NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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NWMO BACKGROUND PAPERS
7. INSTITUTIONS AND GOVERNANCE

7-5 STATUS OF CANADIAN EXPERTISE AND CAPABILITIES RELATED TO HIGH-LEVEL RADIOACTIVE WASTE MANAGEMENT (HLRWM)

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NWMO Background Papers

NWMO has commissioned a series of background papers which present concepts and contextual information about the state of our knowledge on important topics related to the management of radioactive waste. The intent of these background papers is to provide input to defining possible approaches for the long-term management of used nuclear fuel and to contribute to an informed dialogue with the public and other stakeholders. The papers currently available are posted on NWMO's web site. Additional papers may be commissioned.

The topics of the background papers can be classified under the following broad headings:

1. **Guiding Concepts –** describe key concepts which can help guide an informed dialogue with the public and other stakeholders on the topic of radioactive waste management. They include perspectives on risk, security, the precautionary approach, adaptive management, traditional knowledge and sustainable development.
2. **Social and Ethical Dimensions** - provide perspectives on the social and ethical dimensions of radioactive waste management. They include background papers prepared for roundtable discussions.
3. **Health and Safety –** provide information on the status of relevant research, technologies, standards and procedures to reduce radiation and security risk associated with radioactive waste management.
4. **Science and Environment –** provide information on the current status of relevant research on ecosystem processes and environmental management issues. They include descriptions of the current efforts, as well as the status of research into our understanding of the biosphere and geosphere.
5. **Economic Factors** - provide insight into the economic factors and financial requirements for the long-term management of used nuclear fuel.
6. **Technical Methods** - provide general descriptions of the three methods for the long-term management of used nuclear fuel as defined in the NFWA, as well as other possible methods and related system requirements.
7. **Institutions and Governance** - outline the current relevant legal, administrative and institutional requirements that may be applicable to the long-term management of spent nuclear fuel in Canada, including legislation, regulations, guidelines, protocols, directives, policies and procedures of various jurisdictions.

EXECUTIVE SUMMARY

This background paper provides an overview of the current status of Canadian expertise and capabilities related to high-level radioactive waste management (HLRWM). The complete nuclear fuel cycle is reviewed, in order to put into perspective the expertise and capabilities specific to HLRWM: many areas share similar expertise, others are unique. Spent nuclear fuel is the principal high level waste that needs to be managed, although certain reactor components, such as pressure tubes that have been removed from the reactor, also fall under this category.

The tasks and time periods to be considered for the management of spent fuel in Canada include the study phase, during which the NWMO will analyze the alternatives and recommend to the Canadian Government the preferred method for managing Canada's nuclear fuel waste (3 years), selection of site or sites for the preferred method for storing the fuel (3-5 years), environmental assessment and approval of the site (2-3 years), preliminary design and approval of the facility (4-6 years), design and construction of the facility (5-7 years), and its operation, that would start (assuming the above range of estimates hold) between 2020 and 2027. Therefore the total time-frame for which Canadian expertise and capability are considered in this report is up to 25 years, and the nature of the expertise and capability that has been assessed covers the above six phases of the project.

The NWMO's mandate is to study three already defined alternatives, namely

(i) storage at nuclear reactor sites,

(ii) deep geological disposal in the Canadian Shield,

(iii) centralized storage, either above or below ground, and

(iv) other approaches.

This background paper concludes that the necessary expertise and capability exist to implement the already defined three alternatives for HLRWM. If some other, not yet identified alternative is selected, the Canadian expertise and capability for such an approach will need to be assessed when the alternative is known. However, since in this background paper "Canadian expertise and capabilities" have been broadened to include foreign partners of Canadian companies, there is little doubt that whatever expertise and capabilities are needed in the future, they will either already exist in Canada and amongst the partners of Canadian companies, or they will be transferred to one or more of these companies.

In total 41 Canadian Companies, 8 Universities, and 9 Government Agencies/ Departments with involvement in HLRWM were surveyed. In each of these categories, and in particular by recognizing the fluidity of the movements of experts between the various parts of the industry, the required level of capability and expertise exists today to proceed with the management of spent fuel in Canada. Because of the long timelines involved, all the above parties will need to take responsibility to ensure that the level of expertise and capabilities are maintained and new skills are developed, as the phases of the HLRWM project progress and as the waste management method to be implemented is finalized.

The following table summarizes the total number of people with expertise relevant to one or more phases, and one or more HLRWM alternatives, working for the 41 companies surveyed. The number of companies with full or partial capabilities, and the number of experts employed by them, have been grouped by company type, and are given in the following table:

Company type	number of companies		number of expert staff
	full capability	partial capability	
Large Integrated	10	0	500
Large Engineering	1	8	220
Large Environmental	3	2	210
Small & Medium Specialists		13	120
Mining and Utilities		4	50
Total	14	27	1100

The above numbers reflect the total number of experts working in Canada who could be assigned to one or more aspects of HLRWM. Including the experts from the foreign affiliates and subcontractors, the number of experts would more than double. Capability for the multinational companies includes the foreign parent company.

The following two tables show the expertise and capabilities currently available in the 41 companies for each phase of each alternative.

Number of Experts in the Companies surveyed:

	HLRWM Alternatives			
HLRWM Project Phases	**A. On-site**	**B. Deep geological**	**C. Centralized**	**D. Other**
1. Study	# of experts: 340	# of experts: 400	# of experts: 440	# of experts: 30
2. Site Selection	# of experts: 295	# of experts: 340	# of experts: 370	# of experts: 25
3. Environmental Assessment and Site Approval	# of experts: 380	# of experts: 460	# of experts: 470	# of experts: 25
4. Preliminary Design and Facility Approval	# of experts: 375	# of experts: 420	# of experts: 480	# of experts: 25
5. Design and Construction	# of experts: 305	# of experts: 390	# of experts: 450	# of experts: 10
6. Operation	# of experts: 140	# of experts: 260	# of experts: 270	# of experts: 5

Number of Companies in the survey with Full or Partial Capability:

	HLRWM Alternatives			
HLRWM Project Phases	**A. On-site**	**B. Deep geological**	**C. Centralized**	**D. Other**
1. Study	full capability: 14 partial capability: 24	full capability: 14 partial capability: 23	full capability: 14 partial capability: 26	full capability: 1 partial capability: 10
2. Site Selection	full capability: 14 partial capability: 17	full capability: 14 partial capability: 17	full capability: 14 partial capability: 19	full capability: 1 partial capability: 7
3. Environmental Assessment and Site Approval	full capability: 13 partial capability: 19	full capability: 13 partial capability: 19	full capability: 13 partial capability: 21	full capability: 1 partial capability: 7
4. Preliminary Design and Facility Approval	full capability: 11 partial capability: 23	full capability: 10 partial capability: 25	full capability: 11 partial capability: 26	full capability: 1 partial capability: 7
5. Design and Construction	full capability: 10 partial capability: 20	full capability: 10 partial capability: 20	full capability: 10 partial capability: 22	full capability: 1 partial capability: 4
6. Operation	full capability: 8 partial capability: 7	full capability: 8 partial capability: 7	full capability: 8 partial capability: 9	full capability: 1 partial capability: 3

It should be noted that the total number of experts identified for the study phase (1,210) is more than the total number of experts in all the companies (1,100), since experts for many of the common tasks would contribute to (and are therefore counted under) more than one alternative. Similarly, the total number of experts for all six phases of any one of the three identified alternatives is over 1,100, and again several experts would be contributing to more than one phase, as the timelines for the various stages were implemented. Typically no more than a partial overlap between two phases is expected to happen.

Expertise at government agencies and universities was not quantified, but both categories are judged to have the capability to carry out their respective tasks. This judgment is based on the general abilities of government departments to either have the necessary expertise in-house to fulfill their mandates, or to acquire it as they need the expertise to carry out government programs. University faculty and researchers have sufficient flexibility and mobility world wide to respond to the challenging opportunities that the HLRWM would offer.

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Background Paper on the Status of Canadian Expertise and Capabilities related to High-level Radioactive Waste Management (HLRWM)

INTRODUCTION

The Nuclear Waste Management Organization (NWMO) was established under the Nuclear Fuel Waste Act (NFWA) to investigate approaches for managing Canada's used nuclear fuel. The same act also established the Nuclear Fuel Waste Bureau (NFWB) within the federal department of Natural Resources to administer the oversight responsibilities of the Government of Canada, and the Minister of Natural Resources.

The review of different management options involves diverse issues ranging from the identification of technical, economic, societal, ethical and community implications, to specific issues of safety and security in transportation and storage of used nuclear fuel. Critical to the review of the waste management options, as well as to the implementation of the approach approved by the Government of Canada, is the availability of people and organizations with the expertise and capability to carry out the required tasks throughout the projected life-time during which high-level radioactive waste needs to be managed.

This background paper summarizes the key methods under review for HLRWM, the main phases of implementing the various methods, and the current status of Canadian expertise and capabilities related to high-level radioactive waste management.

The Canadian Nuclear Fuel Cycle

Figure 1 illustrates the main stages of the nuclear fuel cycle currently used in Canada, and indicates the alternatives being considered for the storage and disposal of the spent fuel.

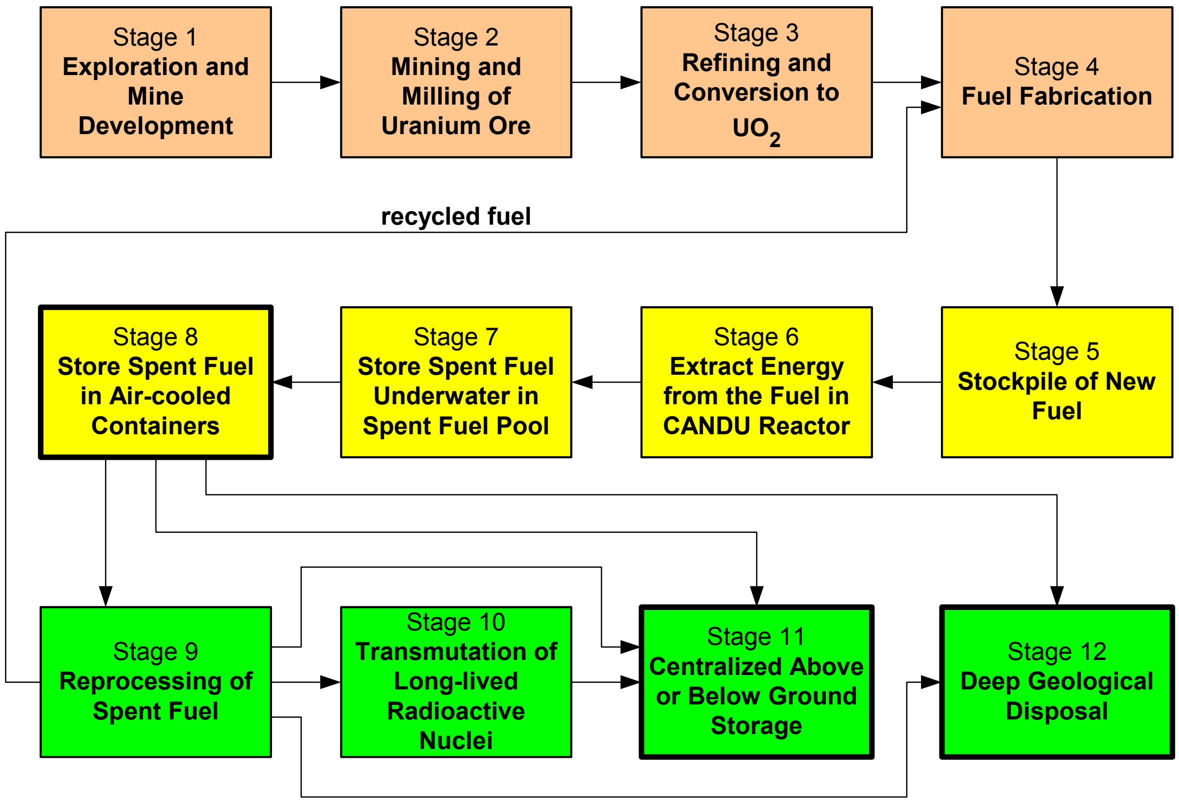

Figure 1: The Nuclear Fuel Cycle: stages 1 - 4 the "front end", stages 5-8 at the power plant site, stages 9-12 the "back-end"

Stages 1 – 4 are the "front end" of the fuel cycle, starting with exploration for uranium and development of sites suitable for mining, the operation of the mine, refining and conversion, and the fabrication of the fuel into a form that is suitable for use in a nuclear reactor.

All the operating nuclear reactors in Canada are of the CANDU® (Canada Deuterium Uranium) type, which use uranium in its "natural" composition, containing 99.3% Uranium-238, 0.7% Uranium-235 and a trace of U-234. It is only the isotope U-235 that is "fissile" i.e. can be split into two nuclei following absorbtion of a neutron, accompanied by the release of a relatively large amount of energy and usually one or more neutrons. Using heavy water to "slow down" the high energy neutrons that result from the fission process, it is possible to maintain such a chain reaction. However, if ordinary or "light" water is used to slow the neutrons, the fuel needs to be "enriched" i.e. the concentration of U-235 raised to the range of 3-5%. In this paper the only fuel cycle that is considered is the one using natural uranium.

Canada is the world's leading uranium producer, accounting for a third of global production and 15% of global reserves. All uranium now produced in Canada comes from five mines, all in the province of Saskatchewan, operated by Cameco and COGEMA Resources. Figure 2 shows the location of the uranium mines, fuel conversion facilities and the nuclear power plants. The two provinces with key roles in the Uranium fuel cycle are Saskatchewan, where the mines are located, and Ontario, where the fuel is fabricated and most of the spent fuel is stored at the nuclear power plants. These two provinces are also the most probable places for the long term storage and/or disposal of the HLRW.

Figure 2. Location of the uranium mines, fuel conversion facilities and the nuclear power plants (Uranium Information Centre).

The mines must be located wherever uranium is found in the amounts and concentrations that make its extraction economical, and the nuclear power plants need to be located close to where the electrical loads are. In Canada, the mines are in Northern Saskatchewan, and the power plants in Southern Ontario. In order to minimize transportation costs, the ore is concentrated in a facility close to the mine. First the rock is crushed and finely milled (stage 2), and then the uranium is separated from the rest of the ore minerals in a series of chemical operations. The resulting concentrate is 75% uranium; it has a yellowish, cake-like appearance, hence the name "yellowcake" (U_3O_8). This raw material is then shipped to one of two Canadian refineries operated by Cameco, where it is reduced to uranium dioxide (UO_2). This black powder is then pressed into cylindrical form and sintered, creating a ceramic UO_2 fuel pellet, a little over a centimeter in both diameter and length (stage 3).

At the CANDU-fuel manufacturing plants of Zircatec and General Electric Canada (stage 4), these pellets are inserted into half-meter-long metal tubes made of a Zirconium-Niobium alloy, both ends of which are welded shut, to form a fuel "pencil". Typically 37 "pencils" form a 10 centimetre diameter cylindrical fuel bundle that weighs approximately 20 kg. Once the fuel bundles have been tested to ensure that quality requirements have been met, the "front end" of the fuel cycle is completed, and the fuel is shipped to the CANDU nuclear power plants.

Stages 5 to 8 in Figure 1 take place at the nuclear power plant sites. One of the many advantages of using natural uranium is that the risk of criticality is virtually non-existent, since neither in air, nor in ordinary water can natural uranium sustain a chain reaction. Although somewhat radioactive, a natural uranium fuel bundle can be safely handled, as illustrated in Figure 3. The storage and inspection of fuel bundles at the nuclear power plant corresponds to stage 5 in Figure 1.

Figure 3. A typical CANDU fuel bundle.

A fuel bundle spends 12-18 months in the reactor (stage 6), and the fissioning of Uranium-235 supplies the heat to generate electricity. During this time the composition of the fuel changes: the U-235 content decreases, the concentration of isotopes produced when U-235 fissions (called "fission products") increases, as do the concentrations of isotopes that result when other nuclei, mostly U-238, absorb a neutron. Plutonium-239, which is produced from U-238, is a particularly important isotope, since it is also fissile. The Pu-239 produced in the fuel typically contributes 30% of the energy generated by a fuel bundle. However, Pu-239 could also be used in nuclear weapons, and remains highly radioactive for thousands of years. It is therefore one of the isotopes that must be taken into account in the management of spent fuel. Most of the fission products are also radioactive, and generate significant amounts of heat as they decay to form stable nuclei. While in the reactor, some of the fission products are strong absorbers of neutrons, and would prevent the chain reaction from continuing, so the fuel must be removed from the reactor. In addition to the fission products, Plutonium and other isotopes produced during reactor operation are all contained within the fuel elements and the fuel pencils. For CANDU reactors the "spent fuel" can be removed and replaced with fresh fuel while the reactor continues to operate.

Figure 4. Spent fuel storage pool (OPG).

Following removal from the reactor, the radioactive spent fuel continues to produce significant levels of radiation and heat. It must be handled by remote equipment, be continuously cooled, and personnel must be shielded from the radiation emanating from the spent fuel. Typically, for the first ten years following removal from the reactor, fuel bundles are kept under several metres of water inside the spent fuel storage pool of a nuclear power plant as shown in Figure 4 (stage 7). After ten years the heat generation has decreased sufficiently to permit the fuel to be kept in dry storage containers (see section 2), which provide the necessary level of shielding, as well as cooling by the transfer of heat to the ambient air. All nuclear power plant sites in Canada have (or in the case of the Darlington plant currently acquiring) the capability to store all the spent fuel that is expected to be generated during the reactor's life-time in above ground dry storage containers (stage 8).

The currently used dry storage containers are expected to have a useful life of 50-100 years. Although the level of radioactivity of the spent fuel will gradually decrease to levels consistent with background radiation, at which stage they will no longer represent a radiological hazard, in the case of CANDU fuel this time period is in the order of 10,000 years. Since the current nuclear power plant sites are not designated to hold the spent fuel and other high level radioactive materials for such long periods, some other means of long term storage or permanent disposal facility needs to be created. The various options available for treating and storing the spent fuel, stages 9 – 12 in Figure 1, are referred to as the "back end" of the fuel cycle.

It should be noted that while stages 1 – 8 lead from one to the next in an essentially consecutive manner, the "back-end" consist of a number of alternatives, and where the stages may or may not follow one another. A key decision that will need to be made by the NWMO and the Government of Canada concerns the reprocessing of CANDU fuel. At the present time there are no economic reasons to reprocess CANDU fuel, since the cost of such fuel would be significantly higher than the fuel produced from mining natural uranium. However, this cost is dependent on the alternative chosen for long term storage or disposal; for example the design, construction, operation and permanent closure of a deep underground disposal facility may add so much to the back-end of the fuel cycle that, reprocessing the fuel in a manner that eliminates the need for deep underground disposal, may prove to be economical. Also, with time, the low-cost uranium mines will be exhausted, and in a few hundred years the cost of mined uranium may rise to a level comparable to the cost of reprocessed uranium. Another factor to be considered in the long term (several hundred years) is that virtually all the U-238 is still in the spent fuel, and it may become cost-effective to use U-238 in a more advanced reactor than the current ones that rely on U-235.

Reprocessing the spent fuel, irrespective of the economic benefit of recycled Uranium, poses the risk that Pu-239 may be diverted for use in nuclear weapons. However, if the safeguards around Plutonium can be guaranteed, the reprocessed fuel (including Pu-239 and all other long-lived isotopes) could be recycled into the reactors, or transmuted (changing atoms of one element into those of another by neutron bombardment, causing neutron capture) in an accelerator-driven device. It should also be noted that CANDU spent fuel has the unique feature of containing Pu-240 as about 26% of the total Pu in the fuel rods. Weapons grade Pu must be less than 7% Pu 240. Hence, CANDU spent fuel under normal burn-up conditions is a poor source for weapon grade material.

The options available for the back-end of the fuel cycle are shown as stages 9 – 12 in Figure 1, and can be summarized as:

- reprocessing of the spent fuel (stage 9), recycling the fissile content and storing the remaining waste in centralized storage, either above or below ground (stage 11)
- reprocessing of the spent fuel (stage 9), recycling the fissile content and disposing the remaining waste in deep geological site in the Canadian Shield (stage 12)
- transmutation (stage 10) followed by storing the remaining waste in centralized storage, either above or below ground (stage 11)
- placing the unreprocessed spent fuel into centralized storage, either above or below ground (stage 11)
- disposing of the unreprocessed spent fuel in deep geological formation in the Canadian Shield (stage 12)

Fuel reprocessing is not an option that is likely to be implemented in Canada, but it is a topic studied by many other jurisdictions, and it has been included above for the sake of completeness in describing the fuel cycle options. The reprocessing option also raises questions of retrievability of the spent fuel from a repository, which is a topic beyond the timeframe considered in this paper.

This paper is principally concerned with identifying the Canadian expertise and capabilities for stages 8, 11 and 12, as well as for other waste management options, such as the ones shown as stages 9 and 10. These four methods are defined as:

Alternative A: Storage at nuclear reactor sites

Alternative B: Deep geological disposal in the Canadian Shield

Alternative C: Centralized storage, either above or below ground

Alternative D: Other approaches

It is also possible that the preferred method includes some combination of the above four alternatives, for example storage at the nuclear reactor sites for an initial period of several years or decades, followed by one of the other alternatives. Since the preferred facility cannot start operation for another 17-24 years, a period of at-reactor storage is inevitable.

The process of arriving at the preferred method of HLRWM, and implementing it over the next 25 years, includes the following phases, irrespective of the alternative method chosen. These phases are:

Phase 1: investigation of alternatives and recommendation of the preferred approach (3 years), with Government approval to proceed with the recommended approach assumed to be given in 2006

Phase 2: selection of site or sites for the approved waste management method (3-5 years), i.e. site selection completed in 2009-2011

Phase 3: environmental assessment and site approval (2-3 years) i.e. site approved in 2011-2014

Phase 4: preliminary design and approval of the facility (4-6 years) i.e. facility approved in 2015-2020

Phase 5: design and construction of the facility (5-7 years) i.e. facility completed and ready for operation in 2020-2027

Phase 6: operation, including receiving and storing high level radioactive waste.

The current status of Canadian expertise and capability for the four alternatives throughout the above six phases is documented in this paper.

For the purposes of this paper, I have defined "expertise" as the qualification, knowledge and experience of individuals employed by an organization, and "capability" as the capacity of the organization to perform work using teams of experts and support staff, computer software and hardware, specialized equipment, processes, procedures and other infrastructure. In the sections that follow, the expertise and capability available in Canada for each of the above four alternatives are documented. However, before discussing the expertise and capability that are unique to each alternative, the many aspects that are common to all of the alternatives is presented.

KEY ELEMENTS

1. Expertise and Capabilities Common to All Alternatives

All the alternatives for HLRWM involve large projects in terms of monies to be spent, time duration, engineering and scientific knowledge, environmental assessment, design, construction and operation of facilities, interactions with government agencies, NGOs, the general public, expert groups, legal matters, and many other aspects. In this section the aspects that are common to all the identified alternatives of managing the spent fuel from the time it leaves the nuclear plant's spent fuel storage pool until it arrives at its final storage or disposal site, are considered.

The main characteristic that distinguishes HLRWM from other large commercial or industrial projects is that the spent fuel remains radioactive at levels above what is found in nature for more than 10,000 years, yet there is no formal experience for predicting the behaviour of man-made containment structures for this length of time. It should be noted that the decrease in radioactivity is very rapid (see Figure 5), a factor of more than a hundred in a hundred years, while non-radioactive wastes do not decay at all. As such, there are issues of science and engineering that attempt to quantify the risks involved with various alternatives, as well as socio-economic issues, as to what is acceptable to our society, including ethical questions that attempt to delineate what needs to be done today in order not to disadvantage future societies.

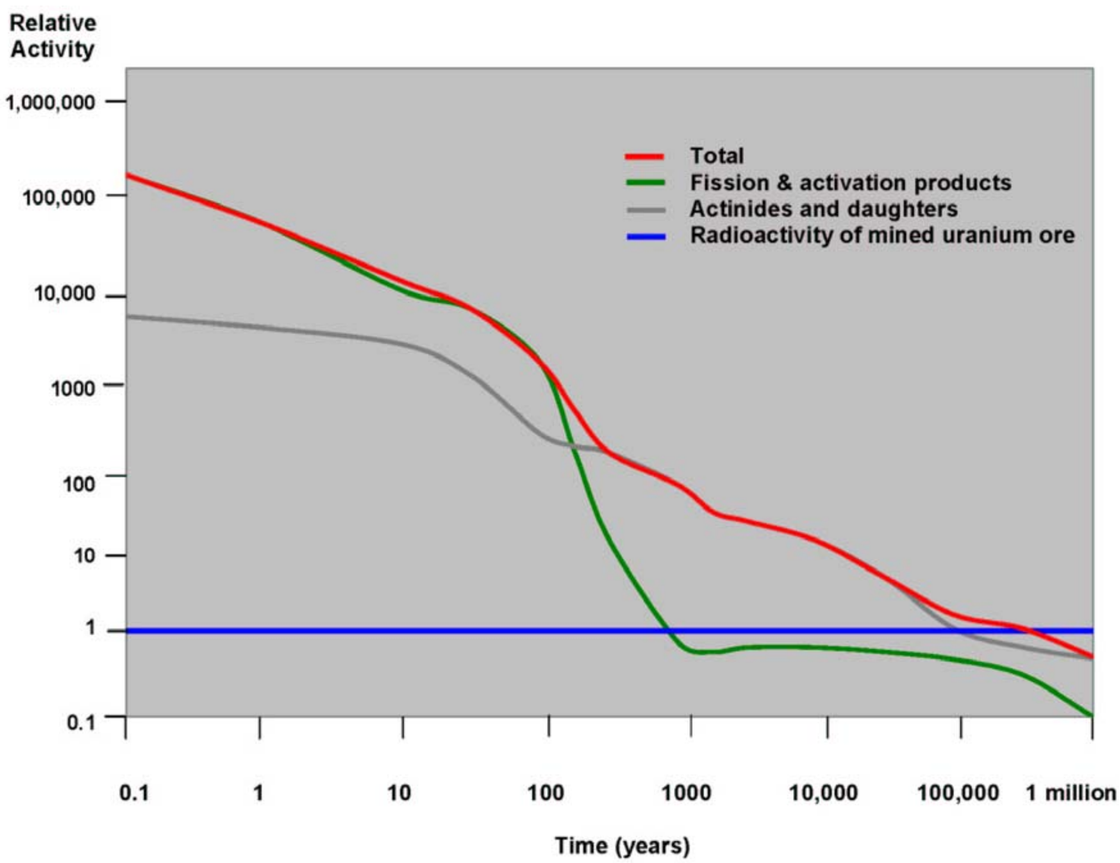

Figure 5. Decay of radioactivity in used fuel as a function of time.

One set of expertise that is needed relates to the ability to evaluate the various alternatives, taking into account all legal, technical and societal aspects. Another set includes the common elements that will be needed to implement the selected alternative, since each will require environmental science, radiological assessment and monitoring, project management, engineering design and construction to build the facility, and once in service, to operate and maintain it.

The following list summarizes the main areas of expertise and specific capabilities that will be needed to conduct the study phase of deciding on the preferred method of HLRWM, as well as to implement any one of the selected alternatives.

1.1 Types of expertise and capabilities common to all alternatives

Project Management

- project management and control
- strategic planning
- capacity building and institutional strengthening
- construction management
- operational risk management
- data management
- training and human resources development

Studies

- economic models for the cost of site and facility design, construction and operation
- site and route selection
- risk, cost and benefit analysis
- expert peer reviews of studies and reports
- technology evaluations and feasibility studies
- logistical studies (fuel handling and shipping logistics)
- benchmarking of technologies, designs, costs and assessment approaches
- institutional requirements analysis
- issues analysis and management
- code verification and validation
- information research

Environmental aspects

- environmental impact assessment
- environmental effects monitoring and follow-up
- ecological sciences
- cumulative effects assessment
- aquatic and terrestrial biology
- environmental policy, regulation, guideline development
- environmental auditing, site assessment and remediation

- environmental software development

Radiological assessment

- fuel waste characterization
- waste-form behaviour
- materials sciences and waste package handling and design
- radiation shielding
- radiological safety assessment
- occupational radiation exposure management
- decontamination methods development and management

Transportation

- design of on-site and off-site equipment for the transportation of spent fuel

Safety analysis

- reliability and probabilistic risk assessment
- hazard and consequence analysis
- licensing services to meet regulatory requirements
- safety and security audit and assessment
- emergency response planning and management

Engineering design

- geological and geotechnical engineering
- hydrology and water resource engineering
- safety engineering

Public consultation and communication

- socio-economic impact assessment, management and community agreement negotiation
- evaluation of societal, ethical and community attitudes
- traditional aboriginal knowledge

Quality management audits and reviews

- quality assurance program and oversight

1.2 Canadian expertise and capabilities common to all alternatives

The very wide range of expertise and capabilities listed above is only found in a few large integrated companies with diverse interests, and even these companies will, in most cases, need to rely on subcontractors and/or foreign partners to complement their in-house experts. In Canada ten such companies have been identified with expertise and capabilities for managing high level radioactive waste: one is a utility (Ontario Power Generation), one a Federal crown corporation (Atomic Energy of Canada Limited), three are private sector Canadian companies (Acres, CANATOM NPM and Wardrop), and the other five are multi-national companies (AMEC, Framatome ANP, NSS-NNC, SAIC, Stone & Webster). All of these companies have, or are willing to take responsibility for, the full range of expertise and capabilities identified as common to all the alternatives.

More typically, large companies in the field of HLRWM are either primarily engineering/ manufacturing/construction companies, or have an environmental consulting/ management focus.

Nine large Canadian engineering companies have much of the expertise and capability required to do the work in HLRWM: E.S. Fox, General Electic Canada. Marshall Macklin Monaghan, Niagara Energy Products, Numet Engineering, RCM Technologies, Spectrum Consulting, Stantec Consulting, and Thermodyne. Each of these companies has expertise and capability relevant to several of the areas identified as common to all the alternatives, with Stantec indicating that they regard themselves as being fully capable in all areas.

In the area of environmental consulting/management, five Canadian companies have significant levels of expertise to manage the tasks common to all the HLRWM alternatives. Gartner Lee, Golder Associates, and SENES Consulting have the full range of expertise and capabilities for the common tasks, while Hardy Stevenson & Associates, and Jacques Whitford Environment have a wide range of applicable expertise, experience and capabilities.

There are thirteen Canadian companies of small to medium size (less than 250 employees), each of which has a range of specific expertise and capability relevant to HLRWM. These are: Aqua Terra Solutions, Atlantic Nuclear Services, Candesco, Decommissioning Consulting Services, Detec, ECOMatters, Kinectrics, Oakhill Environmental, Precision Nuclear, RSRead Consulting, Sanlex, Stern Labs, and Urban & Environmental.

Two mining companies (Cameco and COGEMA Resources), and two utilities (Hydro Quebec and NB Power), complete the list of 41 Canadian companies that have expertise and capability in the management of high level radioactive waste.

The expertise and capability available in Canada is judged to be sufficient to implement the common components of the first three alternatives. With some specialist support in areas unique to “other” alternatives, the Canadian expertise and capability are likely to be adequate to carry out the common tasks for any other alternative.

The company data presented in this background paper are based on the responses of the companies to a request for information (see Appendix E), and/or to information available on the Internet, and rationalized using the author’s knowledge of the industry.

2. Expertise and Capabilities for Storage at Nuclear Reactor Sites

After a period of typically 6-10 years, spent fuel that has been stored in the spent fuel storage pools of each nuclear generating station, has had its radioactivity decay to a sufficient extent to permit transfer of the spent fuel to above ground dry storage containers. These containers are made of steel, and/or steel-reinforced concrete and lead to provide radiation shielding and cooling. The containers are designed and tested to prevent the release of radioactivity under the most extreme conditions, such as earthquakes, tornadoes, hurricanes, floods and sabotage, and are naturally cooled by air. These on-site dry storage facilities are designed to last a minimum of 50 years.

There are a number of specific types of dry storage methods used in Canada, although they are all variations on the basic concepts of steel and concrete. Other systems have been studied to meet the conditions for CANDU fuel, and there are several systems in use world-wide for spent fuel from other types of reactors.

Typical requirements that must be met by every on-site dry storage system are:

- environmental safety
- no radioactive emissions
- highly efficient heat rejection
- low occupational dose rates
- simple, modular construction
- complete structural soundness
- the design complies with stringent regulatory and environmental standards
- can be located adjacent to other buildings

Although the radioactivity of the fuel has decreased significantly while in the spent fuel storage pool (typically a factor of ten, see Figure 5) it must still be handled remotely and with adequate shielding between the fuel and the staff performing the transfer of the spent fuel. The usual process is to lower a shielding cask into the spent fuel storage pool, place “baskets” or “modules” of fuel bundles inside the shielding cask, then remove the cask holding the fuel.

There are two basic systems currently receiving spent fuel at the operating nuclear power plants in Canada, and both meet the above requirements. In one case, the dry storage container (DSC) is its own transfer cask (this is the system used by OPG), in the other case the fuel is transferred from the transport cask into the dry storage module, as in AECL’s MACSTOR system. The main features of these two systems are described in Appendix B. For smaller volumes of spent fuel, such as for the Nuclear Power Demonstrator, Douglas Point and Gentilly reactors, AECL had also developed a Concrete Canister design.

2.1 Types of expertise and capabilities for the storage at nuclear reactor sites

The expertise and capabilities needed to continue with the storage of spent fuel using dry storage methods at the nuclear reactor sites are already present within each utility and its contractors, and include, in addition to the ones listed as common for all alternatives, the following ones:

- design and fabrication of dry storage containers for spent fuel
- design and manufacture of on-site fuel handling and transportation equipment
- design and construction of on-site infrastructure
- operation and maintenance of on-site waste management facility

Transportation and spent fuel handling equipment and operational expertise have already been developed for both systems, and fuel transfer from the spent fuel storage pool to the dry storage facility is part of the routine operation at each nuclear power plant.

There are several alternatives to the designs currently favoured by AECL and OPG, developed in the US and Europe. Although these alternatives have been developed for systems that, unlike CANDU, use enriched fuel rods in light-water reactors, some of these alternatives could be adopted to Canadian conditions. The expertise and capability needed for any one or a combination of dry storage systems is expected to be maintained and be readily available for the Canadian market.

2.2 Canadian expertise and capabilities for the storage at nuclear reactor sites

Design of the dry storage containers has been the principal responsibility of AECL for the MACSTOR (earlier called CANSTOR) system as used for Gentilly 2, and of OPG for the DCS approach used at Pickering and Bruce, and is proposed for Darlington.

The MACSTOR system is manufactured by local contractors in Quebec and New Brunswick, as well as in the countries to which it has been exported, including Korea, Romania and Lithuania. The expertise and capability for design is being retained by AECL, while the fabrication of the metal casks and the pouring of concrete are skills readily available in any industrialized region.

OPG also maintains the expertise needed to continue with the deployment of DSC units, which are currently manufactured by Niagara Energy products. The DSC units are housed in typical metal clad industrial buildings with reinforced concrete floors. Such buildings can be designed and constructed by a range of companies. The fuel handling and DCS transportation equipment, while unique to the nuclear power plants facilities, can be designed and manufactured by several companies.

Development of new on-site storage facilities, such as the one currently being done for Darlington, and expansion of the storage capability at power plants that already have some dry storage capability, will require environmental assessment and public consultations. The requisite capabilities are subsets of the ones identified in section 1.

All 14 of the large integrated companies have expertise and capabilities to conduct the tasks under the Study and Site Selection phases, and 24 of the other companies could contribute to the Study Phase, and 16 to Site Selection.

With the exception of CANATOM, the other 14 large integrated companies would be able to conduct the Environmental Assessment and Site Approval Phase, with 18 other companies offering selected expertise and partial capabilities. Companies that specialize in this type of work include Gartner Lee, Golder Associates, and SENES Consulting.

Preliminary Design and Facility Approval requires companies with significant engineering expertise and capabilities. Three of the companies that have full capability for the common tasks do not have sufficient engineering in-house expertise to be regarded as fully capable to handle all the tasks. These are Gartner Lee, Nuclear Safety Solutions, an SENES Consulting. The above companies, as well 20 others, would still have significant levels of expertise and partial capability for this phase of the project.

Design and Construction requires capabilities beyond those required for the preliminary design. Consequently, somewhat fewer companies have the desired expertise and capabilities, but with 10 companies having full and 20 with partial capability, there are more than enough resources to conduct this phase of the project.

The operation of the on-site dry storage facilities has been managed by the three Canadian nuclear utilities as well as AECL. OPG and AECL are regarded as fully capable in this area, as they have most of the required expertise in-house. Quebec Hydro and NB Power rely on AECL for engineering design. Six other companies have the expertise, resources and experience to be able to take on the tasks involved in managing the operational phase of on-site dry storage of fuel: Acres, AMEC, Framatome, SAIC, Stone & Webster and Wardrop. Companies that would offer partial capability are mostly in the environmental and safety analysis area, and they may be called upon for periodic relicensing and public communication purposes.

The following table summarizes the number of companies and level of capability they have to support the various phases of on-site dry storage of spent fuel, and the number of experts in each of these groups of companies.

Project Phase	number of companies		number of expert staff
	full capability	partial capability	
Study	14	24	340
Site Selection	14	16	290
Environmental Assessment and Site Approval	13	18	375
Preliminary Design and Facility Approval	11	23	375
Design and Construction	10	20	305
Operation	8	7	140

This level of expertise and capabilities, if maintained until the various project phases are scheduled to be performed, is judged to be sufficient to implement the continued storage of spent fuel at the nuclear power plant sites.

3. Expertise and Capabilities for Deep Geological Disposal in the Canadian Shield

The Governments of Canada and of the Province of Ontario initiated the Canadian Nuclear Fuel Waste Management Program (CNFWMP) in 1978 to develop a concept for the safe and permanent disposal of nuclear fuel waste. Under this program, Atomic Energy of Canada Limited (AECL) performed research and development on the technical and scientific basis for the direct disposal of nuclear fuel waste.

The waste disposal method developed by AECL for the CNFWMP is a multibarrier concept based on deep geological disposal (Figure 6). Under this concept the used fuel would be placed in a vault, about 500 to 1,000 metres deep in stable rock formations, such as the Canadian Shield. The vault would be a network of horizontal tunnels and disposal rooms, similar to a conventional hard rock mine. Containers of waste would be placed in the disposal rooms. When a disposal room is full, it would be filled and sealed with buffer and backfill material. When the entire facility is filled, the rooms, shafts and tunnels would also be filled with the same sealing materials. The combination of engineered and natural barriers are designed to protect human health and the natural environment in the long term.

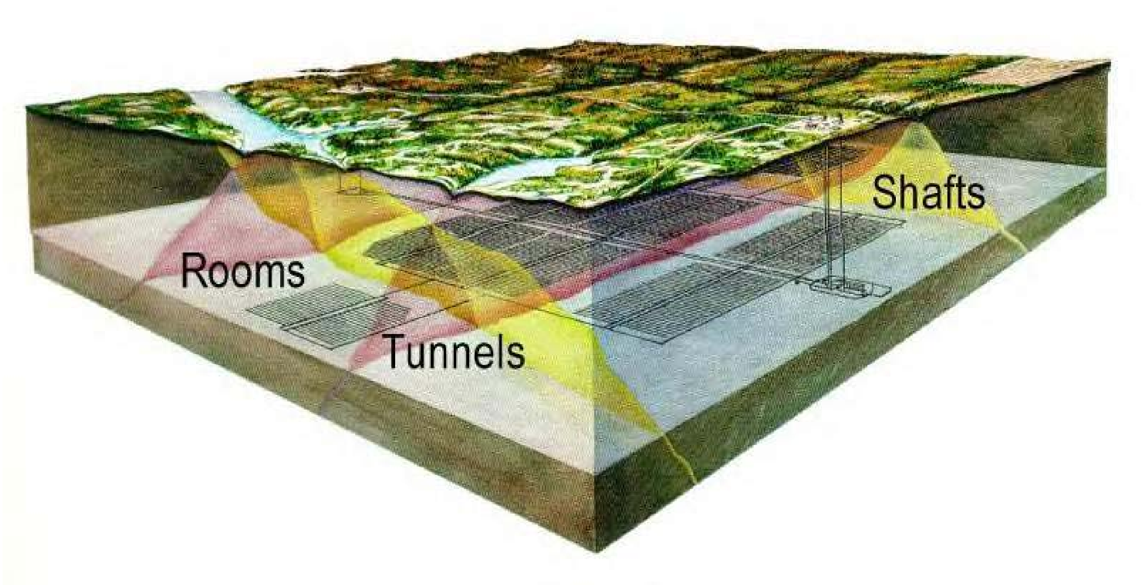

Figure 6. Deep geological HLRW disposal concept (AECL).

Since the likely disposal sites are at significant distances from the currently operating nuclear power plants, transportation and handling radioactive material requirements need to be considered. These include the preferred methods of transporting the spent fuel by rail, ship or truck, the development and licensing of fuel casks, loading and unloading equipment, establishing shipping routes and procedures, before spent fuel can be moved from the power plants to the disposal facility.

3.1 Types of expertise and capabilities for deep geological disposal in the Canadian Shield

The concept of deep geological disposal developed and demonstrated by AECL at the Whiteshell Underground Research Laboratory was recognized by the Seaborn Panel as being technically acceptable. However, gaining the necessary approvals for an actual disposal site, the design, construction, operation and eventual closure of such a facility, will require a wide variety of expertise and capabilities. The expertise and capabilities that are common to all alternatives were identified earlier. This section summarizes the additional unique knowledge and experiences required in order to implement the disposal of spent fuel in a deep geological formation in the Canadian Shield.

The regulatory framework governing the transportation and disposal of radioactive wastes is designed to protect workers, the public, their progeny and valued ecosystem components such as soil, surface water, ground water, air, plants and animals, from both radiological and non-radiological constituents of the waste.

From a regulatory and licensing perspective, two key periods in the life cycle of the wastes need to be distinguished:

- the preclosure period includes design, licensing, construction, operation, decommissioning and closure of the disposal facility; transporting the wastes to the facility; and extended monitoring of the performance of the disposal facility after decommissioning;
- the postclosure phase commences once the disposal facility is sealed and closed and spans many thousands of years while the disposal system remains passively safe, without the need for institutional controls.

Assessment methodologies are needed for estimating the preclosure and postclosure effects of a geologic disposal facility on occupational safety, the health of workers and the public, non-human biota and the natural environment, and the socio-economic environment. These include probabilistic and deterministic safety assessment methodologies. The probabilistic methodology is uniquely suitable to account for system sensitivities and uncertainties. Sensitivity analyses are used to evaluate how siting and design constraints and variations in site characteristics, design parameters and repository layouts affect system performance. Uncertainty analyses are used to evaluate the large variability and uncertainty associated with the long-time frames.

An Environmental Impact Statement (EIS) needs to be prepared, according to guidelines issued by an Environmental Review Panel established by the Canadian Environmental Assessment Agency. It has to fully describe all aspects of a site-specific spent-fuel disposal project, and be subjected to extensive review during public hearings.

The expertise and capabilities required to prepare an Environmental Impact Assessment, to design, construct and operate a spent fuel disposal facility deep in the Canadian Shield include:

Site and Facility Studies

- site screening and site selection
- site investigation and characterisation
- geochemistry of radionuclides
- groundwater flow and mass transport modelling
- disposal facility conceptual design studies
- container spacing – temperature and criticality constraints
- waste emplacements arrangements: in-floor borehole vs. in-room
- performance and safety assessment (e.g., mathematics, physics, computer science)
- costing the repository life cycle from the siting, through construction, operation and decommissioning and ending with the closure and monitoring
- developing and demonstrating a repository and geosphere system safety assessment methodology
- facility decommissioning and closure options, long-term monitoring, nuclear material safeguards and security

Facility Sciences

- environmental science (e.g., biology, limnology, climatology, meteorology, ecology, microbiology)
- geology and geophysics
- hydrogeology and hydrology
- geochemistry and hydrogeochemistry
- characterizing and modelling spent-fuel dissolution
- characterizing candidate corrosion-resistant materials for spent-fuel disposal containers
- developing and modelling durable spent-fuel disposal-container designs
- characterizing and modelling the thermal-mechanical-hydraulic-hygroscopic interactions for the rock-mass, engineered-barrier and groundwater systems
- characterizing and modelling radionuclide transport in the engineered barriers and geosphere
- characterizing candidate sealing and backfilling materials for a repository

Repository Engineering

- geotechnical engineering
- rock mechanics
- engineering repository conceptual designs consistent with the conditions of the geosphere, candidate disposal containers and candidate sealing and backfilling systems
- engineering barrier materials characterization and engineering
- instrumentation and field testing
- sealing materials and methods

- developing and modelling seal and backfill designs for major components of a repository
- backfill and sealing systems design
- major structures and water conducting features
- repository layout
- waste and container handling
- rock-recycle and concrete-batch plants
- environmental and performance assessment technology
- nuclear material safeguard containment/surveillance measures, and site security
- disposal facility closure

Surface works

- spent-fuel receipt and packaging plant
- radioactive and nonradioactive materials handling and processing
- spent-fuel container-fabrication plant
- remote site infrastructure

Underground works

- underground construction technology
- repository shafts and access tunnels with single and multiple levels
- waste disposal rooms using in-floor borehole or in-room waste emplacement configurations
- repository layouts and disposal-room configurations designed (thermal-mechanical-hydraulic responses) for site conditions (e.g., geological structures, groundwater inflow, in-situ stresses, geothermal gradient, wasteform heating, conductive heat transfer, thermal expansion, sealing and backfill system)
- backfill and sealing materials preparation plant and distribution system

Transportation of spent fuel from the reactors sites to the disposal facility

Commissioning and operation of the disposal facility

3.2 Canadian expertise and capabilities for the deep geological disposal in the Canadian Shield

There is a wide array of expertise and capabilities needed for the deep geological disposal of spent fuel in the Canadian Shield, as summarized earlier. Some of these can be shared with the knowledge and experience companies gained on other large, technically difficult, environmentally and politically sensitive projects, while others are unique to the management of high-level radioactive waste. A great deal of the required unique expertise and capabilities were developed and demonstrated during the Canadian Nuclear Fuel Waste Management Program (CNFWMP) between 1978 and 1994, and the Deep Geologic Repository Technology Program (DGRTP), conducted between 1994 and 2002.

OPG plans to maintain and further develop the expertise and capability to implement a used fuel disposal program, through the involvement of several Canadian companies and universities. The technology base is being enhanced through diversification that includes cooperative projects between OPG, its partners, and agencies doing similar work in other countries, such as Sweden, Finland and Switzerland. (Reference R-1-29).

All 14 of the large integrated companies have expertise and capabilities to conduct the tasks under the Study and Site Selection phases, and 23 of the other companies could contribute to the Study Phase, and 16 to Site Selection.

With the exception of CANATOM, the other 14 large integrated companies would be able to conduct the Environmental Assessment and Site Approval Phase, with 18 other companies offering selected expertise and partial capabilities. Companies that specialize in this type of work include Gartner Lee, Golder Associates, and SENES Consulting.

Preliminary Design and Facility Approval phase requires companies with significant engineering expertise and capabilities. Four of the companies that have full capability for the common tasks do not have sufficient in-house expertise to be regarded as fully capable to handle all the tasks. These are CANATOM, Gartner Lee, Nuclear Safety Solutions, and SENES Consulting. A combination of some of these companies would also have the required capability. These companies, as well 21 others, would still have significant levels of expertise and partial capability for this phase of the project.

Design and Construction require capabilities beyond those that are necessary for the preliminary design, so somewhat fewer companies have the desired expertise and capabilities, but with 10 companies having full and 20 with partial capability, there are more than enough resources to conduct this phase of the project.

The Underground Research Laboratory (URL) at Whiteshell was designed to model a deep geological disposal facility. The URL has been managed by AECL, and although the URL is likely to be shut down in the near future, for the time being AECL can be regarded as fully capable in this area However, unless funding is made available to keep the people and facilities working in areas relevant to deep geological disposal, this expertise and capability will atrophy. Cameco and COGEMA Resources operate underground uranium mines, and have many of the operating capabilities that would be needed to operate a spent fuel disposal facility deep in the Canadian Shield. Given sufficient lead time, seven other companies have the expertise, resources and experience to be able to take on the tasks involved in managing the operational phase of an underground repository: Acres, AMEC, Framatome, OPG, SAIC, Stone & Webster and Wardrop. Companies that would offer partial capability are mostly in the environmental and safety analysis area, which may be called upon for periodic relicensing and public communication purposes.

The following table summarizes the number of companies and level of capability they have to support the various phases of deep geological disposal of spent fuel in the Canadian Shield, and the number of experts in each of these groups of companies.

In summary, although much additional work in both the technical and the socio-economic areas remains to be done, the level of expertise and capabilities, if maintained until the various project phases are scheduled to be performed, is judged to be sufficient to implement the deep geological disposal of spent fuel in the Canadian Shield.

Project Phase	number of companies		number of expert staff
	full capability	partial capability	
Study	14	23	400
Site Selection	14	16	335
Environmental Assessment and Site Approval	13	18	455
Preliminary Design and Facility Approval	10	25	420
Design and Construction	10	20	390
Operation	10	5	260

4. Expertise and Capabilities for Centralized Storage, either Above or Below Ground

The need for centralized storage of spent fuel is expected to be the result of the requirement to return the existing nuclear power plant sites to their original status, or to make them available for some other use that excludes the presence of HLRW on the present sites.
While it is unlikely that above ground storage would continue indefinitely, such a storage method could exist for several hundred years. If the centralized storage facility were to become available within a fairly short time relative to the time the irradiated fuel was placed into dry storage (less than 50 years), then the radioactive fuel could continue to be shipped to and stored in the original container at the new site, or in a container of the same design, but constructed at the centralized facility. If the time already spent on-site in dry storage is more than 50 years, the resulting reduction in radioactivity levels may permit the construction of simpler and less expensive storage containers than the ones currently in use, while still providing the required levels of protection. In either case, the type and nature of the expertise and capabilities are expected to be similar to what they are today. Any evolution in the technology is expected to be ongoing, since the dry storage of spent nuclear fuel is likely to continue.

The techniques and containers used for below ground storage also depend on the radioactivity of the fuel, as well as on the geology of the host material, the depth below the surface, and the choice of being a long-term storage versus permanent disposal type of facility. Transportation methods are not expected to be significantly different from the techniques already considered for the previous two methods.

4.1 Types of expertise and capabilities for centralized storage

-
- Most of the expertise and capabilities that are required for above or below ground centralized storage will be similar to those required for either the on-site dry storage, or the deep geological disposal methods. Some of the specific project implementation tasks that will be needed for the centralized storage alternative are:
- studies of the various options for centralized storage will need to be conducted, such as casks and vaults in storage buildings (above ground)
- casks and vaults in shallow trenches (excavations below the ground surface)
- storage in modular vaults (above ground), and
- casks in rock caverns (near surface underground facility)

In general, the expertise and capabilities that will be required to develop and implement one of these four or another, but similar option, overlap with those required for the Deep Geological Disposal and Reactor-Site Extended Storage Options. The specific applications for which expertise and capabilities will be required include:

- site investigation and characterization (geosciences, modelling, engineering)
- geochemistry of radionuclide
- groundwater flow modelling and mass transport
- geotechnical engineering

- facility conceptual design studies
- transportation mode and route analysis
- design and fabrication of dry storage containers for spent fuel
- site development (infrastructure design and construction)
- design and manufacture of centralized fuel handling and transportation equipment
- design and construction of centralized infrastructure
- design, construction and operation of transportation infrastructure from power plants to disposal facility
- operation and maintenance of centralized waste management facility

4.2 Canadian expertise and capabilities for centralized storage

Since the centralized storage of spent fuel is an alternative that is a variation on either the on-site dry storage, or the deep geological disposal technique, the required expertise and capabilities are a combination of what had been presented in the previous two sections. Every Canadian company that has been identified in this paper has some relevant expertise and capability to participate in the study phase of the various options, as well as in one or more of the implementation phases.

In the table below the staff levels are conservative to the extent that for each company I used the larger of the staff level numbers from the previous two alternatives.

Project Phase	number of companies		number of expert staff
	full capability	partial capability	
Study	14	26	440
Site Selection	14	18	365
Environmental Assessment and Site Approval	13	20	465
Preliminary Design and facility Approval	11	26	480
Design and Construction	10	22	450
Operation	10	7	270

5. Expertise and Capabilities for Other Approaches

As indicated in the Introduction, currently envisaged approaches for the management of spent nuclear fuel, other than the three alternatives already discussed, are based on the reprocessing of the fuel as part of the back-end of the nuclear fuel cycle.

During the last decade, interest in partitioning (i.e. the separation of long-lived isotopes from the fuel waste) and transmutation has grown in many countries around the world. In the years to come partitioning and transmutation (P&T) technology is expected to be one of the key technologies for nuclear waste management. If the long-lived nuclides are removed from the spent fuel and eliminated by P&T technology, the requirement for the permanent disposal of spent nuclear fuel may no longer exist, as centralized storage facilities with a life-time of 300-500 years would be able to safely store the materials left in the reprocessed fuel waste. This conclusion is not universally shared, there is a body of opinion holding the view that even if reprocessing and P&T are implemented, some long-lived isotopes will remain, requiring disposal in deep geologic repositories. It should also be noted that the possibility of re-cycling the used fuel and making use of its energy content suggests an interest in retrievability. The best way to achieve retrievability is long term storage, whether above or below ground, rather than permanent disposal.

The companies with expertise and capabilities in spent fuel reprocessing, transmutation, and the subsequent disposal of the remaining nuclear wastes are summarized in this section. If and when approaches other than the ones already discussed are proposed, the materials and technologies required to design, construct and operate such a facility will need to be considered, along with the expertise and capability needed to implement such a technology.

Fuel reprocessing has two main purposes: recovery of fissile materials, principally U-235 and Pu-239, and the separation of long-lived nuclei to reduce the volume of these isotopes in the waste that has to be stored. Extraction of Pu-239 has long been practiced for the purpose of weapons productions, and each of the nuclear weapon states has capability for this task. Extraction of Pu-239 and U-235 is also done for the purpose of recycling unused fuel, and recycled fuel is used in both France and Japan. COGEMA S.A. of France, the parent company of COGEMA Resources Inc., is part of the Areva Group of companies, of which Framatome ANP is also a member. It is not expected that any significant levels of spent CANDU fuel reprocessing would take place in Canada, and if large quantities of Canadian spent fuel were to be reprocessed by COGEMA S.A., it would be handled by one of its Canadian subsidiaries, such as COGEMA Resources or Framatome.

Canada is not involved in the reprocessing of spent fuel for the purpose of extracting Pu-239 for use in nuclear weapons, and given the low U-235 and Pu-239 content of spent CANDU fuel, its reprocessing for the purpose of fuel recycling is not expected to be economical. The technical and socio-economic aspects of recycling CANDU fuel for the purpose of waste management require further studies, but it is not currently expected to be a preferred approach.

AMEC has been involved with fuel reprocessing at Sellafield in the UK, and SAIC at various locations in the USA. AECL has the facilities and some experience in fuel reprocessing, but there are no established significant levels of expertise and capability in Canada at the present time.

GLOSSARY:

ACTINIDES:

Isotopes produced when Uranium nuclei absorb one or more neutrons (also called “transuranic elements”).

ACTIVATION PRODUCT:

Radionuclide formed when the nucleus of an atom captures a neutron. (Actinides are activation products of Uranium).

BACKGROUND RADIATION:

Radiation doses received by the public from sources other than nuclear facilities. These sources can be broadly categorized as: 1. naturally occurring radiation (see 'natural background radiation'), 2. fallout from nuclear weapons testing, 3. radionuclides present in the environment due to technological processes other than the operations of nuclear facilities, 4. irradiation from consumer products and services and, 5. medical diagnostic and therapeutic radiological processes.

BARRIER:

A feature of a disposal system which delays or prevents radionuclides from escaping from the disposal vault and migrating into the biosphere. A "natural barrier" is a feature of the geosphere in which the disposal vault is located. An "engineered barrier" is a feature made by or altered by man and is typically part of the waste package or part of the disposal vault.

BENTONITE:

Absorptive colloidal clay consisting of altered volcanic ash. Sodium-rich bentonite has a particular attraction for water and swells when wet. It is being considered as a major component of the buffer material used in a disposal vault.

BIOSPHERE:

Although usually defined as the portion of the earth inhabited by living organisms, in the CNFWMP this word has a more specific meaning. In aquatic areas the biosphere/geosphere interface occurs between the deep compacted and the shallow mixed sediments, and in terrestrial areas the interface is formed by the water table. Thus, the biosphere includes mixed sediments, surface waters and fish, soils, plants, animals and humans, and the lower parts of the local atmosphere.

CANADIAN NUCLEAR FUEL WASTE MANAGEMENT PROGRAM (CNFWMP):

A program established by a 1978 Joint Statement by the Federal Government and the Government of Ontario "...to assure the safe and permanent disposal" of nuclear fuel waste. AECL was made responsible for researching and developing the concept of disposal of nuclear fuel waste in a deep underground repository in intrusive igneous rock in the Canadian Shield. Ontario Hydro was made responsible for studying interim storage and transportation of used fuel. Other organizations that have contributed to the program over the years include Energy, Mines and Resources Canada, Environment Canada, universities and companies in the private sector. A second Joint Statement in 1981 imposed the restriction that no site could be selected before the concept had been assessed, reviewed and accepted.

CANADIAN SHIELD:

An extensive area of Precambrian rocks exposed over large parts of central and eastern Canada. Approximately, it lies to the east of a line passing through Great Bear Lake, Great Slave Lake, Lake Athabasca and Lake Winnipeg, and to the north of the continuation of this line through Lake Superior, Lake Huron and the St. Lawrence River. It is composed of metamorphic and igneous rocks. orogenic events have occurred over different parts of the Shield at various times but some parts have been free of such activity for about 2.5 billion years. Almost the entire Shield has been stable for the last 900 million years.

CASK:

See "container cask" or "transportation cask", the terms used in the CNFWMP.

CHARACTERIZATION:

In the CNFWMP, the surface and subsurface investigation of a region, area, or site to determine the conditions in the geosphere, biosphere, and human communities. For potential disposal sites, the data obtained would be used for site selection, facility design, and performance assessment. Many of the measurement instruments installed for characterization would also be used for monitoring. Characterization would be a major activity during the siting stage, and would continue at the selected site during the construction, operation, decommissioning, and any extended monitoring stages.

CLAY:

Minerals that are essentially hydrous aluminium silicates or occasionally hydrous magnesium silicates, with sodium, calcium, potassium and magnesium cations. Also denotes a natural material with plastic properties which is essentially made up of fine to very fine particles. Because of good sorption characteristics, certain types of clay are being considered by some countries as a barrier around the waste emplaced in a disposal vault.

CNFWMP:

See “Canadian Nuclear Fuel Waste Management Program”

COMMISSIONING:

Phase of the project between construction and operation where all systems are tested and prepared for full operation.

CONCEPT, WASTE MANAGEMENT:

A set of ideas and principles, and their associated technologies, that constitute a practical method for the disposal of nuclear fuel waste.

CONCEPTUAL DESIGN:

A comprehensive technical description consisting of the facilities, processes, procedures and services needed to handle, package and dispose of nuclear fuel waste. A conceptual design was produced for specific uses in the CNFWMP. See "Used-Fuel Disposal Centre".

CONTAINER:

A durable receptacle for enclosing and isolating radioactive wastes for disposal. In a disposal vault, the containers would serve as one barrier between the waste form and the human population. Sometimes called "waste container" and "disposal container".

CONTAINER CASK:

A heavy shielding vessel in which disposal containers would be transported within a used-fuel disposal facility. It would provide radiological protection during the transfer of the disposal containers from the surface packaging plant to the underground emplacement boreholes.

CONTAINMENT:

1. For a waste disposal system, the retention a radioactive material in such a way that it is effectively prevented from being dispersed into the environment, or released only at an acceptable rate. 2. The structure(s) used to affect such retention.

CRITICALITY:

The conditions in which a system is capable of sustaining a chain reaction of nuclear fission without an additional source of neutrons; that is, the rate of production of neutrons is precisely equal to the rate of loss of neutrons. A supercriticality condition occurs when the chain reaction produces more neutrons at each step than are consumed; the chain reaction is then divergent and the power being released may increase very rapidly. A subcritical condition occurs when each stage of the chain reaction produces fewer neutrons than it consumes.

DAUGHTER:

see “Decay Product”.

DECAY PRODUCT:

Nucleus resulting from a radioactive decay.

DECOMMISSIONING:

The actions required, in the interests of health, safety, security and protection of the environment, to permanently retire a nuclear facility from active service, possible including decontamination of the site. In the CNFWMP, decommissioning of disposal facilities includes the work required to permanently retire the surface facility and surrounding site at the used-fuel disposal centre, leaving it in an end-state that protects the health and safety of the general public and the environment.

DECONTAMINATION:

The removal of radioactive contaminants with the objective of reducing the residual radioactivity level in or on materials, persons or the environment.

DISPERSION:

1. The combined effect of transport, diffusion and mixing which tend to distribute materials from wastes or effluents through an increasing volume of water, air or soil, with the ultimate effect of diluting the materials. 2. In

hydrogeology, the diffusing and mixing of two fluids of different composition due to velocity variations in a geologic medium.

DISPOSAL:

A permanent method of long-term management of radioactive wastes in which there is no intention of retrieval and which, ideally, uses techniques and designs that do not rely for their successes on long-term institutional control beyond a reasonable period of time.

DISPOSAL CENTRE:

See "Used Fuel Disposal Centre".

DISPOSAL FACILITY:

Similar to Used Fuel Disposal Centre but more general. In simple terms, a disposal vault and the supporting surface facilities.

DISPOSAL SYSTEM:

The components and activities by which the safe disposal of waste is achieved. In the preclosure phase, a facility for the safe, permanent isolation of nuclear fuel waste plus the transportation facilities needed to bring the waste to it from interim storage sites.

DISPOSAL VAULT:

A network of horizontal tunnels and disposal rooms excavated deep in the rock, with vertical shafts extending from the surface to the tunnels, for the purpose of disposing of nuclear fuel waste. In the preclosure phase, the disposal vault would include the underground excavations in plutonic rock, the access shafts, access tunnels, underground service areas and installations, and disposal rooms. In the postclosure phase, it would include the disposal rooms and associated access tunnels, the nuclear fuel waste and the engineered barrier systems used to contain the waste and seal all openings.

DOSE:

A general term denoting the quantity of radiation or radiation energy absorbed by a specified mass of a substance. "Dose" is often qualified to refer to specific quantities, and to an individual versus a group of people; examples are: absorbed dose, dose equivalent, effective dose equivalent, committed effective dose equivalent, and collective dose.

EARP

See “Environmental Assessment and Review Process”.

EIS:

See: “Environmental Impact Statement”.

ENVIRONMENT:

The circumstances, objects, or conditions surrounding an organism or facility. In the case of a human, the environment includes:

- air, land, water, plants, and animals (the natural environment) - humans
- social and economic systems created by humans (human communities or the socioeconomic environment)
- physical objects created by humans, including buildings and machines
- materials, emissions, and vibrations resulting from human activities.

ENVIRONMENT, BIOPHYSICAL:

See "biosphere", the preferred term in the CNFWMP.

ENVIRONMENT, NATURAL:

All the conditions and influences, not human-derived, surrounding an organism, human or otherwise, that affect its life, survival, and development, excepting, in the case of humans, those factors covered under "social environment". It includes the biosphere and geosphere.

ENVIRONMENT, SOCIAL:

For the purpose of the EIS, the socio-economic and cultural characteristics of the people living in nearby communities or along the transportation routes that would be affected by the presence of a waste disposal facility or its transportation system.

ENVIRONMENTAL ASSESSMENT PANEL:

A group of individuals appointed by the federal Minister of the Environment under the EARP (see this term) to examine an environmental issue or a project with potential environmental consequences.

ENVIRONMENTAL EFFECT:

For the EIS preclosure assessment, a change to the social and/or natural environment caused by the activities associated with the transportation or disposal of nuclear fuel waste. Social (or socio-economic) effect which are considered to be significant, by the affected community(s), are referred to as impacts. See also 'environmental impact' and 'radiological impact'.

ENVIRONMENTAL IMPACT:

Often used interchangeably with 'environmental effect'. For purposes of this assessment, impact generally refers to a socio-economic effect that is considered to be significant by the affected community(s). See also 'radiological impact'.

ENVIRONMENTAL IMPACT STATEMENT (EIS):

In the CNFWMP, the Environmental Impact Statement on the Concept for Disposal of Canada's Nuclear Fuel Waste, a general Summary and the supporting Primary References are the documents recording the results of the Canadian Nuclear Fuel Waste Management Program for assessing a waste disposal concept and the environmental impacts of its implementation. The documents are to conform to the requirements specified in the Guidelines issued by the Environmental Assessment Panel reviewing the concept.

ENVIRONMENTAL ASSESSMENT AND REVIEW PROCESS (EARP)

Federal policy on environmental assessment and review introduced in 1984, but is no longer in force, having been replaced in January 1995 by the Canadian Environmental Assessment Act.

EXPOSURE:

Irradiation of persons or materials. Exposure of persons to ionizing radiation may be either external, from sources outside the body, or internal, from sources inside the body.

FISSION PRODUCT:

A nuclide produced either directly by nuclear fission or by the subsequent radioactive decay of a radionuclide produced by fission.

FUEL:

See "nuclear reactor fuel".

FUEL ASSEMBLY:

See "fuel bundle", the term used in the CNFWMP.

FUEL BAY:

A facility for storing spent nuclear fuel under water, typically located at each nuclear generating station..

FUEL BUNDLE:

A number of fuel elements held together by end plates and separated by spacers attached to the fuel cladding near the middle of the bundle.

FUEL CYCLE:

See "nuclear fuel cycle".

FUEL DEFECT:

Any flaw in the fuel or cladding from manufacturing or as a result of operational history that could lead to cladding failure and potential radioactive releases.

FUEL ELEMENT:

In a CANDU fuel bundle, the unit which consists of a tube of zirconium alloy containing ceramic fuel pellets of uranium dioxide and sealed at the end with welded zirconium alloy plugs.

FUEL RECYCLING:

Reprocessing used nuclear fuel and recovering the useful materials, such as plutonium and uranium, to make new fuel that could then be used in a reactor to produce electricity.

FUEL WASTE:

See "nuclear fuel waste".

GEOLOGICAL DISPOSAL:

All approaches to the long-term management of nuclear fuel wastes that depend upon placing the wastes underground in a selected host medium to isolate the wastes from humans and the environment.

IAEA:

See: “International Atomic Energy Agency”.

INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA):

The organization established in 1957 by the United Nations as the international body responsible for on-site nuclear reactor inspections and safeguards measures that assist the member states of the Agency to demonstrate that no nuclear material is diverted to non-peaceful purposes from safeguarded nuclear facilities.

IRRADIATED FUEL:

See "Used Fuel".

ISOTOPE:

An atom. Different isotopes of an element have the same atomic number (or number of protons) but a different mass number (protons plus neutrons). Some elements have many isotopes. All isotopes of an element have the same chemical properties, but slightly different physical properties. Radioactive isotopes are called radioisotopes.

LICENSE:

In the nuclear industry, a formal document issued by a regulatory agency for major stages in the development of a nuclear facility which permits the implementing organization to perform specified activities.

LONG-LIVED WASTE:

Radioactive refuse that will not decay to an acceptable activity level in a period of time during which administrative controls are expected to last.

LONG-TERM:

In waste management, refers to periods of time that exceed the time during which administrative controls can be expected to last.

MITIGATE:

To reduce or offset negative socio-economic or biophysical environmental effects.

MITIGATIVE MEASURES:

Actions taken to alleviate the detrimental impacts of an event or continuing activity. They can include actions to avoid, minimize, correct, eliminate or compensate for negative impacts.

MODEL:

An analytical or mathematical representation or quantification of a real system and the ways that the phenomena occur within the system. Individual or sub-system models can be combined to give system models.

MODELLING:

The creation or application of a mathematical representation of a physical, biological or geological system. The mathematical representation is often converted into computer code so that the system can be examined in more detail.

MONITORING:

In the CNFWMP, monitoring would consist of the continuous or intermittent measurement of conditions in the region influenced, or potentially influenced, by the presence of the disposal facility and associated transportation system. Monitoring would be done to determine baseline conditions and to identify any changes from baseline conditions. Parameters indicating conditions in the disposal vault, geosphere, biosphere, and human communities would be measured. Monitoring would be initiated early in the siting stage and would be continued until closure. It could also be continued after closure if required by regulators and/or the public, provided that institutional controls would not be required to maintain the safety of the vault.

MULTIBARRIER:

In a disposal vault, a system using two or more independent means for isolating waste from the biosphere. These can include the waste form, the container, other engineered barriers and the emplacement medium and its environment. See also “barrier”.

NATURAL BACKGROUND RADIATION:

The various types of radiation not made by man, including: 1. External sources of extra-terrestrial (cosmic rays) and terrestrial origin (the radioactive isotopes present in the crust of the earth, the water and the air), and 2. Internal sources, i.e. the radioactive isotopes of potassium and carbon, which are normal constituents of the human body, and other isotopes, such as radium-226 and thorium-232 and their decay products, which are ingested from the environment and retained in the human body.

NATURAL BARRIER:

See "barrier".

NON-PROLIFERATION TREATY:

See "Treaty on the Non-Proliferation of Nuclear Weapons".

NUCLEAR FACILITY:

A facility and its associated land, buildings and equipment in which radioactive or fissionable substances are produced, processed or handled on such a scale that considerations of nuclear safety are required.

NPT:

Non-Proliferation Treaty. See "Treaty on the Non-Proliferation of Nuclear Weapons".

NGS:

See: “Nuclear Generating Station”.

NUCLEAR FUEL CYCLE:

The fuel handling processes required for power production, including obtaining, using, storing, reprocessing and disposing of the nuclear materials used in the operation of nuclear reactors. Also called "fuel cycle".

NUCLEAR FUEL WASTE:

A solid that is either the fuel that has been used in a nuclear power reactor (used fuel) or a waste form incorporating the highly radioactive waste that would be removed from the fuel if the fuel were to be recycled.

NUCLEAR GENERATING STATION (NGS):

One or more nuclear reactors, together with the structures, systems and components necessary for safety, and for the production of power in the form of heat or electricity. Also called 'nuclear power plant'.

NUCLEAR INSTALLATION:

See "nuclear facility".

NUCLEAR REACTOR:

A structure in which a chain reaction of nuclear fission is initiated and controlled with the consequent production of heat, which is typically used for power generation. Another application may be produce radioactive compounds for experimental or medical purposes.

NUCLEAR REACTOR FUEL:

Fissionable and/or fertile material which is the source of energy when placed in a near-critical arrangement in the core of a nuclear reactor. CANDU fuel consists of uranium dioxide pellets, stacked and sealed inside metal tubes. As many as 37 tubes are then welded together to make a fuel bundle.

NUCLEAR SAFETY:

The protection of people and property from the harmful effects of radioactive contamination, exposure to ionizing radiation, or a criticality excursion. In this context, the term “ionizing radiation” may or may not include X-radiation produced by an X-ray machine, depending on national usage. Also known as “radiological safety”.

NUCLIDE:

A species of atom characterized by the constitution of its nucleus: the number of protons, the number of neutrons, and the mass.

PATHWAY:

In performance assessment, the route through the biosphere taken by contaminants as they move from a source to a receptor, such as an individual.

PATHWAY ANALYSIS:

Calculation of the dose to human and non-human biota from a source of radiation by estimating the contribution from different routes or pathways through the biosphere that the radionuclides may take.

PRECLOSURE:

Pertaining to the period of time covering the construction, operation and decommissioning of a disposal vault up to and including the final shaft sealing and surface facility decommissioning. The transportation of used fuel from nuclear generating stations to the disposal facility is also part of the preclosure period.

PRECLOSURE ASSESSMENT:

Safety analysis of the waste disposal system that deals with potential impacts during construction, operation and decommissioning of a disposal facility. It includes an assessment of the transportation of used fuel from nuclear generating stations to the disposal facility.

PROBABILISTIC ANALYSIS:

A statistical method for studying the expected behaviour of a system defined in terms of parameters whose exact values are given as a probability distribution, events whose occurrences are random and/or features which may or may not be present. The analysis gives a corresponding probability distribution of results. See 'deterministic analysis'.

PROBABILITY:

A measure of the degree of belief or frequency of observing the value of a variable in a particular interval (for a continuous variable), or equal to one of a set of discrete values (for a discrete variable). An absolute probability is defined with respect to an exhaustive list of the possible values of the variable; relative probabilities are defined with respect to one another. Frequentist (or "objective") probabilities refer to the expected frequencies of observing different values by continuing a series of identical experiments or samplings; subjective probabilities are defined as the subject's degree of belief that the different values will be observed in a single future observation.

QUALITY ASSURANCE:

Procedures used to provide evidence or demonstrate that the stated degree of quality in a product has, in fact, been achieved. It includes all those planned or systematic actions necessary to provide adequate confidence that a product or service will satisfy given needs.

QUALITY CONTROL:

Actions which provide a means to fix and measure the characteristics of an item, process, facility or person in accordance with quality assurance requirements.

RADIATION:

The very fast nuclear particles and/or photons emitted by nuclei. In the CNFWMP, taken to be synonymous with ionizing radiation. The four major forms of radiation are alpha and beta particles, neutrons and gamma rays.

RADIATION PROTECTION:

Measures associated with limiting the harmful effects of ionizing radiation on people, such as limiting external exposure or bodily incorporation of radionuclides, as well as the prophylactic limitation of bodily injury resulting from either of these. Also, all measures designed to limit radiation-induced chemical and physical damage in materials. Also called 'radiological protection'.

RADIOACTIVE:

Emitting radiation. See “radiation”.

RADIOACTIVE DECAY:

The changing and progressive decrease in the number of unstable atoms in a substance due to their spontaneous nuclear disintegration or transformation into different atoms during which particles and/or electromagnetic radiation are emitted.

RADIOACTIVE MATERIAL:

A substance containing one or more constituents which exhibit radioactivity. For special purposes such as regulations, this term may be restricted to radioactive material with a radioactivity level or specific activity greater than a specified value.

RADIOACTIVE WASTE:

Any material that contains or is contaminated with radionuclides at concentrations or radioactivity levels greater than the 'exempt quantities' established by the regulatory agencies and for which no use is foreseen.

RADIOACTIVITY:

The spontaneous emission of radiation, either directly from unstable atomic nuclei, or as a result of a nuclear reaction.

RADIONUCLIDE:

An unstable nuclide that undergoes radioactive decay.

RECYCLING:

The re-use of fissionable and fertile material after it has been recovered from used nuclear fuel by chemical reprocessing. Also refers to re-use of non-renewable resources. See also "fuel recycling".

RETRIEVABILITY:

A measure of the capability to remove waste from where it has been emplaced.

RISK:

The term risk is commonly used in different ways and is understood in different ways by various segments of society. As used in the CNFWMP, within context, it is the probability that a serious health effect will be suffered by an individual.

RISK ANALYSIS:

A quantified examination of the hazards associated with a practice wherein the possible events and their probabilities of occurrence are considered together with their potential consequences, the distribution of these consequences within the population(s) affected, their distribution over time, and the uncertainties of these estimates.

RISK PERCEPTION:

The intuitive understanding and evaluation of potentially harmful conditions and/or situations. The term is most often used in relation to public attitudes, but is also applicable to experts' perceptions of a wide range of risks.

RISK, CONVENTIONAL:

The non-radiological harmful effects expected from an activity.

ROCKBURST:

A rockburst is the rupture due to natural forces of a volume of rock in situ is such a manner that the energy release can be recorded as a distinct and abnormal seismic event. Rockbursts have been classified in practice as: rockbursts related to a single opening; rockbursts related to geological structure; and rockbursts related to pillar structures.

SAFEGUARDS:

The verification measures taken to detect the diversion of used nuclear fuel or other nuclear materials for weapons manufacture or for unknown purposes. The system is designed to deter diversion through the risk and consequences of early detection by giving timely notification to the International Atomic Energy Agency.

SAFETY ANALYSIS:

The examination and calculation of the potential hazards (risks) associated with the implementation of a proposed activity.

SHAFT:

A vertical access passage excavated from surface to subsurface facilities, and used for transferring personnel, equipment and materials, for ventilation, or for transporting the materials mined or buried.

SHIELDING:

A material interposed between a source of radiation and persons or equipment, etc., to protect them from radiation. Common shielding materials are concrete, water, earth and lead.

SITE CHARACTERIZATION:

See “characterization”.

SITE SCREENING:

In the CNFWMP, the process of identifying a small number of areas that have characteristics desirable for disposal and thus warrant detailed investigation. The activities would include analyzing existing regional scale data (characterization), and developing and applying criteria for accepting or rejecting an area for further investigation.

SITING:

The process of selecting a suitable location for a facility, including appropriate assessment and definition of the related design bases, and numerous other factors.

SOCIAL ENVIRONMENT:

See “environment, social”.

SOCIAL IMPACT:

The significant socio-economic and cultural effects of a waste disposal facility and transportation systems on nearby individuals, communities and regions.

SOCIAL IMPACT ASSESSMENT:

Part of an environmental impact assessment. A systematic identification and evaluation of the socio-economic and cultural impacts that might occur with the implementation of a project, e.g. the construction, operation and closure of a nuclear fuel waste disposal facility and the transportation of used fuel from a nuclear generating station to the facility.

SPENT FUEL:

See “used fuel”, the preferred term in the CNFWMP.

STORAGE POOL:

See “Fuel Bay”.

SURVEILLANCE:

(i) All planned activities performed to ensure that the conditions at a nuclear installation remain within the prescribed limits; it should detect in a timely manner any unsafe condition or degradation of structures, systems and components which could later result in an unsafe condition arising. These activities can be classified as (a) monitoring of individual parameters and system status; (b) checks and calculations of instrumentation; (c) testing and inspection of structures, systems and components; (ii) As used with IAEA Safeguards, the collection of information through devices and/or inspector observation in order to detect undeclared movements of nuclear material, tampering with containment, falsification of information relating to locations and quantities of nuclear material, or tampering with IAEA safeguard devices.

TRANSPORTATION CASK:

A robust shielding vessel which dissipates heat, provides physical containment and radiological protection during the transportation and handling of nuclear fuel waste. In the CNFWMP, transportation casks are assumed to carry used nuclear fuel from generating stations to a disposal facility. Compare with 'container cask'.

TREATY ON THE NON-PROLIFERATION OF NUCLEAR WEAPONS (NPT):

The most significant landmark in the development of safeguards for nuclear materials, this Treaty was created in 1968. Article III of the Treaty specifies that non-nuclear weapons states signing the Treaty must accept safeguards on all source or special fissionable materials "in all their peaceful nuclear activities".

UNDERGROUND DISPOSAL:

See “geological disposal”, the preferred term in the CNFWMP.

UNDERGROUND RESEARCH LABORATORY (URL):

An AECL experimental facility excavated in a granite batholith near the Whiteshell Laboratories, Manitoba. It is used for carrying out subsurface experiments related to rock mechanics, hydroqeoloqy and other disciplines and to demonstrate the technology necessary for safe disposal of nuclear fuel waste. The URL resembles a mine, with a shaft sunk to a depth of about 440m. The main working level is at a depth of 240 m.

URL:

See "Underground Research Laboratory".

USED FUEL:

Nuclear reactor fuel that has undergone fission in a reactor to the point where its further use is no longer efficient due to the buildup of atomic species that hinder the production of heat in the reactor. Sometimes called "irradiated fuel".

USED FUEL DISPOSAL CENTRE:

The land within the disposal site boundaries, the surface and underground site, workings, structures, processes and systems necessary to receive used nuclear fuel in transportation casks, package it in disposal containers, emplace and seal it in a geological medium and provide all the supporting services and systems to do so in a safe and acceptable manner. In the CNFWMP, it is a conceptual design of a used-fuel disposal facility developed for use in concept assessment. The design was used by AECL and Ontario Hydro to assess the engineering feasibility, costs, safety and potential environmental impact of disposing of used nuclear fuel in the manner described in the EIS documents.

VAULT, DISPOSAL:

See "disposal vault".

VERIFICATION:

The process by which one provides evidence or increased confidence that a computer code correctly executes the calculations it is asserted to perform. A verified computer code is one that has correctly translated a specified algorithm into code. Verification can be carried out, for example, by comparing the results of a computer code with results produced by other computer codes or by analytical solutions. Compare with validation.

WASTE DISPOSAL SYSTEM:

The engineered systems (e.g., disposal containers, buffer and backfilled tunnels and rooms, sealed shafts and boreholes) and natural surroundings (e.g., rock and rubble-filled fractures) and local surface biosphere involved in forestalling, retarding and minimizing the effects of any release of waste substances from permanent isolation.

ACRONYMS

ALARA: As Low As Reasonably Achievable

CANDU®: CANada Deuterium Uranium

CEAA: Canadian Environmental Assessment Act

CNFWMP: Canadian Nuclear Fuel Waste Management Program

DSC: dry storage container

DGRTP: Deep Geologic Repository Technology Program

EA: Environmental Assessment

EARP: Environmental Assessment and Review Process

EIS: Environmental Impact Statement

EQ: Environmental Qualification

HLW: High-Level Waste

HLWM: High-Level Waste Management

IAEA: International Atomic Energy Agency

HLRW: High-Level Radioactive Waste

HLRWM: High-Level Radioactive Waste Management

MACSTOR: Modular Air-Cooled Storage

NFWA: Nuclear Fuel Waste Act

NFWB: Nuclear Fuel Waste Bureau

NGS: Nuclear Generating Station

NPT: Non-Proliferation Treaty

NWMO: Nuclear Waste Management Organization

P&T: Partitioning and Transmutation

Pu: the element Plutonium

SIA (SEIA): Socio-Economic Impact Assessment

SRWMF: Solid Radioactive Waste Management Facility

TEK: Traditional Ecological Knowledge

U: the element Uranium

UF_6: Uranium Hexafluoride

UO_2: Uranium Dioxide

URL: Underground Research Laboratory

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8 Canatom NPM
9 Candesco
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12 Detec
13 ECOMatters
14 E.S. Fox
15 Framatome ANP Canada
16 Gartner Lee
17 General Electric Canada
18 Golder Associates
19 Hardy Stevenson and Associates
20 Hydro Quebec
21 Jacques Whitford Environment
22 Kinectrics
23 Marshall Macklin Monaghan
24 New Brunswick Power
25 Niagara Energy Products
26 Nuclear Safety Solutions
27 Numet Engineering
28 Oakhill Environmental
29 Ontario Power Generation
30 RCM Technologies
31 RSRead Consulting
32 SAIC
33 Sanlex
34 SENES Consulting
35 Spectrum Consulting
36 Stantec Consulting
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Appendix A: List and Summary Statement of Canadian Companies with Expertise and Capability in HLRWM

The company summary statements in this appendix were compiled on the basis of the information provide by the companies to the request for information (see Appendix 5) and/or their website. Copies of these documents are available as Reference R-1-#, where # is the number assigned to the company under the list on page 39.

The Acres Group

The Acres Group, with a staff of 1100, is comprised of North American-based infrastructure engineering, planning, construction, consulting and facilities management companies with operations worldwide.

Acres International, based in Oakville, Ontario, provides consulting engineering services for the planning, engineering and delivery of physical infrastructure in the power generation and transmission, transportation, urban infrastructure, industrial, oil and gas sectors. The Company's expertise and capabilities encompass the basic engineering and project execution disciplines: civil, electrical, geotechnical, hydraulic, mechanical, procurement and project services, including economics, planning and environmental management.

Since the early 1970s, Acres has provided a range of services to nuclear plants in North America, and around the world. The Company has had major involvement with CANDU plants and facilities, including projects at the Darlington, Bruce and Pickering facilities in Ontario, Point Lepreau, New Brunswick, in South Korea and Argentina.

Adtech Manufacturing Limited

Adtech Manufacturing Ltd., founded in 1991 and based in Fredericton, New Brunswick, specializes in the design, production and certification of high reliability control systems for hostile environments. The control systems typically integrate hydraulic, fluidic, pneumatic, mechanical electrical and electronic components and subsystems. The hostile environments include high levels of radiation extremes of temperatures and/or pressures, impacts, vibrations and erosion rates.

Products designed and manufactured by the Company are often employed at pressure boundaries encountered in decontamination and radioactive waste reduction equipment and systems. End users of these systems include Ontario Power Generation, New Brunswick Power, and CANDU owners in Korea and China.

AMEC

AMEC, with head office in the United Kingdom, 50,000 employees world-wide and annual revenues over $10 billion, is one of the world's largest engineering services companies. The Company specializes in design, environmental engineering, project delivery and support services in the energy, transport, infrastructure and industrial sectors. The Company's Canadian offices are located in Oakville, Ontario.

AMEC's work in the nuclear sector is focused on the design and delivery of facilities for the retrieval, processing and packaging of 'legacy' waste to a standard that will render it harmless to the environment for many decades to come. In partnership with BNFL, AMEC is managing project elements to restore the environment and eliminate all radiological risks posed by nearly 200 tonnes of nuclear legacy waste currently stored in the B41 silo. AMEC is also responsible for the design, construction and commissioning for the facility, which has a 100-year design life. When completed in 2005 it will provide considerable storage volume for the Plutonium Contaminated Materials that exists from operations performed around the middle of the 20th century.

AMEC expertise and capability in nuclear waste management are in the following areas:

- project management and project services
- engineering
- construction management
- commissioning management

Aqua Terre Solutions Inc.

Aqua Terre, established in 1974, is 100% employee owned, and employs over 150 people worldwide. Corporate headquarters are located in Ottawa, Ontario with other Canadian offices in Toronto, Ontario and Calgary, Alberta. The Company has expertise and capabilities in the areas of environmental assessments, site investigations, remediation, monitoring and environmental management services, including the following areas that are common to all phases and alternatives of HLRWM:

- project management
- environmental impact assessment
- environmental monitoring
- radiological assessment
- waste-form behaviour
- performance assessment
- site screening and site selection
- safety analysis and licensing services to meet regulatory requirements
- risk, cost and benefit analysis
- public consultation and communication

Aqua Terre has experience in using risk assessment methods to evaluate the environmental impacts associated with Contaminated Sites, Construction Projects, Industrial Facilities, Nuclear Waste Disposal Sites and Repositories. Waste Management Services have included Process Evaluation and Optimization, Waste Handling and Storage Procedures, Waste Disposal Site Selection and Disposal Site Operation.

Key Aqua Terre staff have been involved in the Canadian nuclear fuel waste management program since the early 1980s, including the following projects:

- Canadian Nuclear Fuel Waste Management Program (AECL) – field assessment and modelling related to the development of tools and techniques and site characterization of research areas within the Canadian Shield (Chalk River, Atikokan, East Bull Lake, Pinawa).

- CNSC (former AECB) – research programs related to the CNFWMP including assessment of models, inventory and assessment of underground openings and mines in the Canadian Shield, review of subsurface hydrogeologic conditions.
- Environment Canada – modelling of radionuclide transport from a conceptual deep geologic waste repository to the biosphere.
- Ontario Power Generation (former Ontario Hydro) – inventory and assessment of underground openings and mines in sedimentary rock sequences, hydrogeologic testing of sedimentary rocks in southern Ontario.

Atlantic Nuclear Services Limited

Atlantic Nuclear Services Ltd. was founded in 1983 and is a privately owned Canadian corporation. The head office is located in Fredericton, N.B. and a branch office is maintained in Montreal, Q.C. The Company has a staff of thirty professionals and specializes in reactor safety and licensing of CANDU power reactors and has clients throughout the CANDU industry. A core business is the application of information technologies in the design and operation of mission and safety critical systems in order to protect operating staff, the public and the environment while advancing economic development.

The Company has expertise and capability in engineering analysis for safety and licensing requirements, preparation of safety reports for nuclear facilities, probabilistic risk assessment, criticality safety assessments; remote monitoring, diagnostic and intelligent control systems; environmental science, socio-economic impacts and risk assessment; nuclear science including laboratory and measurement services for the medical, environmental, process and manufacturing industries.

Atomic Energy of Canada Limited

AECL is a global nuclear technology and engineering company that designed and developed the CANDU pressurized heavy water reactor, the MAPLE reactors dedicated to the production of medical isotopes and the MACSTOR used fuel storage facility, and it manages the construction of plants and facilities worldwide with international partners.

AECL has more than 50 years' experience in nuclear waste management, and is recognized around the world as a leader in HLRWM. AECL managed the Canadian Nuclear Fuel Waste Management Program (CNFWMP) from 1978 to 1094, with the mandate to develop a concept for the safe and permanent disposal of nuclear fuel waste.

Under this program, AECL performed research and development on the technical and scientific basis for the direct disposal of nuclear fuel waste. Ontario Hydro, (now Ontario Power Generation Inc) conducted studies on interim storage and transportation of spent fuel. The waste disposal method developed by AECL for the CNFWMP is a multi-barrier concept based on geological disposal in the Canadian Shield.

In 1994, AECL submitted the results of the research to the Government of Canada. An

Environmental Impact Statement (EIS), describing the disposal concept and the associated technologies was prepared according to the guidelines of an independent review panel established by the Canadian Environmental Assessment Agency. This Environmental Review Panel submitted its report to the Government of Canada in 1997, and the Government issued a response in 1998 December. The panel concluded that the disposal method proposed by AECL was technologically sound and of high quality.

Between 1994 and 2002, the CNFWMP evolved into the Deep Geologic Repository Technology Program (DGRTP), funded and managed by OPG with technical support from AECL's Waste Technology Business Unit (WTBU).

In summary, with 25 years of experience in managing and performing the CNFWM and DGRT Programs and more than 50 years in managing radioactive waste in Canada, AECL represents a highly qualified technical resource with a skilled and experienced technical staff that can address all aspects of radioactive-waste management including planning, siting, design, operation, performance and safety.

Cameco Corporation

Cameco has its head office in Saskatoon, Saskatchewan. The Company is the world's largest producer of uranium and the largest supplier of combined uranium and conversion services. Cameco is owned 100% by public shareholders.

Cameco has refining and conversion plants in Ontario at Blind River and Port Hope. Cameco supplies about 20% of the western world market for UF_6, and is the world's only commercial converter of natural uranium dioxide (UO_2), the fuel used in the Canadian-built Candu reactor. Cameco produces clean electricity through its 31.6% share of Bruce Power, which leases eight nuclear power plants from Ontario Power Generation.

The Company has full in-house capability for the "front-end" of the CANDU fuel cycle, and through its part ownership of the Bruce Nuclear Power Development, Cameco has a share of the power plant operating expertise. However, the on-site dry storage of spent nuclear fuel on the Bruce site is managed by OPG.

Cameco has extensive expertise in the environmental aspects of the "front-end" of the nuclear fuel cycle. This expertise, along with the other capabilities to manage the "front-end" of the nuclear fuel cycle, could be applied to the "back-end" of the fuel cycle, including the deep geological disposal in the Canadian Shield, and the centralized storage, either above or below ground, alternatives for HLRWM.

CANATOM NPM Inc.

CANATOM NPM Inc. is Canada's largest private sector nuclear engineering, procurement and construction management company and, along with its parent companies: SNC-Lavalin Group and AeCON Industrial, has extensive experience in managing large complex engineering projects worldwide. The Company offers full engineering services including Process, Mechanical, Electrical, Control and Instrumentation, Building and Civil, Nuclear and Production disciplines. These services are integrated by a strong Project Management capability and supported by the latest

Computing and Information Technology Systems. The Company's engineering experience includes conceptual and detailed designs encompassing the specification, design, prototyping, procuring, construction commissioning and decommissioning of nuclear facilities.

CANATOM NPM Inc. and its affiliated organizations have the experience and capability to design, build and operate facilities for the storage and disposal of all forms of radioactive waste. The Company's experience ranges from the operation of delay/decay facilities for the management of short-lived radioisotopes to the design of temporary storage facilities for thousands of cubic metres of contaminated soil, the performance assessment and conceptual design of underground geological disposal sites, and the design and construction of dry fuel storage canisters. Expertise is available in geology, hydrogeology, geochemistry and other disciplines required to provide competent analysis and assessment of all types of radioactive storage facilities.

Many of the CANATOM NPM staff are experienced in the management and operation of nuclear facilities ranging from nuclear power and research reactors to nuclear waste transportation, storage and disposal facilities. The parent and affiliate organizations are all private sector organizations and can bring to the operation and management of nuclear facilities the discipline and economies that must be exercised in order to succeed in private business. The Company's understanding of the hazards, the operating techniques, the risks, the training and licensing requirements associated with the successful operation of nuclear facilities places it in a position to conduct the operation of spent nuclear fuel storage facilities.

Candesco Research Corporation

Candesco is a 100% Canadian-owned company that provides high value-added management and technical services to the energy industry, focusing primarily on the nuclear energy field. Candesco's offices are centrally located in downtown Toronto, Canada.

Candesco staff have extensive experience managing complex multidisciplinary projects and processes in a wide range of areas. These include safety analysis, R&D, regulatory interface, power plant design, engineering analysis software and model development, and software quality assurance for nuclear power plants, research reactors, and similar installations. The Company's personnel have also been heavily involved in many aspects of nuclear plant operation and maintenance, including commissioning, operating and maintaining station systems.

Using expertise in modelling diverse physical and engineering processes, Candesco has participated in the development of a wide range of engineering analysis software. This includes tools for the analysis of fluid and solid mechanics, nuclear physics, statistics, and the environment, which have also been applied to support the licensing of nuclear facilities. Candesco has participated in the establishment of effective, efficient methods for managing the construction and operating licenses for some of the world's largest nuclear facilities, including research, isotope production and power reactors.

COGEMA Resources Inc.

COGEMA Resources Inc., through its parent company COGEMA S.A., is wholly owned by the AREVA Group, an organization committed to the sustainable development of nuclear power facilities around the world. With expertise in exploration and mining, nuclear fuel fabrication and used fuel reprocessing, power plant construction and site decommissioning, the AREVA Group is involved at every stage of the nuclear power cycle. From its head office in France, the AREVA Group operates around the world with 50,000 employees in 30 countries and had 2001 sales revenues of about Cdn. $13 billion, of which approximately 80% were earned in the nuclear industry.

COGEMA Resources Inc. has its head office in Saskatoon, Sasketchawan. The Company owns and operates mining and milling operations at Cluff Lake, is majority owner and operator of the McClean Lake uranium mine, has a 30% share of the McArthur River mine that is operated by Cameco, and is part owner of the Cigar Lake, McArthur River and Key Lake uranium projects.

Decommissioning Consulting Services Limited

Decommissioning Consulting Services Limited (DCS) is a wholly Canadian-owned company established to provide a complete range of environmental services in the fields of site investigation, facility assessment and environmental engineering, design and remediation.

DCS, with its Head Office just north of Toronto in Richmond Hill, Ontario, services Ontario, as well as other Canadian provinces. International locations are also serviced from the Head Office or in conjunction with affiliate offices in Vancouver, Canada; United States and Chile. Since the Company was formed in 1990, over 2000 projects have been completed for a wide range of clients in the public and private sectors.

The Company has expertise in environmental regulatory requirements and practices, civil, mechanical, chemical, mining and geotechnical engineering, as well as hydrogeology, chemistry, industrial hygiene and construction management. DCS also provides project management and construction supervision services associated with site remediation and commercial/industrial facility redevelopment. Typical projects include the assessment of environmental liabilities, subsurface investigations, site cleanup, facility assessment and decommissioning, waste management and geotechnical engineering.

DETEC

DETEC, founded in 1994, is an incorporated company located in Aylmer, Quebec, close to government and academic nuclear laboratories. The Company's staff have extensive experience in the areas of radiation detection technology, DAQ development and high performance computing applied to radiation transport problems.

The Company designs and constructs special purpose detectors and dosimeters, develops data acquisition systems, prepares dose delivery protocols for industrial irradiators, performs shielding calculations and engineering for special projects. DETEC has performed criticality calculations of fuel storage facilities and decommissioning of uranium treatment equipment, as well as working in the radiation protection/health physics fields.

ECOMatters Inc.

ECOMatters was formed in 1998 from Canada's nuclear fuel waste disposal program. As such, the Company is uniquely positioned to offer environmental consulting and R&D services to the disposal of spent nuclear fuel. Staff and associates have worked as a team for many years, and are well-known scientists with extensive publication and project records. ECOMatters specializes in detailed understanding of basic processes in terrestrial and aquatic environments, including the partitioning of contaminants and their uptake by plants and animals. Effects characterization is a particular strength. Development, application and Quality Assurance of environmental computer codes are major activities for the regulatory, industry and agricultural fields. The following specialized services are relevant to the management of high level radioactive waste:

- socio-economic analysis
- ecological risk assessment
- ecological interpretation
- ecotoxicological assays
- soil science
- geology and geochemistry
- contaminant loading
- contaminant pathway analysis
- contaminant fate modelling
- computational environmental physics
- radioecology
- radiological and non-radiological contaminants
- nuclear waste characterization
- nuclear safe-guards

E.S. Fox Limited

Established in 1934, E. S. Fox Ltd. is a privately owned Canadian multi-trade company located in Niagara Falls, Ontario. The Company employs mechanical, electrical and civil engineers, and is undertaking an ever-increasing number of total responsibility projects and can provide any combination of engineering, procurement and construction skills needed.

E.S. Fox Ltd.'s track record in the energy related field dates back to early involvement in Ontario Hydro/Ontario Power Generation projects. Major projects for the Nuclear industry are as diverse as 2 1/2 miles of SF6 aluminum bus duct for the Darlington Nuclear Generating Station, the fabrication of specialized cabinets for the Korean Electric Power Corporation and Transfer Casks for the retubing of the Bruce Nuclear

Generating Station, to the design and construction of a new Radioactive Waste Processing and Storage Facility and installation of a new RadWaste Incinerator for Ontario Power Generation at the Bruce Nuclear Generating Station, and the Restart of 1652 MW of shutdown Nuclear Units (3 and 4) for Bruce Power.

Framatome ANP

A member of the AREVA Group, Framatome ANP is headquartered in Paris with regional subsidiaries in the U.S. and Germany. With a total workforce of 14,000, the Company is active in Eastern and Western Europe, North and South America, Asia and Africa. Its annual revenues total more than $3 billion.

Framatome ANP (Advanced Nuclear Power) is involved in the design and construction of nuclear power plants and research reactors, engineering, instrumentation & control, modernization, maintenance and repair services, components manufacture and supply of nuclear fuel. It was formed in 2001 by merging the nuclear activities of Framatome and Siemens to form Framatome ANP, and acquiring the former Duke Engineering & Services in the United States. In a workforce of 14,000, more than half are employed in North America.

Framatome ANP's integrated outage services portfolio in North America includes outage planning and management, reactor pressure vessel inspection, disassembly and re-assembly, refueling, primary system decontamination, steam generator services, engineering services, chemical services, waste management and disposal.

In France, Framatome is contributing to the French R&D program for HLRWM, which is expected to give the French Parliament and the Government the feasibility information necessary for a decision in 2006 for a French strategy in the fuel back-end domain. The Company’s work includes investigation of methods to reduce the inventory and radiotoxicity of the high level waste, analysis of irradiated fuel behaviour for different conditions of interim storage (wet or dry), and the engineering of interim spent fuel storage facilities.

Gartner Lee Limited

Since its founding in 1973, Gartner Lee Limited has become a global company providing strategic planning and environmental services to clients of all types and sizes in both government and industry. Gartner Lee’s focus on environmental and strategic planning is backed by a team of over 100 professionals from across the spectrum of environmental and social science disciplines.

Environmental Assessment (EA) is a key means of ensuring that development projects in Canada are environmentally sustainable. Under the Canadian Environmental Assessment Act (CEAA), an environmental assessment is required for a variety of projects that involve the federal government. However, the scope of the project and the assessment are not always clear. Gartner Lee can provide clear guidance on what kind of assessment is required or best suited to specific projects. The Company has the expertise, experience and national presence to conduct such assessments, whether they are screening assessments, comprehensive studies, panel reviews or mediations.

An important element of EA and regulatory approvals work for nuclear waste and nuclear power projects is the way in which proponents, regulators and members of the affected community identify and respond to potential social and economic impacts. Gartner Lee can assist Federal authorities and project proponents in understanding the requirements for Socio-Economic Impact Assessment (SIA) under the Canadian Environmental Assessment Act, other provincial and territorial legislation, and help determine how best to integrate social issues regarding nuclear matters into EAs and decision-making.

Gartner Lee Limited considers Traditional Ecological Knowledge (TEK) an important part of the knowledge base and not a token. To achieve integration, the Company's socio-economic impact assessment practitioners create a framework that views science and TEK as complementary, not competing forms of knowledge. They also create an atmosphere of co-operation, not of competition, and treat all studies as a collaborative effort between the EA researchers and the Aboriginal communities.

Golder Associates

Golder Associates is a premier global group of consulting companies, specializing in ground engineering and environmental science. Operating as an employee-owned group since its formation in 1960, the Company has created a unique culture with pride in ownership and a commitment to providing technically sound and cost-effective consulting and contracting services. Golder Associates has experienced steady growth for more than four decades and has more than 3,000 people in 80 offices across 22 countries in Africa, Asia, Australia, Europe, North America and South America.

Golder Associates has been involved in managing environmental licensing of 50,000 MW of thermal power projects. In the waste management field, the Company has provided services to industry for 30 years, pioneering the use of geomembrane liners in the disposal of toxic mine wastes in the 1970's. Since that time, Golder has helped companies implement the many evolving and current practices in the industry at more than 900 facilities.

Hardy Stevenson and Associates Limited

Hardy Stevenson and Associates Limited (HSAL) is a full service consulting firm specialized in social and socio-economic impact assessment (SEIA), moral and ethical analysis, public consultation, policy and environmental planning, facilitation, Aboriginal consultation, community impact agreements and communications, land use planning, engineering and management consulting. The Company's social scientists and public consultation professionals have expertise and experience in managing the staff of large engineering and technical firms. Because HSAL is able to provide in-depth social science analysis of the people side of a problem as a first priority, the Company has built a reputation for successfully managing difficult and potentially contentious projects with sensitivity to social and environmental concerns. A great deal of HSAL's work has focused on the High Level Radioactive Waste Management Program.

Hardy Stevenson and Associates Limited considers 'moral and ethical analysis of nuclear waste management ', as a core area of its practice. HSAL has a library of articles, conference proceedings, technical journals and books on the subject, and has also designed and hosted related conferences and workshops. The Company's views on social and ethical issues were influential and were referred to by the Seaborn Panel Report on the former Nuclear Fuel Waste Management Concept. HSAL has experience in drawing policy and program implications and identifying appropriate scientific and technical actions pertaining to ethical issues such as: obligations to future generations; risks vs. rights; institutional analysis; conflicting theological views and Aboriginal world views in relation to nuclear waste decision making.

Since 1990, Hardy Stevenson and Associates has successfully managed over $15 billion worth of client projects. This experience includes hazardous/ nuclear waste facilities, water and wastewater projects, energy management projects, transportation projects, aggregates, pipelines, solid waste landfills, 3Rs recycling waste reduction strategies and development proposals of various scales. For many of these projects HSAL completed Local, Provincial and National public consultation programs. Of late, in addition to being involved in reviewing Centralized Storage for the NWMO, HSAL has been retained as peer reviewers for the Port Hope Area Initiative, Low Level Radioactive Waste Management Program by the Municipalities of Clarington and Port Hope.

Jacques Whitford Environment Limited

Established in Dartmouth, NS in 1972, Jacques Whitford is a multi-disciplinary firm with over 900 consulting engineers, scientists and technical specialists. The Company has 23 offices across Canada, 8 offices in the United States, joint ventures in Trinidad, Moscow and Buenos Aires, and project offices in China. Jacques Whitford has provided environmental and human heath risk assessment, environmental engineering, hydrogeological, and geotechnical/materials expertise to over 2,500 clients in government, and industry, involving over 30,000 projects.

In the HLRWM area, Jacques Whitford can offer professional services and training in the following specialties:

- environmental and human health risk assessment and risk management
- environment site assessment
- safety analysis
- decommissioning project planning and implementation
- geotechnical engineering
- environmental engineering
- hydrogeology
- environmental sciences and planning
- materials engineering & research
- archaeology, agronomy
- environmental management system design and implementation
- information technology
- remediation technologies and
- building condition surveys.

Experience with the radioactive waste management projects include the following:

(i) Jacques Whitford is presently completing an Environmental Assessment (EA) for modifications to the Solid Radioactive Waste Management Facility (SRWMF) at the Point Lepreau Nuclear Generating Station (PLGS), in New Brunswick. The scope of the EA includes the modifications to the SRWMF (construction of new waste storage structures), as well as a consideration of the station retubing and refurbishment activities that will generate the waste, and the incremental environmental effects of continued operation of the PLGS during the extended lifetime of the station. The EA addresses the potential environmental effects of the proposed project on the environment, including both the natural environment, and the human environment (worker health and safety, public health and safety, and socioeconomic factors).

(ii) The Company was commissioned by NRCan to assess, specify and manage the decommissioning of several radiological laboratories that were used to investigate environmental issues related to mining at the CANMET research facility at Elliot Lake, Ontario. The radioactive decommissioning work was for unconditional release of the building and any remaining materials to the satisfaction of the AECB (now CNSC).

(iii) Jacques Whitford conducted a review of Operational Control Monitoring programs at the Atomic Energy of Canada Chalk River radioactive waste management areas. The review focused on groundwater, and defining appropriate locations, depths, screened intervals, sampling frequency and analyte range for each waste management area. The report prepared for this project formed the basis of a proposed monitoring program to be continued as a licensing condition with the CNSC.

Kinectrics Inc.

Kinectrics is a member of the AEA Technology Group (UK), which has more than 30 years of experience in the nuclear fuel cycle business, serving customers across the world. AEA Technologies offers extensive R&D services for nuclear materials processing and fuel reprocessing, at all major stages of the nuclear fuel cycle.

Based in Toronto, Canada with over 250 employees, Kinectrics has over 85 years of continuous experience solving the most advanced technical challenges of North American and global utilities. Formerly known as Ontario Hydro Technologies, Kinectrics has over 30 years experience in the nuclear industry.

Some of the key services that Kinectrics offers include waste reduction and disposal, development of effective emissions controls, minimization of environmental-related impacts, materials engineering, characterization, testing, assessment (including reactor core materials), on-site and in-lab monitoring, repairs, testing and technical procedure development for electrical and water systems, metallurgical, mechanical and structural elements, complete equipment and product testing services, using state-of-the-art equipment and facilities, for qualification and evaluation purposes.

Marshall Macklin Monaghan Limited

Marshall Macklin Monaghan (MMM) is one of Canada's largest and most successful project management and consulting engineering firms. The staff complement totals some 500 professional, technical and support staff, conducting projects throughout Canada and abroad. A significant component of the Company's business is focused on nuclear-related projects with respect to both power generation and the management of radioactive waste, from low-level radioactively-contaminated soil to spent nuclear fuel. MMM is currently involved in waste management initiatives at all three nuclear generating installations in Ontario, and on several assignments throughout Canada dealing with mid and low-level radioactive waste management and disposal. The Company's typical project delivery strategy involves full service to the clients. In some cases, this necessitates joint venture or partnership associations and MMM maintains close working relationship with many national and international firms offering complementary services. This is especially true of the nuclear aspects of the business, where the community of professionals is generally limited and quite interactive.

Niagara Energy Products Corporation

Niagara Energy Products Corporation (NEP) was established in Hamilton Ontario in 1951, originally as a supplier of forged fittings and flanges to the nuclear industry. The Company was relocated to the current 125 000 square foot facility in Niagara Falls, Ontario in 1995. NEP is a certified N285.0 supplier of Class 1, 2, 3, and 4 nuclear material, components, and valve parts. NEP's Quality Program is also certified to CAN3-Z299.2-85 Quality standards. NEP's manufacturing facility is operated by approximately 50 employees with capabilities for semi-automated and manual welding, CNC machining, high-density concrete batching, painting, and non-destructive testing.

Since 1993, NEP's primary product line has been Dry Storage Containers, supplied to Ontario Power Generation for the storage of spent nuclear fuel at the Bruce and Pickering Nuclear Generating Stations.

Nuclear Safety Solutions Limited

Nuclear Safety Solutions (NSS), as the largest privately held consultancy in the Canadian nuclear industry, provides specialised multi-disciplinary technical solutions and services to nuclear utilities and related organizations.

NSS is the former Safety Analysis Division of Ontario Power Generation (OPG), supplemented by additional staff recruited from throughout the Canadian industry. NSS skills and knowledge have recently been enhanced with the acquisition of the Canadian nuclear waste management specialist company Monserco Ltd, the dominant Radiation Safety Management Services company in Eastern Canada.

NSS has grown to over 200 employees with highly respected skills in waste management, environmental consultancy, thermal hydraulics, structural integrity, reactor and radiation physics, technical methods and probabilistic risk assessment. NSS's work also includes fuel inspections, CNSC licensing support, and delivering safety cases to increase the reactor power for Bruce and Darlington plants.

In addition to the above areas of expertise, NSS is able to call on the resources of its parent company NNC Ltd, the UK's premier nuclear engineering service provider. NSS and NNC have key experience in diverse Waste Management projects internationally, and is the largest supplier of engineering services to British Energy and British Nuclear Fuels, as well as providing consultancy and implementing major decommissioning and waste management projects for the UK's other major waste producer, the United Kingdom Atomic Energy Authority (UKAEA). It is also a major supplier of consultancy to the UK's waste management organization, UK Nirex Ltd., and to the responsible ministry in the UK, the Department of the Environment, Food and Rural Affairs (DEFRA) and to the European Commission.

Numet Engineering Limited

Founded in 1971 and based in Peterborough, Ontario, Numet Engineering Ltd. (N.E.L.) specializes in the design and manufacture of high-reliability, precision-engineered systems and equipment for the Nuclear Energy and Hazardous Waste Management sectors. Products supplied include NQA-1 qualified storage and transportation vessels, tritium handling equipment, nuclear-class process equipment and nuclear decontamination systems. The Company also designs and supplies state-of-the-art remote handling equipment, special-purpose manipulators and multi-axis automatic control systems for use in High Level Waste environments.

Ontario Power Generation Inc.

Ontario Power Generation (OPG, formerly Ontario Hydro) is an Ontario-based company whose principal business is the generation and sale of electricity to customers in Ontario and in interconnected markets. Ontario Power Generation owns and operates the Pickering and Darlington Nuclear Power Stations, which supply a significant portion of Ontario's electricity.

OPG has accumulated and is responsible for the bulk of the high level nuclear waste in Canada. The spent fuel and other highly radioactive reactor components are stored at the Bruce, Pickering and Darlington Nuclear Generating Stations.

Starting with the Pickering Waste Management Facility which began in early 1996, OPG has a mature program in place to store spent fuel above ground in the DSCs in compliance with CNSC and Safeguard requirements. The Western Used Fuel Dry Storage Facility came into operation in the fall of 2002, and the Darlington facility is scheduled to be operational by 2007.

OPG has maintained and developed used fuel disposal technology since AECL submitted its Environmental Impact Statement to the Seaborn panel. Since 1995, OPG has invested almost 150M$ in used fuel disposal technology and have introduced several modifications to the AECL concept in response to recommendations coming out of the environmental assessment process. These include a robust copper shell disposal container, 100% bentonite clay buffer, detailed design of an in-room emplacement option and allowance for extended monitoring prior to closure. Over the next four years OPG intends to invest a further 30M$ to ensure Canada has the capability to implement a used fuel disposal program, should the Canadian government decide on this direction.

OPG intends to continue to resource work with AECL's Waste Technology Business Unit in the areas of geotechnical aspects of siting, repository engineering, and safety assessment codes. Working relationships have been established with the Universities of Western Ontario, Waterloo, Laval, Toronto and New Brunswick and will be expanded to other Canadian universities. OPG has established information exchange agreements with SKB in Sweden and Posiva in Finland, and further international joint development programs will be established.

RCM Technologies Canada Corporation

RCM Technologies is a registered Ontario professional engineering company with head office in Mississauga, Ontario. RCM has been intimately involved in the nuclear power generation and related industry since 1978, from an Environmental Qualification (EQ) and Safety perspective. The Company maintains strong relationships with the numerous other suppliers of services and products in the industry and possesses the ability to form relevant and effective alliances where necessary. RCM employs engineers from many different disciplines; civil, electrical, mechanical and chemical and has a staff of approximately 200 in Canada alone. Although RCM has not managed a large project specifically with high level radioactive waste, the Company offers many tangible skills and services that can benefit such a project from both a technical and logistical perspective.

Experience, expertise and capabilities relevant to HLRWM include:

- project manager for the Bruce A Restart project from an EQ perspective, and overseeing the design, procurement and construction for this portion of the refurbishment;
- design experience with the semi permanent storage of radioactive sources, such as gamma emitters for industrial use, and includes shielding calculations for materials and the structures;
- seismic analysis (both static and dynamic) for equipment and structures, pressure vessel expertise, spent fuel handling;
- safety and security audit and assessment / emergency response planning and management;
- qualification laboratory on-site in Mississauga that is capable of performing environmental and seismic tests along with various other destructive test methods. This lab could be utilised for testing any speciality containers during the development of handling equipment or storage containers.

RSRead Consulting Inc.

RSRead Consulting Inc. is a Canadian engineering consulting firm specializing in applied rock mechanics and geotechnical engineering. The Company's main office is located in Okotoks, Alberta just south of Calgary. Dr. Rodney Read, P.Eng., P.Geol., is the firm's President and Principal Consultant.

RSRead undertakes project planning and management, design, site characterization, instrumentation and monitoring, data processing, reporting and numerical analysis, as well as targeted research and development activities. The Company's business is focused on engineering issues associated with:

- international nuclear waste management
- rock mechanics and geotechnical research for radioactive waste disposal
- design of underground excavations for waste disposal research
- surface and underground characterization of rock masses
- thermal-mechanical numerical modelling of underground openings
- underground excavations, mines and quarries

Science Applications International Corporation

Science Applications International Corporation (SAIC) is the largest employee-owned technical services company in the U.S., with over 40,000 employees and $ 5.5 Billion in annual sales. SAIC was founded in 1969 as a small technical group specializing in nuclear studies and providing high technology research and development services to government and industry. Since that time, SAIC has grown into a mature organization capable of responding to the full spectrum of technical and managerial challenges.

SAIC's environment and infrastructure professionals have technical expertise across all environmental domains, including management of the entire environmental, safety & health functions at facilities, providing cost effective solutions for specific needs, and performing critical environmental analysis. The Company brings together science, facility operating parameters, regulatory requirements and stakeholder concerns in an integrated format, to facilitate timely decisions and optimum performance.

SAIC and Bechtel have recently been awarded a 5-year $3.2 B US contract to support the Yucca Mountain project, including responsibility for a staff of 1200, managing the engineering and design of the repository (above ground, below ground, support facilities, transportation within Nevada), and producing the site recommendation study to support licensing of the Yucca site decision, environmental safety and health, public out reach and communication.

Sanlex Development Group Inc.

Sanlex Development Group Inc. (1993) is a Canadian company with the head office located in Toronto, Ontario, and branch offices in U.S.A. and the Caribbean. Sanlex specializes in international development issues, and provides consultation on residential, commercial and industrial construction projects. The Company has a trained, diversified team of professionals, and offers a full range of services, ranging from construction, building renovations, interior and shell construction, construction management and consulting services to architectural/design drawings, process and project management.

Sanlex has recently completed a Life Cycle Cost Estimate of Nuclear Waste Management for Ontario Power Generation.

SENES Consultants Limited

SENES Consultants Limited was founded in 1980 as a wholly Canadian company, with head office in Richmond Hill, Ontario. The Company's work has included the private sector, industrial associations, regulatory agencies, all levels of government, funding institutions, and various public interest groups.

SENES' experience includes over 3000 local and worldwide projects spanning a breadth of environmental service areas. Across these service areas the Company's staff have been involved in policy development and review, technical assessments, delivery of specialized and expert advice, peer reviews, and all levels of project management and implementation.

Recently SENES, along with others, completed a cumulative effects assessment as part of a Comprehensive Study Report for a Used Fuel Dry Storage Facility at the Bruce Nuclear Power Development, including the effects of:

- the proposed facility
- existing operations (e.g. reactors, waste management area)
- ancillary facilities such as the steam plant and central maintenance facilities
- proposed projects (e.g. waste management areas, heavy water plant decommissioning and steam plant replacement);
- the cumulative effects resulting from the restart of shutdown reactors, and the eventual shut down and safe storage of all reactors on site

Spectrum Consulting Inc.

Spectrum Consulting Inc. was founded in 1971 in Peterborough, Ontario as Spectrum Engineering Corporation Ltd., with a mandate to provide high quality technical and management services to utilities, government agencies, commercial and industrial clients. Since that time, the Company has greatly expanded its resources and staffing to become a multi-disciplinary consulting engineering firm that offers a full range of engineering, design, development and management services.

The Company's staff comprises professional engineers, technologists, designers, detailers and administrative staff in Project Management, Civil/Structural, Architectural, Electrical, Mechanical, Instrumentation and Control disciplines.

Projects that illustrate the Company's expertise and capabilities that could be applied to HLRWM include:

- feasibility study for plutonium fuel processing facility (AECL-SP)
- fuel transportation study for reprocessing of fuel in Europe (AECL-SP)
- spent fuel packaging project for NPD decommissioning (AECL)
- reliability and safety analysis of Safety System 1, Safety System 2 and Reactor Regulating System (Maple-X10 Reactor, AECL-CRL)
- design and development of special purpose tooling for multi channel replacement (Bruce-A NGS)

- design, procurement and commissioning of containment isolation radiation monitoring system (Bruce-A NGS)
- design of area, stack and contamination radiation monitoring systems (Kanata Radioisotope Processing Facility, Nordion International Inc.)
- seismic qualification of structures (Pickering-A NGS)
- stress analysis of fuelling machines (Pickering-A NGS)
- stress analysis of spent fuel racks (Pickering-A NGS)
- waste handling system for bitumenized nuclear waste (AECL-CRL)

Stantec Inc.

Stantec Inc. is a Canadian company with its head office in Edmonton, Alberta, and a staff of 4500 employees across North America, including approximately 3500 professional engineers and scientists. The Company offers a full range of engineering and environmental services. Many staff members of Stantec are recognized experts in various aspects of facility design, siting, environmental assessment and approval. The Company employs approximately a dozen staff with such expertise and experience specifically related to high and/or low level radioactive waste management.

Stantec has become one of the largest environmental consulting firms in Canada and is committed to growth in this area, including the environmental aspects of nuclear waste management. The Company has and plans to maintain considerable expertise in this area, with the addition of new related skill sets as opportunity arises.

Stern Laboratories Inc.

Stern Laboratories Inc., based in Hamilton, Ontario, is a Canadian owned private corporation. The Company conducts reliability and safety experiments under contract to utilities, nuclear reactor and fuel vendors, government agencies and nuclear equipment suppliers. Stern Labs also manufactures specialized equipment, such as nuclear fuel simulators, for use in other laboratories. The Company has a specialized team of 28 permanent employees, mainly professional engineers and engineering technologists, and has served the Nuclear Industry in Canada and in many other countries for over 40 years.

The laboratory specializes in the design and construction of experimental devices and facilities to simulate reactor heat transport systems, safety systems, fuel and fuel channel components, conducting experiments in these facilities and analyzing and reporting the results. Highly specialized computing hardware and software are available for precise control of test conditions. In relation to spent fuel, Stern Labs has developed tooling for in-bay fuel handling, disassembly and examination, and is continuing with the development of robotic and optical devices, as well as manually operated tools.

Stone and Webster

Stone & Webster (S&W) has been responsible for the development, consulting, engineering and construction of nuclear, fossil-fuelled, geothermal and hydroelectric power generation projects. S&W has a portfolio of power projects spanning over 50 countries, six continents and 112 years. The Company's environmental activities cover clean up at former nuclear weapons production facilities, and environmental permitting services for industrial and utility facilities.

Stone & Webster has extensive experience and capabilities in the design, construction and operation of waste management facilities and programs. The Company has a large number of personnel with waste management experience on commercial utility and government projects that are capable of providing total project support. This experience includes all aspects of High Level, Low Level, and Mixed Radioactive Waste, as well as the extended storage spent nuclear fuel. These personnel include project managers capable of establishing and/or managing waste management programs, engineers from each of the appropriate disciplines (civil, mechanical, structural, chemical, etc.), as well as construction managers, health physicists, industrial hygienists, regulatory specialists, planners, and cost estimators.

Stone & Webster has developed waste management programs for operating nuclear facilities and major decommissioning projects, and helping to optimize the nuclear industry's waste management capabilities. Over the last three years Stone & Webster staff have prepared numerous Waste Management Program Plans as part of Decommissioning Planning Documents for large and small nuclear facilities. Radioactive waste capabilities and experience are complemented by a highly experienced and deep Environmental Services Division capable of providing hazardous and toxic waste characterization, regulatory support, design, remedial action, and restoration services. Stone & Webster capabilities with the development and management of waste management programs include: Characterization (High Level, Low Level, Mixed and Hazardous Waste) Packaging, Transportation, Processing and Volume Reduction Technologies, and Final Disposal.

Thermodyne Engineering Limited

Thermodyne Engineering Limited, based in Toronto is a consulting engineering and qualification/ certification testing company. The Company's specialties are in mechanical and structural areas, such as: equipment design and development, piping design and stress analysis, pipe hangers design and analysis, machine design, automation, instrumentation and controls, implementation of quality assurance systems, procedures and training. Out of a workforce of 1000, the majority are engineers and technologists.

Urban & Environmental Management Inc.

Urban & Environmental Management Inc. (UEM) is a professional planning, engineering and project management company located in Niagara Falls, Ontario. UEM is comprised of a team of professionals experienced in the planning, site selection, design and approval of solid waste management systems and facilities. Although we do not have extensive expertise in High Level Nuclear Waste Management (HLNWM), site selection, environment assessment, approval process and preliminary design phases are similar whether non-hazardous solid waste or high level nuclear waste is involved.

In addition to the more traditional planning and engineering services, UEM also provides expertise in public/private partnerships, infrastructure development management, alternative service delivery, change management, organizational review, public consultation program development and implementation and providing expert evidence at hearing tribunals.

Wardrop Engineering Inc.

Wardrop is a Canadian employee-owned company, founded in Winnipeg in 1955, and currently comprising a group of five companies in five Canadian offices and three International offices, with more than 450 staff. The Toronto office has expertise and capability in nuclear waste management, fusion energy, and environmental assessment. Services in the environmental area include site screening and selection, waste facility design, risk assessment, public participation programs, environmental impact studies and management plans, regulatory submissions and environmental approvals.

The Company has significant expertise in geotechnical engineering that has been applied to site evaluations, field investigations, engineering analysis and design related to earth structures, groundwater control, and earth pressures for retaining structures.

In the nuclear waste management area Wardrop has expertise and capability related to spent fuel handling and storage facilities, transportation casks, and the permanent disposal of nuclear wastes. The Company has responsibility to design and build the Radioactive Waste Operations Site 2 at the Bruce facility for OPG. The project includes the Dry Storage Container (DSC) Processing Building, the DSC Storage Building for about 2000 DSC's, Replacement of the Radioactive Waste Incinerator, and a new Amenities Building.

Wardrop has a long history of assisting First Nations with community development. Projects have included environmental audits, assessments and management plans, human health risk assessment, contaminated site remediation, community development and institutional strengthening.

Appendix B: Canadian University Expertise and Capabilities

Many of Canada's universities have expertise and capability that could be used in the planning and implementation of a permanent spent fuel storage/disposal facility. In particular, the following universities are known to have researchers with specific expertise in engineering and the physical, biological and social sciences that are expected to be involved in HLRWM:

- Carleton University
- Ecole Polytechnique
- Laurentian University
- McMaster University
- Queens University
- Royal Military College
- Trent University
- Universite Laval
- University of Alberta
- University of British Columbia
- University of Calgary
- University of Guelph
- University of Manitoba
- University of New Brunswick
- University of Ontario Institute of Technology
- University of Ottawa
- University of Saskatchewan
- University of Toronto
- University of Waterloo
- University of Western Ontario

The following universities are presently conducting research on topics related to HLRWM, with individual researchers currently doing or recently having done work on specific aspects of spent fuel management.

Laurentian University is a partner in the Mining Innovation, Rehabilitation and Applied Research Corporation (MIRARCO), founded in 1998. It is a not-for-profit applied research and technical service company formed through collaboration between Laurentian University and the private and public sectors.

The services and facilities available to faculty and researchers at Laurantian University and MIRARCO include:

The Geomechanics Research Centre (GRC) carries out engineering and technical R&D in the geotechnical field and applies its findings to promote safer and more economical mining. GRC supports design for hard rock mining, especially under rockbursting conditions, including the development of methods for recording rockburst damage and for assessing the potential for rockburst damage. They provide rockburst risk assessment, whereby seismic and historical damage information are used to develop risk and hazard models for rockbursts, seismic tomographic imaging, in situ stress and deformation monitoring, and numerical modelling of dynamic failure processes around underground excavations.

Two members of GRC, Dr. Luigi Cotesta and Dr. Peter Kaiser, have been doing research to apply virtual reality technologies for the interpretation of complex site characterization data and for the development of conceptual geosphere models. A project has been undertaken at a recently established state-of-the-art virtual reality laboratory (VRL), which is part of Laurentian University's Centre for Integrated Monitoring Technology (CIMTEC). The Moderately Fractured Rock (MFR) experiment, ongoing at Atomic Energy of Canada Ltd's Underground Research Laboratory in Pinawa, Manitoba, provides an ideal dataset for representation in the VRL facility. The data is both complex and multidisciplinary: combining observational, modelled and interpreted data within a single block of a moderately fractured rock mass with a volume of approximately 100,000 m^3. The utility of the VRL has been demonstrated by enhancing and establishing credibility in the experimental findings from the various teams involved in the MFR project. Examples of the data sets included in the pilot project were the URL excavation, surface topography, geometry of the large scale fracture zones, the MFR borehole network and associated fracture logs, permeability measurements, crosshole radar surveys, interpreted fracture domains and sub-domains, and numerical models used for flow and transport predictions.

The Centre for Environmental Monitoring provides monitoring and development services to aid resource industries in the solution of problems in ecosystem remediation, rehabilitation and restoration. Areas of interest include environmental toxicology, specifically the effects of radionuclides and heavy metals on various steps in ecological food webs. The Centre is an important partner of the Canadian Shield Environmental Research Network (CSERN), which is a multidisciplinary group of organizations and individuals with a common interest in the environmental health of the Canadian Shield. Through collaborative research among universities, colleges, industries and government, its goal is to understand the changes affecting the Shield's terrestrial and aquatic ecosystems and to contribute to actions that will sustain them.

The Centre for Mining Technology (CMT) provides applied research and development focused on monitoring and control systems, simulation of operations research, systems engineering and mine equipment and systems automation. Currently, CMT is doing research in the areas of waterjet technology, equipment design and process simulation, and virtual reality in Health & Safety applications, with an initial focus on Best Practice Operations Analysis related to optimizing equipment, people and material utilization.

Universite Laval

Dr. Rene Therrien is Associate Professor in the Department of Geology and Geological Engineering at Universite Laval. His search interests are in hydrogeology, the modelling of natural systems, and contaminants in the environment.

One of his recent research projects, in collaboration with Dr. J.-M. Lemieux, has been on the Numerical Simulation of Fluid Flow and Solute Transport in the Moderately Fractured

Rock Domain at the Underground Research Laboratory. Their project involves the application of a previously developed model to 1) simulate fluid flow and solute transport in the Moderately Fractured Rock (MFR) domain, located within the Underground Research Laboratory; 2) compare results of equivalent porous medium transport simulations to preliminary dual-porosity simulations; and 3) conduct insight modelling to help design future hydraulic tests in the MFR domain. The simulations were done with the existing conceptual model developed for the MFR, based on the equivalent porous medium approach but including heterogeneity in permeability and porosity in the MFR domain.

University of British Columbia

Dr. Ulrich Mayer is Assistant Professor in the Department of Earth and Ocean Sciences, with expertise in Groundwater Hydrology. His research concentrates on the geochemical evolution of low-temperature groundwater systems with a focus on groundwater contamination and remediation. Dr. Mayer conducts research on how dissolved inorganic and organic chemicals are affected by a variety of physical and chemical processes. Two research areas of specific interest to HLRWM are:

- Development of a process-oriented multi-component reactive transport model and its use to investigate the complex groundwater systems and its application to a large number of reactive transport problems in the fields of environmental sciences and engineering.
- Numerical analysis of groundwater contamination problems and remediation solutions with the goal to quantify, and potentially improve, existing conceptual models.

University of Manitoba

Dr. James Graham is Professor Emeritus in the Department of Civil Engineering, and is Director General of the Canadian Geotechnical Society. His research interests include:

- Use of sand-bentonite mixtures for containing nuclear waste in the Canadian Shield. Involves high-pressure, high-temperature triaxial tests on saturated and unsaturated sand-bentonite; and constitutive modelling.
- Quartz sand and glass ballotini for filling containers of nuclear waste. Involves tests for creep, compressibility, and strength of strong granular soils at temperatures and pressures much higher than those normally used in geotechnical laboratories.
- Hydraulic conductivity in plastic clays. Involves fundamental studies of very low hydraulic conductivities in the dense sand-bentonite buffer proposed for nuclear waste containment.

Dr. James Blatz is Assistant Professor in the Department of Civil Engineering. His research interests include:

- soil-structure interaction
- practical geotechnical modeling
- unsaturated soils engineering
- elastic-plastic constitutive modelling of soil behaviour
- GIS applications in geotechnical engineering

University of New Brunswick

Dr. Kerry MacQuarrie is Associate Professor of Civil Engineering. He is the holder of the Canada Research Chair in Groundwater-Surface Water Interactions, and is the Coordinator of the UNB Groundwater Studies Group. Some of his research topics are:

- physical and chemical processes related to the transport and fate of subsurface contaminants, especially reactive solutes
- finite-element and analytical modelling of groundwater flow and solute transport
- multi-component reactive transport modelling

University of Toronto

Dr. W.R. Peltier is Professor in the Department of Physics. His expertise is in Atmospheric and Geophysics (Theoretical), including research in the stability of stratified rotating flows, nonlinear hydrodynamic waves in the atmosphere and oceans, physics of planetary interiors, mantle convection and continental drift, glacial isostasy and the dynamics of the ice-age earth, paleoclimatology and global change, magneto-hydrodynamic processes in the earth's core, and computational fluid dynamics with supercomputers.

One of his current projects is the development of a Design Basis Glacier Scenario (DBGS) to support performance assessment modelling of a used nuclear fuel repository, assumed to be located on the Canadian Shield. The scientific basis for the DGBS consists of geophysical and climatological literature concerning the reasons for the occurrence and the impacts upon the geosphere and biosphere of the glaciation-deglaciation cycle that has been a persistent component of climate system variability for the last 900,000 years. Each glacial cycle during this period lasted approximately 100,000 years, and at the time of maximum glaciation the Canadian Shield was covered by a veneer of ice that reached a maximum thickness of approximately 4 km. An interesting issue arising from this study is the predictability of the continuing cyclic glaciation of the North American continent. The ability to predict the occurrence of past instances of glacial onset has been somewhat limited, although recent advances have yielded means to conduct useful analyses. In this regard, a focus of this report has been to illustrate the ability of modern general circulation models of the coupled atmosphere-ocean system to adequately predict the most recent episode of continental glacial inception that began approximately 116,000 years ago.

Dr. Greg Evans is Professor in the Department of Chemistry and Chemical Engineering, and Director of the Research Cluster in Environmental Chemistry and Nuclear Science. His work examines the environmental impact of nuclear facilities and the application of radiochemistry and radiation chemistry in order to investigate other environmental systems. Some of the Cluster's research topics include fission product chemistry, retention of heavy metals by soils and treatment of pollutants using radiation.

University of Waterloo

The University of Waterloo is involved in a wide range of research projects that are relevant to HLRWM. Professors in the Department of Earth Sciences and in the Department of Civil Engineering are active participants in research related to spent fuel management. The University is a key member of Network for Environmental Risk Assessment and Management (NERAM) that integrates the scientific knowledge and expertise that exists across many diverse disciplines in Canada. Such a comprehensive approach to environmental risk assessment and risk management supports more effective and efficient environmental protection practices and decision-making.

Dr. Shaun Frape is Professor in the Department of Earth Sciences. His has been involved in research that includes the geochemistry of groundwaters found in crystalline rock environments; the mineralogy, isotopic analyses and geochemistry of fracture minerals found in association with groundwaters from crystalline and sedimentary rock environments; and the nature of hydrogeochemical processes in clay deposits.

One of Dr. Frape's research projects aims to advance the understanding of groundwater chemical and isotopic evolution during freezing as might be associated with long-term climate change in a crystalline Canadian Shield setting. As part of the study, a series of controlled batch and column freezing experiments were conducted with different types of Canadian groundwaters. The experiments have yielded a unique and comprehensive data set that includes full water chemistry and some stable isotopes. Comparison of these data to similar theoretical evolutionary freezing paths has provided a basis to compare the applicability of experimental outcomes to the interpretation of groundwater flow system evolution and dynamics.

Dr. Edward Sudicky is Professor in the Department of Earth Sciences. Some of his research projects include mathematical modelling of groundwater flow and mass transport in hydrogeologic systems by numerical and analytical methods, algorithm development, multiphase flow and subsurface remediation, stochastic analysis in heterogeneous porous and fractured geologic materials, coupled surface/groundwater flow and contaminant migration in hydrologic systems, groundwater hydraulics and geostatistical characterization of material properties at field sites.

Dr. Jon Sykes is Professor in the Civil Engineering Department, with a primary focus on Environmental and Water Resources Engineering. His research includes hydraulics, hydrology, hydrogeology, liquid and solid waste disposal, treatment of drinking water and wastewater, remote sensing, water resources planning and management.

University of Western Ontario

Dr. David W. Shoesmith is Professor in the Department of Chemistry, and holder of the Industrial Research Chair in Nuclear Fuel Disposal Chemistry. His main research aim is to solve various industrial corrosion and environmental contamination problems. A recent focus has been the study of waste containers and waste forms for the disposal of high level nuclear wastes. The solution to such problems requires a combination of experimental and modelling approaches. Dr. Shoesmith's experimental approach involves the application of a wide range of electrochemical techniques, often under hostile conditions, such as high temperatures in the presence of aggressive environments. These methods are supplemented by various surface and near-surface analytical techniques, such as X-ray photoelectron (XPS) and Auger (AES) spectroscopies, scanning electron microscopy (SEM) and neutron reflectometry (NR). The nature of models varies from detailed deterministic process models to statistical/probabilistic and environmental performance assessment models.

On-going studies in modelling include a mixed potential model for nuclear fuel behaviour under waste disposal conditions and a performance assessment model for a carbon steel/nickel alloy dual wall container for disposal of nuclear waste in the United States. Future plans include models for HIC of titanium alloys and deterministic models for crevice corrosion.

Dr. Shoesmith's studies have encompassed the range of detailed reactions (electrochemical, chemical, metallurgical, transport) which are embodied in complex localized corrosion processes such as crevice corrosion, pitting and hydrogen-induced cracking. The initiation of localized corrosion involves stochastic events determined by the combination of the exposure environment, the metallurgical properties of the specific material and the chemical and physical properties of the oxide films on the material's surface. He and his group are studying many of these processes on titanium and nickel alloys, under the saline groundwater conditions anticipated in a nuclear waste disposal vault constructed in the Canadian Shield.

The long-term corrosion resistance of many materials is determined by the protectiveness of the oxide films, which form on their surface. Dr. Shoesmith and his co-workers are probing the nature of these films, and how they change with exposure to various environments, using techniques such as electrochemical impedance spectroscopy (EIS), neutron reflectometry and noise (signal) analysis. Future plans include the application of techniques such as atomic force microscopy and photoelectrochemistry, and the study of a wider range of industrially important materials applications.

Dr. S. Ramamurthy is a Senior Research Scientist in the Surface Science Laboratory, where he is doing research on corrosion/surface analytical measurements for nuclear applications, electrochemical studies of coated materials, Auger electron spectroscopy of oxides and thin films. The Surface Science Western is an analytical laboratory specializing in the surface characterization and failure analysis of materials. It is a consulting and research laboratory handling all aspects of material surface properties, with strong research programs in the areas of corrosion and metallurgy, microelectronic materials, polymer chemistry and catalytic reactions.

He has been involved in research to determine the suitability of Oxygen-free phosphorous-doped (OFP) copper as the primary corrosion-barrier material for used-fuel containers in a hypothetical deep geologic repository. (Maak 1999). The proposed container design consists of an outer copper corrosion-barrier vessel and an inner carbon steel load-bearing vessel (Maak and Simmons 2001). The inner vessel is responsible for withstanding all external loads, while the outer copper vessel is to provide sufficient resistance to both general and localised corrosion processes throughout the container design life of not less than 100,000 years (Maak 2001).

Appendix C: Canadian Government Agency Expertise and Capabilities

The following Canadian government agencies have, or are expected to have, significant involvement in HLRWM:

- Canadian Nuclear Safety Commission
- Environment Canada
- Canadian Environmental Assessment Agency
- Natural Resources Canada
- Nuclear Fuel Waste Bureau
- Geological Survey of Canada
- Health Canada
- Radiation Protection Bureau
- Transport Canada

Canadian Nuclear Safety Commission

The Canadian Nuclear Safety Commission (CNSC) regulates the nuclear industry in Canada under the provisions of the Nuclear Safety and Control Act. The regulatory system is designed to protect people and the environment from licensed sources of man-made radiation resulting from the use of nuclear energy and materials. This is accomplished through a licensing process that requires the licensees to prove that their operations are safe. The CNSC staff monitor and inspect licensed activities. At the basis of the regulatory system is the principle that no technology is failproof, so licences must incorporate multiple layers of protection whenever radioactive materials are used. The key responsibilities of the CNSC that impacts on HLRWM follow.

Radiation Protection

The CNSC's Radiation Protection Regulations prescribe regulatory limits on the dose of radiation that the public and workers may be exposed to from the use of nuclear energy and radioactive materials. Licensees are required to implement radiation protection programs to keep doses below regulatory limits and "As Low As Reasonably Achievable" (the ALARA principle). The CNSC also monitors on-site radiation protection programs, and evaluates the doses to members of the public who live in the vicinity of nuclear facilities.

Emergency Preparedness

The CNSC maintains an Emergency Response Plan and implements it through a comprehensive emergency preparedness program. The CNSC's emergency preparedness and response activities involve cooperation and planning with licensees, provincial and federal government agencies, and international organizations. The CNSC's role during an emergency is to monitor the response of the licensee, evaluate emergency response actions, provide technical advice and regulatory approval when required, and inform the government and the public on its assessment of the situation.

Packaging and Transportation

The CNSC issues packaging and transportation certificates and transport licences for the shipment of nuclear material in Canada and to or from abroad. CNSC transportation staff and regional inspectors conduct transport compliance actions such as routine inspections, special investigations, follow-up and responses to actual or potential emergencies.

Waste Management

All radioactive waste management facilities are constructed and operated under CNSC licences. There are no specific requirements to certify operating staff or to approve the staff training program. At both the Pickering and Bruce Waste Management facilities the Department Manager is the only authorized position by the CNSC. This authorization is done by submitting a resume of educational qualifications and experience. There are no examinations and testing. The main CNSC roles for on-site HLRWM are:

- review the safety analysis submitted to the CNSC via a Safety Report and also results of the Environmental Assessment.
- CNSC regulations require that facility performance be reported regularly. This includes any non-compliance with the licence conditions and any significant equipment and personnel safety events. CNSC staff has a mandate to perform independent audits and assessments of the facility.
- The CNSC regulations establish threshold values for the facility to report e.g. worker dose, spills etc. CNSC also has to be informed what has been done to prevent such events from happening again.
- Although CNSC staff is assigned at each reactor site to interface with the station organization and changes and procedural steps as required by the agreed upon Operating Policies and Procedures, there is no specific site officer for the waste management facility. A CNSC specialist visits each waste management facility once a quarter.

Organizational Safety Performance and Workplace Competence

CNSC specialists in quality management, human factors and event investigation verify that licensees have an appropriate safety culture and have implemented policies, processes and practices that support safe operations. The CNSC determines, through the administration of examinations and evaluation of licensees' training programs, whether licensees' workers are competent to perform duties in key nuclear generating station positions. CNSC staff also conducts site compliance audits and evaluations, and incident investigations.

Human Resources

One of the key strategic objectives of the CNSC is to attract and retain excellent staff. In support of this objective, the CNSC developed a Workforce Sustainability Strategy to make the CNSC one of the world's best nuclear regulators. This strategy was developed to position the CNSC as an employer of choice, by strengthening its market reach and profile while promoting a supportive corporate culture.

Environment Canada

Environment Canada's mandate is to preserve and enhance the quality of the natural environment, including water, air and soil quality; conserve Canada's renewable resources, including migratory birds and other non-domestic flora and fauna; conserve and protect Canada's water resources; carry out meteorology; enforce the rules made by the Canada - United States International Joint Commission relating to boundary waters; and coordinate environmental policies and programs for the federal government, under the Department of Environment Act.

Environment Canada's (EC) National Environmental Assessment (EA) Program is a national network of managers, practitioners, analysts, and scientists who work together to deliver EA services in order to protect and conserve Canada's environment. Across the country, those working in EC's EA Program examine projects and proposals, perform environmental assessments, and provide advice to other departments and senior management within EC.

The EA program's objectives are to ensure Departmental compliance with the Canadian Environmental Assessment Act (CEAA) and the 1999 Cabinet Directive on the EA of policy, plan, and program proposals; to define Environment Canada's position with respect to projects; to co-ordinate and integrate our science and policy objectives into decision-making; and to ensure national consistency in the application of CEAA.

Canadian Environmental Assessment Agency

The Canadian Environmental Assessment Agency ‘s (CEAA) mandate is to promote environmental assessment as a planning tool to protect and sustain a healthy environment, and to meet Canadians’ expectations of a growing economy in harmony with a healthy environment. The CEAA reports directly to the Minister of the Environment and operates independently of all federal departments and agencies, including Environment Canada.

The CEAA was established under the Canadian Environmental Assessment Act, which is the federal statute for conducting environmental assessment of projects involving the federal government. Four key regulations, the Comprehensive Study List, the Law List, the Exclusion List and the Inclusion List were promulgated at the time when the Act come into force. The Comprehensive Study List regulation is of particular relevance to HLRWM, as it describes those types of projects that must be assessed through a more detailed study. These projects have the potential of causing significant adverse environmental effects and often generate considerable public concern. Examples include:

- large oil and natural gas developments
- projects in national parks and protected areas
- major electrical-generation projects
- large mining projects
- major pipelines
- nuclear power facilities, including uranium mines
- large industrial plants

Under the Act, an environmental assessment is required or triggered when a federal department or agency is asked to provide a licence, permit, certificate, or other regulatory authorization for a project which is listed on the Law List Regulations. All spent fuel storage and disposal facilities require a licence from the CNCS, and hence fall under the jurisdiction of the CEAA. The Law List defines the scope of the Act by identifying those federal statutory and regulatory approvals that will be counted as triggers for an environmental assessment.

Natural Resources Canada

Natural Resources Canada (NRCan) is a federal government department specializing in the sustainable development and use of natural resources, energy, minerals and metals, forests and earth sciences. NRCan provides four main services to Canadians:

- conduct leading-edge science and technology to provide Canadians with ideas, knowledge and technologies, and to help Canadians to use the country's resources wisely, reduce costs, protect the environment and create new products and services;
- build and maintain a national knowledge infrastructure on Canada's land and resources, so all Canadians can easily access the latest economic, environmental and scientific information;
- ensure that federal policies and regulations on issues such as the environment, trade, the economy, Canadian land and science and technology enhance the natural resources sector's contribution to the economy, and at the same time make sure these policies and regulations protect the environment and the health and safety of Canadians;
- together with international agencies and other nations, promote Canada's international interests. This helps Canada meet its commitments related to natural resources, and keeps access open to global markets for Canadian products, services and technology.

Nuclear Fuel Waste Bureau

The Nuclear Fuel Waste Bureau was formed within the federal department of Natural Resources (NRCan) to administer the oversight responsibilities of the Government of Canada, and the Minister of Natural Resources under the 2002 Act respecting the Long-term Management of Nuclear Fuel Waste, or in short, the Nuclear Fuel Waste Act.

The objective of the Nuclear Fuel Waste Act is to ensure that the long-term management of nuclear fuel waste will be carried out in a comprehensive, integrated and economically sound manner. This Act complements the Nuclear Safety and Control Act that oversees the health, safety, environment and security aspects of the long-term management of nuclear fuel waste.

The Bureau is largely staffed by officials from the Uranium and Radioactive Waste Division of NRCan's Energy Sector. Along with the Nuclear Energy Division, these officials are the chief policy advisers on nuclear issues. They were largely responsible for the Nuclear Fuel Waste Act.

Geological Survey of Canada

The Geological Survey of Canada (GSC) is a part of the Earth Sciences Sector of Natural Resources Canada. The GSC is Canada's premier agency for geoscientific information and research, with world-class expertise focusing on geoscience surveys, sustainable development of Canada's resources, environmental protection, and technology innovation.

GSC supplies the fundamental national geoscience knowledge base required to support effective mineral and hydrocarbon exploration and development across Canada, to provide the geological basis necessary to understand and address health, safety and environmental issues, and to advocate the interests of Canadian geoscience at the international level.

GSC has an extensive capability in onshore and offshore geoscience surveys and in interpreting and managing geoscience information. This expertise is applied to assessments of energy and mineral resources, natural hazards, environmental and policy issues, and the development of exploration technology. GSC supports the Canadian economy by working with industry, universities and other government organizations in Canada and throughout the world.

Health Canada

Health Canada is the federal department responsible for helping the people of Canada maintain and improve their health. Health Canada strives to improve the health of all Canada's people, while respecting individual choices and circumstances. In partnership with provincial and territorial governments, Health Canada provides national leadership to develop health policy, enforce health regulations, promote disease prevention and enhance healthy living for all Canadians. Health Canada ensures that health services are available and accessible to First Nations and Inuit communities. It also works closely with other federal departments, agencies and health stakeholders to reduce health and safety risks to Canadians.

Through its Health Intelligence Network, the Department works with other levels of government and the health care system in the surveillance, prevention, control and research of disease outbreaks across Canada and around the world. It also monitors health and safety risks related to the sale and use of drugs, food, chemicals, pesticides, medical devices and certain consumer products. In addition, Health Canada negotiates agreements regarding hazardous materials in the workplace, performs medical assessments for pilots and air traffic controllers and conducts environmental health assessments.

Radiation Protection Bureau

One of the key agencies within Health Canada that has a significant involvement in HLRWM is the Radiation Protection Bureau. Its mandate includes:

- support Canada's role in the Comprehensive Nuclear-Test-Ban Treaty by operating the Canadian portion of the International Monitoring System for radionuclides and providing one of 16 national radionuclide laboratories specified under the Treaty;
- conduct assessments under the Canadian Environmental Assessment Act;
- coordinate federal nuclear emergency preparedness as the lead department for the Federal Nuclear Emergency Plan (FNEP) and provides Health Canada's technical support to FNEP;
- develop guidance to protect Canadians from the effects of nuclear accidents, radioactivity in water and food, radon in indoor air, and naturally occurring radioactive materials from non-nuclear industries;
- operate the Canadian Radioactivity Monitoring Network and laboratory to provide health assessments regarding existing levels of radioactivity and effects of nuclear/radiological accidents from a national perspective;
- conduct research on the health effects of radionuclides in the environment;
- operate the National Dosimetry Services which provide personal radiation monitoring to Canadians exposed to ionizing radiation as a result of their work;
- manage the National Dose Registry, a centralized radiation dose record system which contains the occupational radiation dose records of all monitored radiation workers in Canada, and conduct research on exposure trends for radiation workers over time and on the health outcomes of occupational exposures to radiation;
- provide medical and technical advice to federal departments and agencies, other levels of government, industry, universities, hospitals, workers and the public on health issues related to exposure to radiation.

Transport Canada

Transport Canada’s mission is to develop and administer policies, regulations and services for the best transportation system for Canada and Canadians - one that is safe and secure, efficient, affordable, integrated and environmentally friendly. Transport Canada’s responsibilities encompass:

- setting of policies, regulations and standards to protect the safety, security and efficiency of Canada's rail, marine, road and air transportation systems, including the transportation of dangerous goods and sustainable development;
- working in partnership with other federal, provincial, territorial and municipal departments and organizations, the Transportation Safety Board, the Canadian Transportation Agency, NAV CANADA, other private organizations, stakeholders, and members of the transportation industry;
- promoting and enforcing departmental policies, regulations and standards through inspection, education and consultation;
- monitoring and assessing the performance of the transportation system;

- administering the transfer of ports, harbours and airports to communities and other interests and operating the facilities not yet divested.

The Transportation of Dangerous Goods (TDG) Act, Regulations and Standards require dangerous goods to be contained in a safe means of containment. A safe means of containment prevents the release of dangerous goods that could constitute a danger to life, health, property or the environment under normal conditions of transport. There are specific Regulations for the Packaging and Transport of Nuclear Substances.

Appendix D: Principal Methods used in Canada for the On-Site Dry Storage of Spent Fuel

D.1 Dry storage module approach

The MACSTOR (Modular Air-Cooled Storage) dry storage modules developed by AECL are reinforced high-density concrete structures of approximately 25 metres long, 5 metres wide and 5 metres long, capable of holding several thousand fuel bundles.

The air-cooled MACSTOR module is a concrete vault, as shown in Figure D-1. Each MACSTOR module encloses 16 sealed storage cylinders. Each storage cylinder contains a sealed canister holding CANDU fuel. The top of each cylinder is closed with a concrete plug to provide the second containment for the spent fuel. Each canister is made of thick carbon steel plates and covered with a corrosion-resistant protective coating. Modules are typically constructed in rows of two.

Figure D-1. CANDU MACSTOR modules at Gentilly, Quebec (AECL).

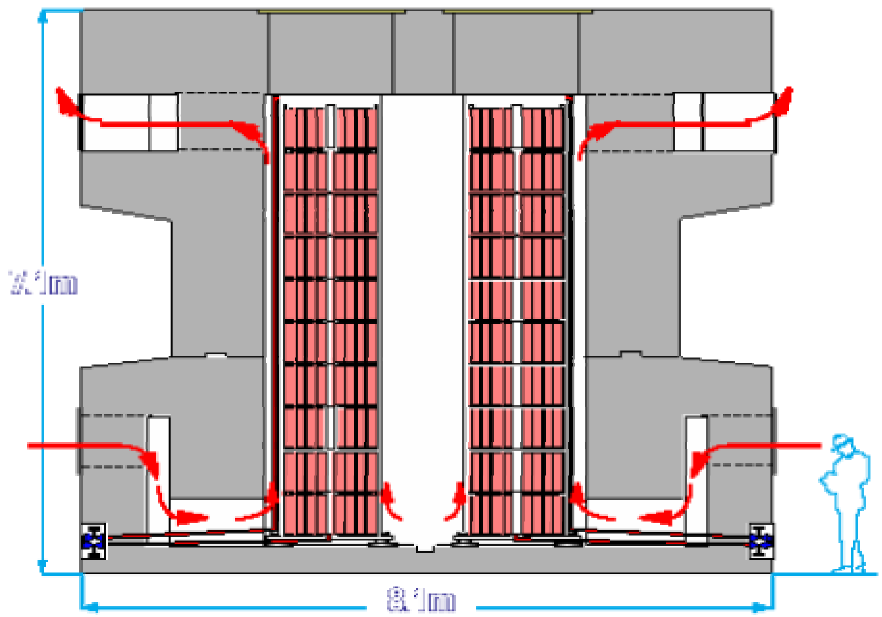

Figure D-2. CANDU MACSTOR by AECL (Protected Commercial).

To disperse decay heat from the spent fuel, air is circulated up around the sealed cylinders, absorbing the excess heat, as shown in Figure D-2. The warm air is passively vented out at the top. Eight air inlets are located near the base of the module, and 10 outlets are just below the top slab.

Fuel is easily and safely transferred from a station's spent fuel storage pool in specially-designed, shielded transfer casks and loaded by crane directly into the MACSTOR modules, as illustrated in Figure D-3. With its massive shielding, the dose rate from the transfer cask is lower than that from other cask technologies and is well within all regulatory requirements. The transfer of spent fuel from the pool to the MACSTOR module is a routine, short-duration activity, typically performed by station staff who received the necessary training.

Figure D-3. Shielded transfer cask holding spent fuel is lowered into MACSTOR unit (AECL).

MACSTOR is designed and constructed with both the environment and people in mind. Its simple, modular construction provides efficient air-cooling ventilation to dissipate the heat generated by the spent fuel, and protects the stored spent fuel from the elements. There are no radioactive emissions. The robust design of its concrete structure allows safe access for the operating personnel. Modules can be safely located close to existing buildings. When fully loaded with fuel, the dose rate from a MACSTOR module is much lower in comparison to cask technology. No additional shielding walls or barriers are required to protect the public or environment.

The MACSTOR system is backed by a 30-year history of expertise in concrete-based storage systems. In 1990, AECL, in conjunction with a US partner, began developing MACSTOR. After rigorous testing and an in-depth comparison of safety, economics and performance with all other technologies, it was selected by Hydro-Québec as the best technology to satisfy all of its future spent fuel storage needs. AECL provides its experience and knowledge to support customers through all phases of the MACSTOR project: design, manufacture, construction, staff training, commissioning and operation.

When it is required to transfer the spent fuel from the on-site dry storage facility to an off-site centralized storage facility, the spent fuel can be loaded into an off-site transport cask directly from the MACSTOR module.

While AECL is the designer and project manager for MACSTOR, local companies are used to supply, fabricate and install the main materials, such as concrete, steel, etc. AECL has the design, engineering, welding and project management knowledge to support MACSTOR. Heat transfer and criticality expertise is important and AECL has solid capability in those areas. These capabilities are expected to be maintained over the next 25 years as there will be continuing transfer of spent fuel from wet to dry storage.

Summary of Technical Specifications for this MACSTOR Module:

Module dimensions	H 6.2m/W 9m/L 22m
Module material	Regular density reinforced concrete
Nominal concrete wall thickness	2.25m
Minimum air inlet/outlet wall thickness	1m
Nominal end wall thickness	1.25m
Nominal top slab thickness	1.5m
Nominal seismic pad thickness	1m

D.2 Dry storage container approach

Ontario Power Generation uses individually transportable Dry Storage Containers (DSC) for the on-site dry storage of spent fuel. Three "baskets" or "modules" of fuel bundles may be loaded in the spent fuel storage pool into one DSC, and using a custom-designed transporter (Figure D-4), the DSC is moved into the dry storage building.

Figure D-4. Dry storage container and transporter (OPG).

The DSC has a very robust design and is made of reinforced concrete 0.5 metre thick and lined inside and outside with 1.5 centimetre thick steel, as shown in Figure D-5. Each unit has a base of 2 by 2.5 metres, and is 3.5 meters high. Each container can hold 384 used fuel bundles and weighs over 80 tons when filled. The Phase I building at Pickering NGS holds 700 DSCs and the Phase II building will hold 800 DSCs, which is expected to satisfy the needs of the station to the end of its life-time.

The DSCs are engineered to last at least 50 years and will provide safe, interim storage until a long-term management program is in place. The Containers are also designed to allow shipment of the spent fuel directly to a long tem storage or disposal facility.

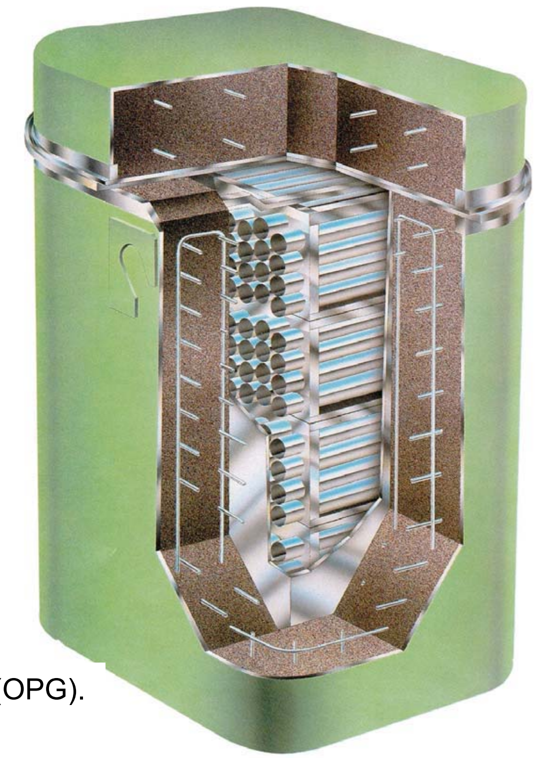

Figure D-5. Dry Storage Container (OPG).

Figure D-6. Dry storage containers holding spent fuel inside the Phase I Building at Pickering NGS (OPG).

Appendix E: Information Request for Canadian Expertise and Capabilities for High Level Radioactive Waste Management (HLRWM)

The Nuclear Waste Management Organization (NWMO) has the mandate to identify and implement a long term management approach for used nuclear fuel in Canada. As part of that work, I am compiling information on the status of Canadian expertise and capabilities that will be needed to manage Canada's high-level radioactive waste over the next 25 years. This is a request for information on the relevant expertise and capabilities in your Company that exists today and is likely to remain available during the various phases of implementing a HLRWM program in Canada.

The project phases relating to HLRWM over the next 25 years for which Canadian expertise and capabilities need to be considered are:

Phase 1: investigation of alternatives and recommendation of the preferred approach (3 years), with Government approval to proceed with the recommended approach assumed to be given in 2006

Phase 2: selection of site or sites for the approved waste management method (3-5 years), i.e. site selection completed in 2009-2011

Phase 3: environmental assessment and site approval (2-3 years) i.e. site approved in 2011-2014

Phase 4: preliminary design and approval of the facility (4-6 years) i.e. facility approved in 2015-2020

Phase 5: design and construction of the facility (5-7 years) i.e. facility completed and ready for operation in 2020-2027

Phase 6: operation, including receiving and storing high level radioactive waste.

There are four alternatives that the NWMO will study to manage Canada's used nuclear fuel. Since the recommended method will not be known until the end of Phase 1, the expertise and capability relevant to all four methods needs to be reported. The four methods are:

Alternative A: Deep geological disposal in the Canadian Shield

Alternative B: Storage at nuclear reactor sites

Alternative C: Centralized storage, either above or below ground

Alternative D: Other approaches

It is also possible that the preferred method includes some combination of the above four alternatives, for example storage at the nuclear reactor sites for an initial period of several years, followed by one of the other alternatives.

The four alternatives in combination with the six project phases result in up to 24 specific project areas in which expertise and capability can be specified. Your Company may wish to identify its expertise and capability for all phases and alternatives, or for one or more of the six phases and/or four alternatives, or for specific combinations of Project Phase (1-6) and Alternative (A-D). If possible, please state the number of experts in each area, and indicate with "Y" or "N" if the capability is fully within the Company or not (i.e. it will need to contract out parts of the task). Where you have expertise and/or capability, please specify the subject areas in which you have expertise and capability. For the purpose of this report, I am defining "expertise" as the qualification, knowledge and experience of individuals employed by the company, and "capability" as the capacity to perform work using teams of experts and support staff, computer software and hardware, specialized equipment, processes, procedures and other infrastructure. Typical subject areas are listed following the table on the next page.

The 24 combination of Alternatives and Phases of the HLRWM Project for which Canadian expertise and capabilities are requested are shown in the following table:

	HLRWM Alternatives			
HLRWM Project Phases	**A. Deep geological**	**B. On-site**	**C. Centralized**	**D. Other**
1. Study	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:
2. Site Selection	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:
3. Environmental Assessment and Site Approval	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:
4. Preliminary Design and Facility Approval	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:
5. Design and Construction	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:
6. Operation	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:	# of experts: full capability:

Listed below are several subject areas of expertise and capabilities that are likely to be needed to support the above tasks, but this list should not be regarded as complete, and the Company is encouraged to identify additional areas.

Expertise and capabilities common to all phases and alternatives:

- project management
- environmental impact assessment
- environmental monitoring
- radiological assessment
- economic models for the cost of site and facility design, construction & operation
- waste-form behaviour
- radioactive material handling
- transportation
- site screening and site selection
- safety analysis and licensing services to meet regulatory requirements

- engineering design
- risk, cost and benefit analysis
- public consultation and communication
- evaluation of societal, ethical and community attitudes
- traditional aboriginal knowledge
- safety and security audit and assessment
- emergency response planning and management

In addition to these common areas, various specific expertise and capabilities will be required for the different alternatives.

Alternative 1: Deep Geological Disposal in the Canadian Shield

- site investigation and characterisation (geosciences, modelling, engineering)
- site development (infrastructure design and construction)
- design, construction and operation of transportation infrastructure from power plants to disposal facility
- geochemistry of radionuclides
- groundwater flow modelling and mass transport
- geotechnical engineering
- sealing materials and methods
- disposal facility conceptual design studies
- disposal facility design and construction
- disposal facility closure technologies
- operation, maintenance and overall management of an underground waste disposal facility

Alternative 2: Storage at nuclear reactor sites

- design and fabrication of dry storage containers for spent fuel
- design and manufacture of on-site fuel handling and transportation equipment
- design and construction of on-site infrastructure
- operation and maintenance of on-site waste management facility

Alternative 3: Centralized storage, either above or below ground

- above ground storage is assumed to use the same or similar technology to the on-site storage methods currently used
- below ground storage is assumed to require a subset of the expertise and capabilities listed for Alternative 1
- responding Companies are encouraged to identify expertise and capabilities that would be unique to a particular approach for centralized storage that the Company may wish to propose

Alternative 4: Other approaches

While many alternatives for HLRWM have been considered, including disposal into space, under ice sheets, the ocean floor, with or without reprocessing and/or transmutation. If the Company plans to recommend an approach to the NWMO other than the three methods already considered, then the response to this enquiry should report the status of the expertise and capability in Canada for the proposed method, or the practically of transferring such a technology to Canada.

Recognizing the long time-frame over which the expertise and capability the Company has been asked to report, comments on the Company's ability and plans for maintaining the existing skill levels and developing new ones, should be included.