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MANAGING NUCLEAR FUEL WASTE IN CANADA

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The safe disposal of nuclear fuel waste poses a special challenge to resource managers and governments. Not only is the material to be disposed of highly dangerous, but it requires isolation from the habitable environment for thousands of years. The planning horizons of most organizations rarely exceed a decade. In Canada, the process is under way to evaluate the feasibility of disponsing nuclear fuel waste in a deep geological repository. This paper reviews the method by which this proposed facility is being evaluated and examines some of the consequences of the assessment procedure.

Key words: nuclear fuel waste, environmental assessment, radiological effects

1 INTRODUCTION

A major challenge for public agencies and resource managers in the next decade will be to safely dispose of nuclear fuel waste (NFW). The longevity of the material and the requirement to isolate it from the habitable environment for thousands of years pose special challenges. No country has yet found a way to permanently dispose of its nuclear fuel waste, although many are evaluating a number of proposals.

In Canada, the feasibility of the technology for the permanent disposal of NFW is being assessed. Deep burial in plutonic rock in the Canadian Shield is the option favoured by the

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Canadian government and nuclear agencies. An environmental impact assessment began in 1989 and is expected to be completed by 1996 (AECL, 1990). The assessment process has two stages. The first is concerned with the feasibility of the technology for deep geological disposal. If this technology is deemed to be viable, the second phase of the assessment will commence; to locate a specific site for a NFW repository and to determine its detailed suitability.

The proposed Canadian nuclear fuel waste disposal concept and the evaluative process to determine its feasibility will be described and evaluated. The methodology used by the Atomic Energy of Canada Limited to assess the technlogical feasibility of the proposed disposal facility also will be discussed.

2 ENERGY IN CANADA

Canada has historically been an energy-rich nation. The development and use of its indigenous supplies of fossil fuels and hydro-electric potential has played a major role in the emergence of Canada as a major supplier of resources, and has contributed to the high standard of living Canadians enjoy. The level of demand for energy has increased dramatically since the turn of the century. Significant increases occurred particularly after 1930, with the most rapid increases (greater than 6 % per annum) occurring in the 1960s. The demand for energy in Canada is presently increasing at a comparatively lower rate. Throughout the 1980s, demand increased approximately 1,2 % per annum. This trend is expected to continue until the year 2010 (NEB, 1991).

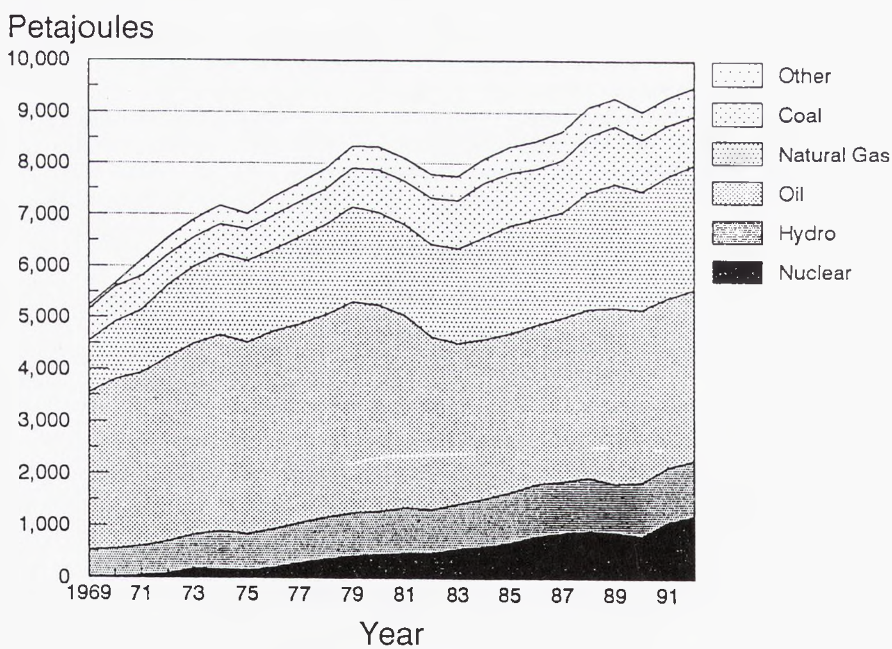

Fig. 1. Primary energy demand in Canada by fuel type: 1969–1992

The major types of energy resources used in Canada have also changed since the turn of the century. Coal initially provided the vast majority of energy. Petroleum and later natural gas became the predominant fuels in the 1950s and they remain so. This coincides with the discovery and development of oil and gas reserves in Alberta beginning in 1947. The present period is characterized by a diverse mix of energy resources (Fig. 1). Natural gas plays an increasingly important role as established reserves of conventional oil decline. Hydro electricity will continue to remain a key component in the overall energy delivery system as Canada taps its vast hydrological resources. Continued development in the James Bay region of northern Quebec in particular would add substantial amounts of electricity for domestic use and consumption. Nuclear power provides approximately 12 % of Canadian energy needs (NEB, 1991). Forecasts as to the future of nuclear power development in Canada are uncertain at present as a moratorium has been declared on the construction of new nuclear power facilities (Ontario Hydro, 1992).

3 NUCLEAR FUEL WASTE MANAGEMENT IN CANADA

The first large scale commercial nuclear reactors were built in the Province of Ontario in the late 1960s and were operating in the early 1970s. There are now 21 reactors at six generating stations located in three provinces. Almost all of the nuclear generators (19) are situated in the Province of Ontario and supply about half of the province's electricity requirements. Despite the present moratorium on the construction of new nuclear power facilities, the nuclear component is, and will remain for some time, an important element in electricity supply.

By 1989, 14 000 tonnes of nuclear fuel waste (NFW) has accumulated and approximately 1800 tonnes are generated each year (AECL, 1990). The issue of used nuclear fuel management is thus one of disposing of a relatively low volume of highly radioactive waste. At present NFW is stored on site at each nuclear station. Once the irradiated fuel is removed from the reactor core, it is placed in water-filled pools for storage. Experiments have been conducted to determine the feasibility of storing NFW in above ground silo-shaped concrete containers which would be viable for about fifty years (EMR, 1988). Although present storage measures have sufficed, they are still considered interim and a permanent disposal option is required.

The Canadian Nuclear Fuel Waste Management Program was established in 1978 to "develop storage and disposal concepts that would ensure that NFW would not have any adverse effects on (people) or the environment" (AECL, 1985a, p. i). The strategy chosen was to minimize the burden on future generations by ensuring that the disposal method would be one "in which there is no intention of retrieval and which, ideally, uses techniques and designs that do not rely for their success on long-term institutional control" (AECL, 1990, p. 6).

To determine the type of facility that would most suit the Canadian nuclear program and setting, a commission was set up to evaluate disposal options. The commission, known as the "Hare Commission", considered a number of disposal options (e.g. transmutation, depp-sea burial, burial in Arctic ice sheets, and disposal in outer space) before deciding that deep burial in plutonic rock in the Canadian Shield was the most viable (Hare, 1977).

The proposed option had to meet four requirements: 1) the project must comply with the radiological risk quidelines set out by the International Commission on Radiological Protection; 2) the disposal system must be environmentally and socially benign, according to the standards set by the Federal Environmental Assessment Review Office (FEARO); 3) the disposal system must be technically and economically feasible; and 4) it must be capable of implementation in the near future (AECL, 1984b).

The proposed disposal facility will resemble a deep mine, 500 to 1000 metres deep. The used fuel will be sealed inside corrosion-resistant containers which will then be placed in holes drilled in the floor of the disposal rooms. An underground network of tunnels and disposal rooms covering approximately two square kilometres will be constructed; enough to hold 191 000 tons of used fuel (AECL, 1990). This capacity will be sufficient, given present installed nuclear electricity capacity, to accommodate Canada's used fuel to beyond the year 2035.

A series of natural and engineered barriers will be required to ensure that the used fuel is isolated for the long term. Since the only way that buried wastes can reach the environment is by being dissolved and transported in groundwater (AECL, 1990), it is important that the used fuel containers are highly insoluble and surrounded with barriers that will block the movement of water and trap and retard radioactive materials that eventually escape.

4 ENVIRONMENTAL ASSESSMENT

The assessment of the Canadian disposal concept for nuclear fuel waste is being undertaken by the Federal Environmental Assessment Review Office (FEARO). A detailed environmental impact statement is required as part of the process which is divided into two essentially separate phases. First, the feasibility of the deep burial concept and the required technology is to be evaluated (Fig. 2). This process began in 1989 and is still in progress (1993). Detailed requirements for an environmental impact statement have been formalized and submitted to the Atomic Energy of Canada Limited, the major project proponent. Once the environmental impact statement is completed, it will be submitted to FEARO and then be opened up to public scrutiny. If the disposal concept is deemed acceptable, the second major phase of the environmental impact assessment process will start. The focus of this phase will be to select and evaluate a candidate site for the repository. It is hoped that the entire process can be completed by 1996.

Studies undertaken to date by the AECL which contributed to the consideration of the underground disposal facility were "generic" analyses. In other words, the studies, although based on actual environmental parameters, were not location-specific. This was because no location for the proposed facility has been publicly advanced. Furthermore, the site selection process has not been agreed upon and will not be formally considered until after the first phase of the environmental assessment is completed. The fact that the analyses were not location specific can be viewed as a major drawback to the entire process in that local conditions and attributes which may have a significant impact on the feasibility of a repository are not taken into account. It may also be viewed as a way of establishing and testing the methodological robustness of the environmental assessment analyses.

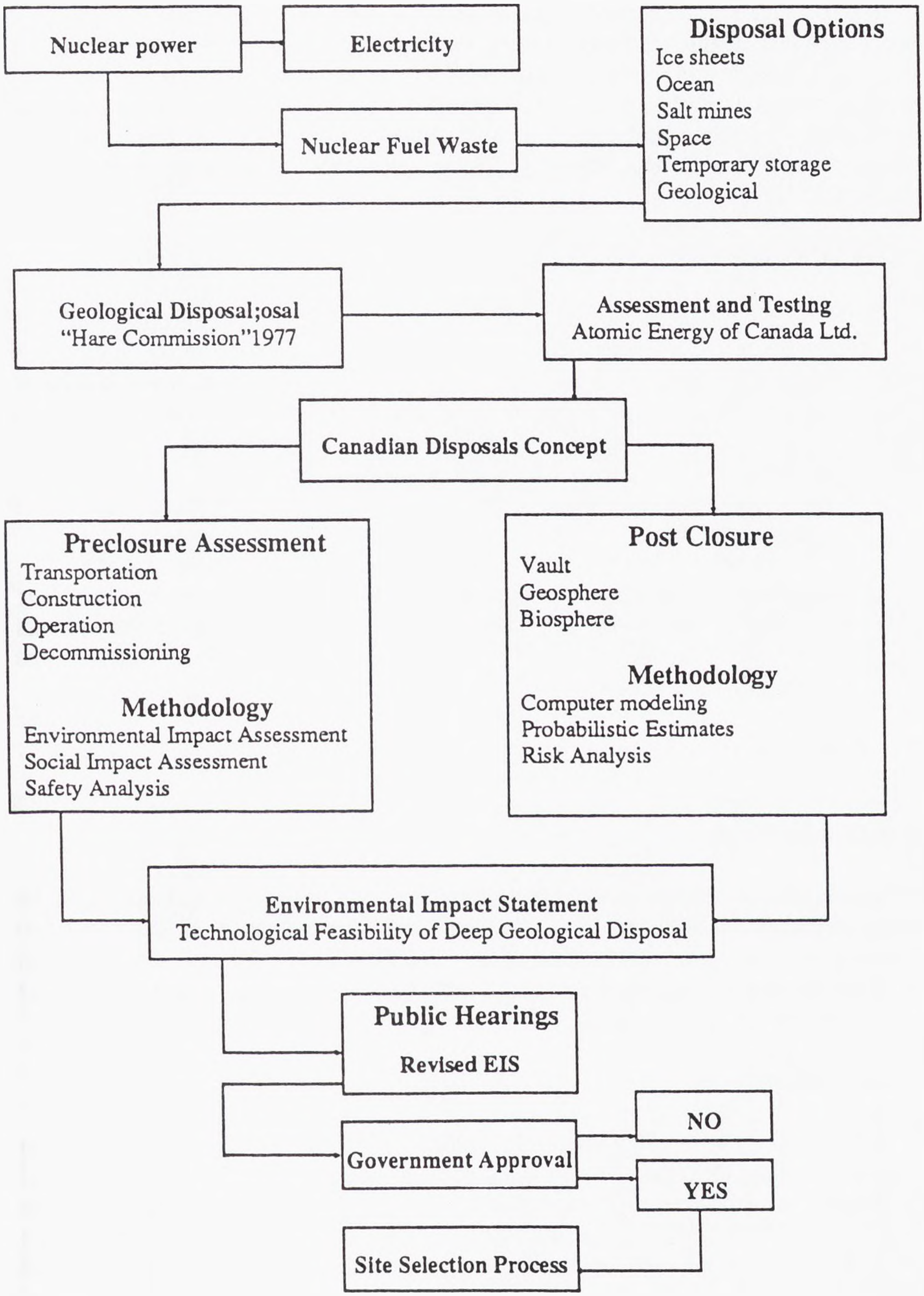

Fig. 2. Nuclear Waste Disposal Process

The first phase of the environmental impact assessment (technological feasibility) has two stages, recognizing the two broad requirements of the proposed facility. The first is termed the "pre–closure assessment", concerned with the construction of the facility prior to the placement of NFW. The second phase is the "post–closure assessment" dealing with the possible implications and impacts of the facility once the NFW is deposited. Both these phases assume fundamental importance in the assessment process and will now be discussed.

PRE–CLOSURE ASSESSMENT

The pre–closure assessment of nuclear fuel waste disposal is concerned with the activities associated with the transportation of the waste to the disposal site, the construction and operation of the disposal facility, the closing of the vault, and the decommissioning of the surface facilities. In many ways, this assessment resembles analyses performed on conventional mining activity structures and processes.

The objectives of the pre-closure assessment are to:

1. assess the environmental and socio-economic effects that would occur during the pre-closure activities;
2. identify ways to mitigate adverse impacts and maximize potential benefits;
3. assess the potential public and occupational hazards of the pre-closure activities;
4. develop environmental and socio-economic guidelines to aid in the eventual selection of a site, if the concept is accepted by the Governments of Ontario and Canada (AECL, 1985a, p. 10).

The pre–closure assessment requires a comprehensive analysis of the many components and eventualities that may arise from building and operating the disposal facility. The major components and some preliminary results will be outlined.

Impact on resources

Labour requirements for the construction and operation of the disposal facility, and the transportation of the used fuel, would be significant. Approximately 10 000 to 13 500 person–years of local direct labour would be required during the lifetime of building and operating the disposal facility. Additionally, 100 000 person–years of indirect and spinoff labour would be generated (AECL, 1985b, p. 13).

Capital and operating costs

Estimates of the costs of building and operating the facility vary depending on different assumptions about the types of material requirements (e.g. lead or other fill material) and the distance the depository will be build from nuclear power stations located in southern Ontario. The AECL (1985b, p. 13) has estimated that capital cost will range between 544 and 637 million dollars, while annual operating costs range between 137 and 397 million dollars.

Radiological effects of normal operation

In implementing the disposal system, some radiation exposure to people and the environment will occur. Sources of radiation exposure can be grouped into four categories:

1. natural radionuclides released by excavation;
2. exposure during transportation of used fuel;
3. airborne emissions from the disposal facility;
4. waterborne emissions from the disposal facility.

The AECL has conducted extensive investigations attempting to extimate maximum radiation doses to people resulting from the construction and operating of the facilities. For each of the above categories, doses were predicted to be less than naturally occurring background radiation (AECL, 1985d).

Non–radiological effects on the natural environment

The assessment of non–radiological effects of the disposal facility focuses on three primary activities: construction of the disposal facility; transportation of used fuel to the disposal facility; and operation of the disposal facility.

During construction, most environmental effects would be similar to those resulting from conventional mining operations. For example, the clearing of vegetation cover, dust and particulate emissions, runoff from the construction site into local water bodies and localized effects on wildlife species.

The total land surface required for the facility would be approximately 27 square kilometres, although less than 10 % of this area would be developed. Reclamation of the site following the closure of the facility will be required.

Socio–economic effects

The effects of a disposal facility will have numerous impacts on the social characteristics of the community hosting the facility and on the population along the transportation corridor. To understand and predict the impacts, a social impact assessment procedure is required. Issues that must be considered include: the effect of increased demand for services resulting from the influx of construction workers (e.g. housing, recreation, water and sewage facilities), impacts on the lifestyle and values of resident community members; perceptions of risks and dangers perceived by community members and health and safety concerns. Impacts related to transportation include those relating to traffic, employment, the consequences of perceived risk; and noise.

Occupational safety

Concerns over occupational safety include both the nonradiological and radiological effects. The transportation of the used fuel and the construction, operation, and decommissioning of the disposal facility must be considered. The AECL (1985c) estimated that the potential non–radiological effects of operating and constructing the facility would be comparable to those expected of any large industrial facility. No radiological effects would arise as a result of facility construction since there would be no radioactive material present on site. Once used nuclear fuel is brought to the facility for disposal, risks to workers (and the general public) will have to be monitored closely and preventative measures will need to be in place. Preliminary estimates of radiological and conventional occupational risks were estimated by the AECL (1985c) to be about 3 to 5 fatalities per 100 million person–hours. This level is comparable to those in other industries.

Radiological effects from abnormal operation and accidents

Possible radiological effects from abnormal conditions must be considered for both the disposal facility and the transportation of used fuel. The initiating events that may lead to accidental releases of radionuclides are classified into three categories (AECL, 1985c, p. 67):

1. Natural events such as earthquakes, floods and meteorite impact;
2. External human-induced events such as aircraft impact and collision events involving shipping casks;
3. System and equipment failures and operator errors such as dropping fuel bundles.

All stages in the pre-closure stage must be taken into account in this analysis and mitigative measures must be considered. The key stages include the transportation of used fuel, handling and burial of the used fuel containers, and the immobilization of the containers in the disposal vault.

In summary, the pre-closure phase of the assessment process will require three types of assessment. The first, an environmental assessment, will examine the radiological and nonradiological impacts arising from the transportation and construction of the disposal facility. Second, a socio-economic assessment will be conducted to assess the potential impacts the disposal facility will have on populations most likely to be affected. Included in this analysis will be an evaluation of the cost and benefits of building and operating a disposal facility. The third assessment is a safety analysis focusing particularly on potential radioactive exposure during the decommissioning phase of the disposal facility.

POST-CLOSURE ASSESSMENT

The objective of the post-closure assessment is to estimate the potential long term effects of the disposal system on people and the environment once the disposal facility is closed. Specifically, the objective is to determine the impact on people and the environment that could result from the transport of radionuclides from the disposal vault through the overlying rock to the surface (AECL, 1985d). The AECL maintains that the only feasible way for radionuclides to reach the surface would be by groundwater that could penetrate a disposal vault, corrode the containers, dissolve the radionuclides in the waste and carry them to the surface. Once on the surface, the radionuclides would then be dispersed or concentrated in water, soil, plants, animals, and air, potentially cousing harm to people (AECL, 1985d).

The post-closure assessment is based on the modelling of the transport of radionuclides and elements through the disposal system. The AECL has developed a computer model to undertake the analysis. The model, known as SYVAC (System Variability Analysis Code) contains a set of submodels representing the major components of the disposal system; the vault, the geosphere, and the biosphere. The vault submodel is used to calculate the time-varying transport of radionuclides and elements from the vault into the surrounding geosphere. Specifically, the model simulates the corrosion of the containers, the release of contaminants from the waste, and the transport of contaminants through the buffer and backfill materials in the vault (AECL, 1990).

The geosphere submodel is used to calculate the time-varying transport of radionuclides and elements from the vault to the biosphere. Specifically, the model simulates the movement of groundwater through the rocks surrounding the vault, the transport of contaminants in the groundwater, and the discharge of contaminants at locations in the surface and near-surface environment. The biosphere submodel is used to calculate the time-varying concentrations of radionuclides and elements in soil, water, and air, and the resulting time-varying dose to people. It will be used to estimate the radiological impact on the people most affected because of their location and lifestyle. Specifically, this model simulates the transport of contaminants within the biosphere through surface water, soil, plants, air and animals and the exposure to people to internal radiation (e.g. from food, water, and air) and to external radiation (from soil, water, air, and buildings) (AECL, 1985d; 1990).

Calculations with each of these three submodels are carried out in series. In other words,the output from the vault model is included in the geosphere model. Similarly, the output from the geosphere model is incorporated into the biosphere submodel. The three models are interconnected in the SYVAC computer program whereby the outputs from one submodel to the next are carried out. The results of each SYVAC simulation include the following:

1. the total dose at several specified times;
2. the value and time of occurrence of the maximum total dose up to each of several specified times (100 000 years, 1 million years, and 10 million years);
3. the values and times of occurrence of the maximum doses from ingestion, inhalation, and external exposure;
4. the values and times of occurrence of the maximum doses from several specified radionuclides, and the total doses at these times;
5. the names and concentrations of the three highest contributors to the maximum total dose;
6. the maximum concentrations in soil and water for the chemically toxic elements (AECL, 1985d, p. 13).

The SYVAC computer model has been applied by the AECL to assess the consequences of the disposal of used fuel and fuel recycled waste. Based on more than 1000 scenarios, employing a variety of parameters and estimates, the AECL (1990, p. 32) has concluded that "no consequences [annual dose less than 10^{-10}mSv] were predicted for tens of thousands of years after disposal". They go on to state that "no unacceptable risks or effects would be experienced due to the implementation of the used fuel disposal system for at least tens of thousands of years" (AECL, 1990, p. 34). Thus, as assessed by one of the major project proponents, the risks associated with the deep burial of nuclear fuel waste are deemed to be extremely low, and acceptable.

5 DISCUSSION

The process under way in Canada to assess the feasibility of deep geological disposal of NFW has to date been relatively uncontroversial and problem-free. This is in stark contrast to the attempt in the United States to construct a disposal facility at Yucca mountain in Nevada. The primary difference between the Canadian and American experience is the fact that phase one of the assessment process in Canada is focused only on the feasibility and viability of the disposal technology. As such, it is not location-specific.

The decision to conduct the environmental impact assessment process in this manner can be viewed as a "divide and conquer" strategy. By focusing initially on the technology of constructing and closing a disposal facility, questions as to the necessity and safety of nuclear energy generally, and (perhaps more crucially) securing the support of a community of host the proposed facility are delayed. Furthermore, because of the decision of the Hare Commission in 1977 that Canada should focus on deep geological disposal, other options are not being considered in detail during the current EIA process.

The relatively narrow focus of the Canadian EIA process is not the only limitation regarding the ultimate decision as to whether or not, and how, a facility is to be constructed. A major limitation may come as the locational decision looms closer. The lessons from the United States, and indeed in Canada regarding hazardous waste facilities, are instructive. The greatest barrier to the location of waste facilities is public opposition. This opposition is mobilized through the formation of special interest groups or by private submissions to public hearings, the media, or elected officials. The ascendancy of interest group and public power has characterized the Canadian political process for the past two decades. Indeed, the procedures for conducting environmental impact assessments require that the public be given substantial opportunity and financial support to submit their views. Decision makers are also finding it difficult to overrule public wishes as the sophistication of interest group and public lobbying has increased in efficiency and effectiveness.

A second and related issue which will be problematic to the siting of a repository will be the varying and often dichotomous perceptions of risks associated with nuclear power generally and nuclear fuel waste specifically. Slovic et. al (1991, p. 1603) commment on this with respect to the American attempt to construct a NFW facility at Yucca Mountain in Nevada:

The program has been brought nearly to a halt by overwhelming political opposition, fuelled by perceptions of the public that the risks are immense. These perceptions stand in stark contrast to the prevailing view of the technical community, which argues that nuclear wastes can be disposed of safely, in deep underground isolation.

A significant component of the environmental impact statement is the consideration of risks associated with the construction and operation of the disposal facility. The risks include those potentially affecting both the natural and human environments. This requires initially a definition of risk and health and the identification of the potential sources of radiation in the natural and human environments. The assessment of these risks by those in the nuclear industry is often fundamentally different from that of the general public or special interst groups. This difference is sometimes referred to as actual and perceived risk. The former is generally associated with the quantitative assessment of radiological risks by scientists, while the latter is the risk perceived by the general public or by a variety of public interest groups ("qualitative assessment"; Kunreuther et al. 1988; 1990; Slovic et al. 1991).

Evidence of this dichotomy in Canada can be seen in the submissions to the scoping meetings held in 1990 as part of the first phase of the environmental impact assessment. A wide spectrum of interests and opinions both in support of the proposed facility and vehemently opposed were voiced. Most of the dissention came from environmental organizations, citizen coalitions, Native organizations, and private citizens (FEARO, 1991a; 1991b). The focus was on the perceived risks associated with radiation and the perceived long term threat to residents living in the vicinity of a proposed repository or transportation corridor. These perceived risks were substantially greater than those identified by the AECL and referred to earlier.

This disparity in perspectives is to be expected. As Oppenshaw et al. (1989, p.1) have noted with respect to British NFW management, "the process of finding a site for a facility is not as it may appear at first sight, a purely technical and objective scientific process, but one which involves complex and difficult value judgements, combining technical and broader socio-economic and political concerns". The challenge for decision makers is to bridge this dichotomy by providing a comprehensive technical methodology to assess the likely and unlikely consequences of a disposal facility, while at the same time giving equal importance and attention to social concerns, objections, and proposals. Within the context of the initial assessments undertaken by the AECL, the first of these challenges has been met. The technological assessment and research has been comprehensive. However, substantially less effort has gone into the social and political considerations of managing nuclear fuel wastes. Without this latter focus, the Canadian Disposal Concept is more than likely to be met with delay and failure.

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HOSPODÁRENIE S JADROVÝM ODPADOM V KANADE

Bezpečné uloženie rádioaktívnych odpadov je veľkou úlohou najbližšieho desaťročia pre odborníkov zaoberajúcich sa využívaním zdrojov. Rôzne možnosti riešenia tohto problému prehodnocujú a skúmajú vo viacerých krajinách.

Štruktúra využívania primárnych zdrojov energie sa v Kanade menila a jej vývoj v rokoch 1969–1992 je zachytený na obr. 1. Jadrová energia sa začala využívať koncom 60. rokov. V Kanade je v súčasnosti v prevádzke 21 jadrových reaktorov, v šiestich elektrárňach lokovaných v troch provinciách. Tieto zariadenia vyprodukovali do roku 1989 14 000 t rádioaktívneho odpadu. Tento odpad je v súčasnosti lokovaný v dočasných úložiskách pri každej jadrovej elektrárni.

V roku 1978 bol prijatý program zaobchádzania s rádioaktívnym odpadom a začal sa výskum trvalého uloženia rádioaktívnych odpadov (RO). Z viacerých alternatív umiestnenia odpadu vyhodnotila komisia ako najvhodnejšiu a najbezpečnejšiu alternatívu vybudovania hĺbkového podzemného trvalého úložiska vo vyvrelých horninách Kanadského štítu. Úložisko by bolo tvorené sieťou vydolovaných podzemných tunelov a úložných miestností v hĺbke 500–1000 metrov.

V roku 1989 sa začalo hodnotenie vplyvu trvalého úložiska na životné prostredie (EIA), ktoré pozostáva z dvoch etáp a má byť ukončené v roku 1996. V súčasnosti prebieha prvá etapa, hodnotenie samotnej koncepcie hĺbkového úložiska a vhodnej technológie jeho realizácie. Schéma jednotlivých krokov tejto etapy je znázornená na obr. 2. V prípade, že sa uvedená technológia ukáže ako realizovateľná, bude v druhej etape nasledovať výber konkrétneho miesta lokácie úložiska.

Prvá fáza EIA (technologická vhodnosť) má dve etapy. Prvá etapa „hodnotenie vplyvu úložiska pred uzavretím" sa zaoberá výstavbou a konštrukciou úložiska pred umiestnením RO. Druhá etapa „hodnotenie vplyvu úložiska po uzavretí" sa zaoberá možnými vplyvmi a dôsledkami zariadenia na okolie po uložení RO.

„Hodnotenie vplyvu pred uzavretím" vyžaduje komplexné analýzy mnohých komponentov a eventualít, ktoré môžu vzniknúť pri výstavbe a prevádzke úložiska. Hlavnými komponentmi hodnotenia sú: vplyv na zdroje, kapitálové a prevádzkové náklady, radiačné efekty normálnej prevádzky, neradiačné efekty na prírodné prostredie, socioekonomické efekty, bezpečnosť zamestnancov, radiačné efekty abnormálnej prevádzky a nehôd.

„Hodnotenie vplyvu po uzavretí" je založené na modelovaní transportu rádioaktívnych prvkov cez systém úložiska a okolitú horninu na povrch zeme. Vyvinutý počítačový model SYVAC obsahuje niekoľko submodelov reprezentujúcich hlavné zložky systému úložiska: submodel priestorov úložiska, submodel geosféry a submodel biosféry.

Technologickým aspektom zaobchádzania s rádioaktívnymi odpadmi v Kanade bola venovaná veľká pozornosť a úsilie. Menšia pozornosť sa venovala sociálnym a politickým aspektom. Problémy je možné očakávať pri určovaní konkrétneho miesta lokácie trvalého úložiska rádioaktívnych odpadov.

Preklad Ján Szöllös