lead or lead shot. The canisters will be placed in boreholes drilled in the floors of tunnels and the boreholes will be backfilled with highly compacted bentonite. On closure the tunnels will be backfilled with a mixture of sand and bentonite.

The impact analyses covered defects in technical barriers, potentially unfavorable geologic or biospheric changes and disruptive events (e.g., faulting, human intrusion, etc). None of the scenarios resulted in higher individual dose rates than the dose limit of 0.1 milliSievert/year adopted by the safety authority.

9.5 - Italy

Waste management policy regulations and the licensing of repositories are the responsibility of the National Nuclear Regulatory Body under the Ministry of Energy. Operational responsibilities for the management of radioactive wastes lie with the National Electricity Board (ENEL), the largest producer of radioactive waste, who has formed Nucleco to manage these matters.

Italy has four nuclear power stations with a total capacity of 1472 MW. However, none of these stations is operating at the present time. A fifth nuclear power station with 2000 MW capacity was under construction but the government has decided to convert it to a fossil-fuel plant. A decision was made in November 1987 to delay the construction of nuclear power plants for 5 years while the National Energy Plan is being reexamined and reformulated.

It is estimated that 2500 Mg of vitrified waste will accumulate by the year 2025. Spent fuel is stored in water-filled pools at the reactor sites until it is reprocessed in the UK.

After the HLW is vitrified at foreign plants it will be placed in a centralized interim storage facility in Italy for 50 - 70 years. Italy has chosen clay formations as the host medium for their HLW repository because of its wide distribution. The clays are self-sealing, make an excellent barrier against radionuclide migration, and tend to adsorb seismic stresses. No potential sites have been selected for investigation. However, an underground research laboratory was excavated to a depth of 160 m but due to local opposition, all work has been suspended. Italy is also participating in international research on the potential for HLW disposal under the seabed.

On the basis of data collected to date HLW can be disposed either in a mined repository or in a matrix of deep boreholes drilled from the surface. The latter concept is favored because of its flexibility and lower costs. Also the repository design presents some concerns with the construction and support of tunnels at depths in Italian blue clays (Chapman and Gera, 1985).

9.6 - Japan

Japan's Atomic Safety Commission is ultimately responsible for licensing HLW repository facilities. The Power Reactor and Nuclear Fuel Development Corporation plays a key role in geological disposal technology in conjunction with the Geological Survey of Japan, and will also construct and operate a vitrification facility and construct storage facilities for the vitrified solids. The Japan Atomic Energy Research Institute carries out safety assessments on vitrified solids and other related matters.

Treatment (vitrification) and interim storage facilities for HLW are expected to be available in Japan in the 1990s. A firm schedule for the repository has not yet been developed but research activities are presently underway to select candidate disposal sites.

The nuclear power capacity of Japan in 1986 was 26,000 MW which is expected to increase to 53,000 MW by the year 2000. It is estimated that Japan will accumulate about 1100 Mg of spent fuel by the year 2000, increasing to 2000 Mg by the year 2030. Japan's nuclear waste management policy requires that all HLW be reprocessed.

A 5-year experimental program is underway at two mine sites in crystalline and sedimentary rocks. One is the Tono Sandstone uranium deposit and the other is the Kamaishi iron deposits in crystalline rock. Other sites are also being investigated in sedimentary and

crystalline rock. Eventually an underground research laboratory is planned for each rock type.

After solidification and interim storage for 30 - 50 years, the HLW will be placed in a repository several hundred meters underground. No design concepts for the repository have yet been published.

Since research and development activities are barely underway, no results on the impact analyses are expected to be available for several years.

9.7 - Netherlands

Th Central Organization for Radioactive Waste was established in 1982 and is responsible for the collection, management, interim storage and disposal of radioactive wastes. The utilities operating the Netherlands' two nuclear plants have the principal shareholdings in this organization with the state having a 10% share and right of veto (Rippon, 1987).

Generic feasibility and safety assessment studies on the potential for radioactive waste disposal in salt domes either underground or under the seabed off the Dutch coast have been carried out. As with all CEC countries, the Netherlands' has contributed to compilation of the "European Catalogue of Geological Formations Having Favorable Characteristics for the Disposal of Solidified High-Level and/or Long-Lived Radioactive Wastes".

9.8 - Norway

There are no nuclear power reactors in Norway although small amounts of low- and intermediate-level waste have been produced by two research reactors since 1951. At present there are no geologic disposal studies in Norway, but Norwegian experts participate in a number of joint Scandinavian research projects on waste management.

9.9 - Spain

The Spanish Nuclear Waste Management Authority was established in 1985. As of 1986, Spain had a nuclear energy capacity of 5,800 MW (Rippon, 1987).

In October, 1987 the Spanish government approved its first waste management plan which established two key principles in their HLW management program (NEA, 1988)

- direct disposal of spent fuel in a deep underground repository within any of three geological formations (clay, granite, and salt) available in Spain.

- a temporary storage facility will be required for spent fuel and other types of HLW until a deep underground repository is available. A mix of wet and dry storage techniques is foreseen.

9.10 - United Kingdom

NIREX (the Nuclear Industry Radioactive Waste Executive) was established in 1982 to implement the government's strategy for the disposal of low- and intermediate-level radioactive waste. NIREX's shares are held by the Central Electricity Generating Board, British Nuclear Fuels, South of Scotland Electricity Board and the United Kingdom Atomic Energy Authority. A special share is also held by the government.

NIREX has, as yet, no responsibility for the final disposal of HLW and the current UK policy is to maintain vitrified HLW in surface storage for at least 50 years (Mogg, 1988).

Commercial nuclear power stations have been operating since 1956 and provide about 20% of the electricity generated in the UK. The volume of HLW arising from the first stage of reprocessing spent fuel will total about 4000 Mg by the end of the century (Ginniff, 1986).

A vitrification plant is under construction at Sellafield which will transform HLW into borosilicate glass blocks which will be encapsulated in metal containers for surface storage until a HLW repository is developed.

The present emphasis in the UK is on finding a deep (200 - 1000 m) repository site (either land-based or under the seabed) for the disposal of low- and intermediate-level wastes. Host media being considered include hard rock (anhydrite and granite) as well as rock salt and clay.

No investigations for a HLW repository have yet been undertaken and no agency has yet been given this responsibility.

9.11 - U.S.S.R.

In the 1970s, radioactive waste disposal techniques in the U.S.S.R. consisted primarily of liquid waste injection into deep aquifers. However, this brought criticism from the western scientific community and the emphasis of research in this decade appears to be concentrating on deep geological formations, particularly rock salt. Other rock types being investigated include granite, clay, porphyrite, diabase and tuff. Information from the U.S.S.R. is very limited.

9.12 - Yugoslavia

This country has one 635-MW nuclear power plant which started operation in 1981. At the present time there is no repository in Yugoslavia but a temporary storage facility is located at the Krsko Nuclear Power Plant.

A low- and medium-level repository was scheduled to be constructed by 1991 but this schedule has now been adjusted to between 2000 and 2005 (Lovasic et al, 1988).

9.13 - Other Countries

Other countries which generate nuclear power, but whose waste management programs have not been discussed in this report, include Argentina, Brazil, Bulgaria, Cuba, Czechoslovakia, the German Democratic Republic, Hungary, India, Korea, South Africa and Taiwan.

10 - INTERNATIONAL COOPERATION

10 - INTERNATIONAL COOPERATION

10.1 - Cooperative Programs

There is a realization of the benefits and indeed necessity for international cooperation in the field of research and development on nuclear waste disposal. The most obvious benefit is an economic one, since duplication of effort can be avoided. In those instances where excavation and operation of underground facilities are involved the savings can be quite substantial. Keeping abreast of international development allows a nation to focus its program onto one specific geological medium, knowing that information concerning other media is available from other countries. This kind of exchange also feeds fresh perspectives into a program, thus permitting a broadening of ideas and research approaches. For these reasons there has been vigorous and very fruitful cooperation in international nuclear waste disposal research.

However, when it comes to the actual implementation of programs for the disposal of radioactive waste, there is a dogmatic insistence that each individual country develop its own disposal facilities. This was not always the case. There was a period in the 1960's when there was a good deal of interest in a European multinational fuel cycle center, including disposal facilities. However, with the rise of public agitation against all matters nuclear, it became impossible for politicians of any country to accept radioactive wastes for disposal from another country.

Much of the international cooperation is coordinated by several international organizations or is performed directly under their auspices. The main organizations are described in Section 10.2. However, a great deal of collaboration also takes place directly through bilateral arrangements. Due to the multitude of these only the main ones are described briefly here.

One of the prime examples of international cooperation to date has been at Stripa Mine, Sweden, an abandoned iron mine in granitic rocks. In 1977 the US and Sweden initiated a series of experiments using electric heaters to simulate nuclear wastes. Hydrogeologic, geophysical and buffer/backfill experiments were also performed. A second phase of research was undertaken under the auspices of NEA from 1980 to 1984 involving eight countries. A third phase of research is currently in progress. Involving seven countries, it will be completed in 1991.

Cooperative work has taken place at most of the major underground testing facilities such as at Mol, Belgium, and Asse, Germany. Sweden, the US and Japan have been involved in Canada's underground research laboratory. In addition, many countries have bilateral agreements with other countries for exchange of information.

Sweden has managed a number of international projects since 1981 for the evaluation of conceptual and mathematical models for radionuclide and groundwater transport in the geosphere. These projects are INTRACOIN, HYDROCOIN and most recently INTRAVAL.

10.2 - International Organizations

A number of international organizations are involved in promoting cooperation in the field of nuclear waste disposal and are discussed below. These organizations are more important in the European scene than in other parts of the world. This is due mainly to the Commission of European Communities.

The Commission of European Communities (CEC) has a geologic disposal program consisting of two components. The first is a direct action program consisting of R&D activities, aimed primarily at performance

assessment, carried out at their Joint Research Center at Ispra, Italy. Some programs are managed directly from CEC headquarters in Brussels. The second component is the indirect action program which contributes financially to the activities of CEC countries. Because it has financial input, the CEC has considerable influence in European waste disposal research. The PAGIS project (Performance Assessment of Geological Isolation Systems), conducted over a 6-year period, was completed in 1987. Using data from reference sites in clay, granite, salt and the sub-seabed, the general capability of waste disposal systems to confine radionuclides was assessed.

The International Atomic Energy Agency (IAEA) involves all United Nations countries and has implemented an ambitious program essentially aimed at achieving international consensus on the regulatory aspects of nuclear waste management as well as promoting worldwide exchange of information. The IAEA has been particulary effective in developing regulatory standards in the area of radioactive waste transportation. The IAEA is also active in providing advice and assistance to developing nations on radioactive waste management matters.

The Council for Mutual Economic Assistance promotes cooperation amongst its member countries which include the Soviet Union and most east-European countries. Information about their activities is not readily available.

The Nuclear Energy Agency (NEA) of the Organization for Economic and Cooperative Development (OECD) is probably the most important international organization from the Canadian perspective. It has the following objectives: to promote exchange of information between member countries; to promote coordination of national R&D activities; and to promote international cooperation through cooperative experiments and research projects. The first two objectives are achieved by a number of means including the organization of workshops on technical topics, the sponsoring of international symposia and by the issuing of publications, proceedings and a nuclear waste bulletin which provides an update on policies and programs of member countries and the NEA.

Some of NEA's activities are listed below.

- Performance Assessment Advisory Group
- Probabilistic Systems Assessment Codes User Group
- Advisory Group on In-Situ Research
- International Stripa Project
- Thermochemical Database Project
- Sorption Database
- Alligator River, Australia, Natural Analogue Project
- Seabed Working Group

Expanding on the latter activity, several NEA member countries have R&D programs aimed at assessing the feasibility of disposal in the sediments underlying the deep ocean floor. The high cost associated with marine research plus the fact that the oceans have international status makes seabed disposal research an excellent candidate for international cooperation. These programs are coordinated by the Seabed Working Group of the NEA of which Canada is a member. An eight-volume report which summarizes 10 years of research activities has just been released (OECD, 1988).

11 - SUMMARY

11 - SUMMARY

In this section some of the information presented in the preceding sections is summarized in more concise form to assist the reader in drawing comparisons between the programs and approaches of different countries and how they relate to Canada.

11.1 - Organizations and Progress

Table 11.1 identifies the organization which has the main responsibility for implementing the disposal of HLW in its country. It is clear that every country is developing its own program; there is no consideration of a multicountry repository, not even in Europe where nuclear cooperation is at its strongest. In general, the lead organizations fall into two categories, either government or utility. Of the thirteen countries listed in Table 11.1, five have utility operated lead agencies and eight government agencies. There are no private industry organizations.

In Canada, AECL is the lead organization for research and demonstration of the safety of nuclear waste disposal. This responsibility is only for HLW and does not include LLW. It should be noted that, except for the USA and the United Kingdom, most other countries combine LLW and HLW responsibilities in one organization. It should also be noted that, in Europe particularly, considerably more emphasis is placed on LLW than in Canada. AECL's mandate is only defined to the end of the concept assessment phase. After that point the schedules and responsibilities are not defined.

TABLE 11.1

LEAD ORGANIZATIONS
AND PROGRESS BY COUNTRY

Country	Lead Organization	Underground Research Laboratory	Repository Site Selection	Proposed Disposal Date
Belgium	National Agency for Radioactive Waste and Fissile Materials (ONDRAF/NIRAS)	HADES completed in 1984 at Mol-Dessel	HADES URL to be used as repository if proven acceptable	2030
Canada	Atomic Energy of Canada Ltd., (AECL)	URL in use at Whiteshell Research Area	No site selection planned until at least 1993	2025 ?
Federal Republic of Germany	Physikalisch-Technische Bundesanstalt (PTB)	Asse rock salt mine in use since 1965	Gorleben salt dome selected as repository site in 1977	2000 +
Finland	Finnish Ministry of Trade and Industry (KTM)	No URL; Finland participates in OECD/NEA Stripa project in Sweden	Five sites under investigation as of 1987; one site to be selected by year 2000	2020
France	National Agency for the Management of Radioactive Wastes (ANDRA)	Fanay-Augeres Mine. Four potential sites under investigation; selection/construction at one site scheduled for 1990 - 1991	Plan is to construct repository at URL following site validation	2010
Italy	National Energy Organization (ENEL)*	URL was excavated but local opposition led to suspension	No site selection underway as of 1988	2030+
Japan	Power Reactor and Nuclear Fuel* Development Corporation (PNC)	Mine tests. URL planned at Moronobe mine in crystalline rock.	Investigation of candidate sites now underway	?

*utility-operated

TABLE 11.1 (continued)

LEAD ORGANIZATIONS
AND PROGRESS BY COUNTRY

Country	Lead Organization	Underground Research Laboratory	Repository Site Selection	Proposed Disposal Date
Netherlands	Central Organization for Radioactive Waste (CORA)	None presently planned	No site investigations underway as of 1988	?
Spain	Spanish Nuclear Waste Management Authority (ENRESA)	None presently planned	No site investigations underway as of 1988	?
Sweden	Swedish Nuclear Fuel and Waste Management Company (SKB)*	Stripa (former iron ore mine) in operation since 1977; Swedish Hard Rock Laboratory to commence construction in 1990	Fourteen sites have been investigated since 1977; final site selection scheduled for 1998 - 2000	2020
Switzerland	National Co-operative for the Storage of Radioactive Waste (NAGRA)*	At Grimsel. New URL scheduled at repository site in 1998	Selection of final site scheduled for 1993	2020
United Kingdom	Nuclear Industry Radioactive Waste Executive (NIREX)*	None planned as of 1988	No site selection investigations underway as of 1988	
United States	Office of Civilian Radioactive Waste Management (DOE)	In salt, granite, basalt; US participated in Sweden's Stripa and Canada's URL. Tuff URL to commence 1989.	Selection of final site scheduled for 1994	2003

The degree of progress that each country is making in its disposal programs is also indicated in Table 11.1. The yardsticks that have been selected are whether an underground research laboratory has been established, and how far site selection has progressed. The planned start-up date for a repository is not a good yardstick since there is a trend toward long-term storage (up to 50 or more years) prior to disposal. It is seen that although Canada has made good progress in research and development activities, it lags behind the Federal Republic of Germany, France, Sweden, the USA, Belgium and Switzerland in the implementation of a siting and construction program. Canada is about on a par with Japan and Spain. Of the major nuclear power users, the United Kingdom has probably made the least overall progress. Italy and the Netherlands also have not made much progress.

11.2 - Waste

The quantity of HLW that will need to be disposed is a direct function of the nuclear generating capacity of each nation. Table 11.2 lists the installed nuclear capacity for 13 countries that have nuclear programs. Canada ranks sixth in the world, only barely behind the United Kingdom.

Of the countries listed in Table 11.2 Canada is the only one that uses natural uranium fuel (that is the isotope U-235 is in its natural proportion to the isotope U-238). Most countries are planning to dispose of reprocessed spent fuel which has been solidified into a glass matrix and then encapsulated into a metal container (referred to as vitrified waste in Table 11.2), or a combination of vitrified waste and spent fuel. Only Canada, Finland, Spain and Sweden are planning no reprocessing of their spent fuel prior to disposal. It should be noted that reprocessing removes some of the long-lived radionuclides that generate heat. Mayman et al (1980) show that temperatures of 80 to 100°C would be maintained in a repository containing spent fuel for

TABLE 11.2

INSTALLED NUCLEAR CAPACITY, HLW TYPE AND PACKAGING BY COUNTRY

Country	1988 Installed Nuclear Capacity (MW)	Waste Type	Age at Disposal (Years)	Container Exterior
Belgium	5,540	Vitrified waste	50	Titanium
Canada	12,500	Non-enriched spent fuel	10	Titanium
Federal Republic of Germany	18,926	Enriched spent fuel; vitrified waste		
Finland	2,300	Enriched spent fuel	30 - 40	Copper
France	44,000	Vitrified waste	20 - 30	Steel
Italy	1,472	Enriched spent fuel; vitrified waste	50 - 70	Steel
Japan	26,000*	vitrified waste	30 - 50	
Spain	5,800*	Enriched spent fuel		
Sweden	9,650	Enriched spent fuel	30 - 40	Copper
Switzerland	3,000	Vitrified waste	40	Steel
United Kingdom	12,800	Vitrified waste	50	
United States	97,200	Enriched spent fuel; vitrified waste	10	Steel

*As of 1986

about 20,000 years, whereas temperatures near a repository containing only reprocessed (vitrified) waste will dissipate to ambient levels in a few hundred years. The much longer time frames of elevated temperature and associated thermal stresses must be accounted for in repository design and the associated safety analyses.

In all cases the waste container is intended to play a major role in isolating the waste and preventing its release into the groundwater with a thick metal wall of either titanium (Canada), copper or steel used to resist leaching and corrosion.

11.3 - Repository Design

It is noteworthy that all countries have selected burial deep in a stable geologic formation as their method for HLW disposal. However, the specific medium varies depending largely on the geologic conditions in each country (Table 11.3). The following geologies have been selected:

Crystalline rock: Canada, Sweden, Finland

Salt: Federal Republic of Germany, Netherlands, USA

Clay: Belgium, Italy

Tuff: USA

Undecided: France, Japan, Spain, Switzerland

Only Switzerland is considering combining two media (crystalline and sedimentary rocks) at one site.

TABLE 11.3

HLW REPOSITORY DESIGN BY COUNTRY

Country	Geologic Medium	Depth (m)	Size (m)	Areal Heat Loading (Watts/square metre)	Borehole Barrier Material	Tunnel/Shaft Backfill Material
Belgium	Boom clay	220 +		1.5		Clay/sand mixture
Canada	Crystalline rock	500-1000	2000 x 2000	10	Sodium-bentonite clay/silica	Clay and crushed granite
Federal Republic of Germany	Salt	840				
Finland	Crystalline rock	500				
France	Clay, salt, crystalline rock or schist					
Italy	Clay				Bentonite clay	
Japan	Crystalline or sedimentary rock	Few hundred meters				
Netherlands	Salt domes					
Spain	Clay, crystalline rock or salt					
Sweden	Crystalline rock	500	1000 x 1000	5.25	Bentonite clay	Quartz sand/bentonite
Switzerland	Crystalline or sedimentary rock	1200	1550 x 880	2.5		Bentonite clay
United States	Welded tuff (volcanic)	300	3500 x 2300	14		Crushed tuff

As shown in Table 11.3, the proposed depths for a repository range from 220 m to 1200 m, although the majority lie between 500 and 1000 m, as is proposed in Canada. It is generally accepted that greater depth results in greater isolation of the waste; however, this is counterbalanced by the difficulty of keeping very deep openings stable and associated safety problems during the operational phase of the repository.

There is close similarity in the proposed repository designs, which are generally located on one level, and in some cases two levels, with a series of parallel openings and disposal of the waste containers into cylindrical holes in the tunnel floors. Backfilling of the container boreholes, tunnels and shafts is by a combination of bulkheads and clay and/or bentonite material.

One variation in design has been proposed by Italy which involves using a series of long boreholes drilled from the surface for waste container emplacement.

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APPENDIX A

NATIONAL AND INTERNATIONAL ORGANIZATIONS

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NATIONAL AND INTERNATIONAL ORGANIZATIONS

(Additional information may be obtained by contacting the following organizations)

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Switzerland

NAGRA/CEDRA
(Nationale Genossenschaft für die Lagerung radioaktiver Abfälle/
Société cooperative nationale pour l'entreposage de déchets
radioactifs)
Parkstrasse 23
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United Kingdom

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United States

Office of Civilian Radioactive Waste Management
US Department of Energy
Mail Stop RW-40
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APPENDIX B

GLOSSARY OF TERMS
AND ACRONYMS

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ANDRA	- Agence Nationale pour la Gestion des Dechets Radioactifs, the French National Agency for the Management of Radioactive Wastes
AECL	- Atomic Energy of Canada Limited
AECB	- the Canadian Atomic Energy Control Board
CANDU	- Canada Deuterium Uranium, referring to Canada's reactor system which uses natural uranium and heavy water (deuterium oxide) as a moderator
CEC	- Commission of European Communities
Crystalline rocks	- a generic term referring to a variety of hard rocks such as granites. Igneous and plutonic rocks are included in this term.
DOE	- the US Department of Energy
EARP	- the Federal Environmental Assessment and Review Process of Canada
EPA	- the US Environmental Protection Agency
HLW	- High-Level Radioactive Waste, spent fuel and/or waste from reprocessing spent fuel. In Canada, HLW is also called nuclear fuel waste.
IAEA	- International Atomic Energy Agency
ICRP	- International Commission on Radiological Protection
kg	- kilogram, unit of weight, 1000 grams
m	- metre, unit of length
mm	- millimetre, one thousandth of a metre (m)
Mg	- unit of weight, megagram, a million grams
MRS	- the US Monitored Retrievable Storage facility
MW	- megawatt, unit of electrical energy, a million watts

NAGRA	- the Swiss National Cooperative for Storage of Radioactive Waste
NEA	- the Nuclear Energy Agency of the OECD
NRC	- the US Nuclear Regulatory Commission
Nuclear Fuel Waste	- see HLW
NFWMP	- the Nuclear Fuel Waste Management Program of Canada
LLW	- radioactive waste which, because of its low radionuclide content, does not generate heat nor require shielding during normal handling
OCRWM	- the US Office of Civilian Radioactive Waste Management
OECD	- Organization for Economic and Cooperative Development
ONDRAF/NIRAS	- Belgium's National Agency for Radioactive Waste and Fissile Materials
PAGIS	- Performance Assessment of Geological Isolation Systems, an international program under the CEC
PTB	- Physikalisch-Teknische Bundesanstalt, Germany's Federal Institute for Science and Technology
SKB	- Svensk Karnbranslehantering, Swedish Nuclear Fuel and Waste Handling Company
Sievert	- a unit of radiation dose
TAC	- the Canadian Technical Advisory Committee
Transuranic	- refers to waste which has LLW properties except that it also contains some nuclides having atomic numbers above 92 such as plutonium. These tend to be very long-lived.
Tuff	- a rock formed by consolidation of materials ejected explosively from a volcanic vent. This rock type is under consideration by the USA.
URL	- Underground Research Laboratory
Vitrified waste	- HLW that has been reprocessed and immobilized into glass.
WIPP	- the US Waste Isolation Pilot Plant, a repository for defence transuranic waste