

RESULTS OF THE PRELIMINARY ENVIRONMENTAL AND SAFETY ASSESSMENT
OF THE CANADIAN NUCLEAR FUEL WASTE MANAGEMENT CONCEPT: PRE-CLOSURE PHASE

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ABSTRACT

The results of a preliminary environmental and safety assessment of a concept for disposal of intact used CANDU nuclear fuel are presented in this paper. This assessment is part of the Concept Assessment phase of the Canadian Nuclear Fuel Waste Management Program.

INTRODUCTION

The Nuclear Fuel Waste Management Program, which is coordinated by Atomic Energy of Canada Limited (AECL), is seeking to develop a disposal concept which is technically effective and feasible as well as environmentally and socially acceptable. The proposed concept is to immobilize used fuel or recycle waste and subsequently emplace it deep underground in a stable rock formation within the Canadian Shield region of Ontario. Ontario Hydro's assistance to AECL in this program includes environmental and safety assessment^(1,2) of the pre-closure phase of the concept. The division between pre- and post-closure periods is taken to be the point at which the underground vault and shafts have been backfilled and sealed, surface facilities have been removed and the site restored or released to some other use. The assessment of post-closure environmental risks is being carried out by AECL. The plan is to assess the concept in stages, with three interim assessments reflecting progress in research and development, and to submit a final concept assessment document to government for approval prior to beginning site selection. The results of the second interim pre-closure assessment, based on direct disposal of used fuel are summarized in this paper. The Second Interim Concept Assessment Document is to be published later this year by AECL. The third interim assessment will also address recycled waste disposal.

ASSESSMENT APPROACH

Concept assessment studies are generic in that no specific site is assumed. Yet to be meaningful, the pre-closure assessment is based on a "reference environment" approach which incorporates environmental conditions representative of the Shield region of Ontario. The reference environment data base is based on existing information or information which could be generated from available raw data.

The reference environment approach for assessment of potential radiological (normal, abnormal and accidental) and biophysical effects is based on environmental conditions representative of the Shield region of Ontario. With this approach the Shield region has been divided into three smaller regions: southern, central and northern. Three reference distances (400, 800 and 1600 km) are associated with these regions for purposes of fuel waste transportation analysis. Variations in environmental conditions are taken into account as appropriate in the assessment.

The assessment of potential social effects of a disposal facility takes a similar approach, being based on four reference communities; a town, township, county and a new town. These communities are considered generally representative of communities in the Shield region. The assessment identifies the main social and community effects of a disposal centre including common effects, which may occur in any community (although they may vary in intensity and are generally due to characteristics of the facility) and community specific effects (which are generally due to the characteristics of the specific community).

The assessment of potential social impacts of used fuel transportation is based on human settlement patterns representative of the Shield region. These patterns are urban, cottage/recreational and rural/agricultural. This approach differs somewhat from the reference community approach because transportation is a linear activity, passing through a number of communities while a disposal centre is a fixed facility, likely to affect a specific community. Therefore it is likely to have different and less wide ranging effects than would a disposal centre.

The assessment of potential environmental and safety implications of the disposal concept is based on AECL's conceptual disposal centre design⁽³⁾ "superimposed" on the reference environment/community data base. The pre-closure assessment, which is the product of a multidisciplinary team effort, includes an analysis of the potential (a) radiological effects of normal operations; (b) non-radiological effects on the natural environment and resources; (c) social impacts; (d) occupational risks; and (e) radiological effects of abnormal operations and postulated accidents. The analysis utilized a multitude of analytical models, the results of a wide variety of studies and Ontario Hydro's experience in constructing and operating nuclear facilities and other projects.

INTERIM ASSESSMENT RESULTSRadiological Effects

The objective of the radiological pathways analysis is to estimate the potential radiation dose to man and other biota due to operation of a disposal centre and from transporting used fuel to the facility. The analysis is based on the conceptual disposal centre design developed by AECL⁽³⁾. Since this design has not yet been fully developed and because there is relatively little experience in transporting, immobilizing and disposing used CANDU fuel, the calculation of individual and collective radiation doses to the public incorporate many conservative assumptions in both the estimation of radiological emissions (i.e., with respect to fuel defect rates) and in the analytical models which were used. The overall effect of these assumptions is that the emissions from a disposal centre have likely been over-estimated. Hence, the individual and collective dose estimates should be regarded as illustrative until more definitive estimates of emissions can be made.

The pathways analysis resulted in a range of dose estimates depending on pathways and regional environment conditions as shown in Table 1. The calculated doses to individuals via airborne emissions is much smaller than the normal variation in natural background radiation dose. This is because the dilution available for airborne emissions is almost independent of site, depending mostly on distance downwind.

However, the dilution available for emissions to waterbodies was found to be highly site dependent as evidenced by the results of the aquatic pathways analysis shown in Table 1.

Dose to the public from emissions to water are, as expected, dependent upon the size of receiving lakes or flow rate of receiving rivers. The results show that smaller lakes typical of the Shield region may not provide as much diluting capacity as desirable to keep individual dose smaller than the normal variation in natural background radiation dose. However, the questionable accuracy of the source terms must be kept in mind. Similar to the results for the airborne pathways, the dose to individuals via waterborne emissions are small, with the exception of small lake scenarios, depending largely upon the assumed dilution capacity of small versus large waterbodies. Emissions to small waterbodies are considered to warrant further design and environmental analysis.

In addition to the analysis of airborne and waterborne emissions, the release of radon and its daughters during excavation of the disposal vault were also considered. The results of this analysis showed that radon emissions (estimated to be 0.7 TBq/a Rn-222) would be less than the natural radon emanation from 1 km² of natural soil in the environment. Radon emissions from bedrock excavation thus represent a very small increase to natural radon emissions in the environment.

The fuel transportation system will have to meet all of the requirements of the International Atomic Energy Agency, the Atomic Energy Control Board and Transport Canada and is not expected to result in any unacceptable radiological consequences under normal (or accident) conditions. The results indicate that the radiological effects of fuel transportation

TABLE 1RESULTS OF INTERIM RADIOLOGICAL ANALYSIS

A. Estimated Annual Effective Dose Equivalent (Sv/a) to an Individual from Airborne Emissions

<u>Region</u>	<u>Dose Estimate</u>	<u>% of Background*</u>
South	7.6×10^{-6}	0.4
Central	5.8×10^{-6}	0.3
North	4.8×10^{-6}	0.25

B. Estimated Annual Effective Dose Equivalent (Sv/a) to an Individual from Waterborne Emissions

<u>Region - Water Source</u>	<u>Dose Estimate</u>	<u>% of Background*</u>
South - Rivers	4.6×10^{-5}	2.4
- Lakes	1.8×10^{-5}	0.9
- Chain Lakes	$5.7 \times 10^{-5} - 1.3 \times 10^{-3}$	3.0 - 68.4
Central - Rivers	7.8×10^{-6}	0.4
- Lakes	1.4×10^{-5}	0.7
- Chain Lakes	$5.5 \times 10^{-5} - 1.1 \times 10^{-3}$	2.9 - 57.9
North - Rivers	9.6×10^{-6}	0.5
- Lakes	1.2×10^{-5}	0.6
- Chain Lakes	$9.3 \times 10^{-5} - 1.4 \times 10^{-3}$	4.9 - 73.7

*Estimated annual effective dose equivalent from natural sources in Ontario = 1.9×10^{-3} Sv/a.

will only be a small fraction of natural background radiation exposure, regardless of the mode of transport. Truck transport would probably result in a slightly larger population dose than rail or barge transport, but the estimated effects are well within regulatory limits in all cases.

Non-Radiological Effects on the Natural Environment and Resources

The main results of the assessment of potential non-radiological effects from construction, used fuel transportation, operation and decommissioning of a nuclear fuel waste disposal centre and from the commitment of resources to fuel disposal are summarized in the following discussion.

Although the total land area required by a nuclear fuel disposal facility is relatively large (approximately 27 km²), less than 10 percent of this land would actually be developed. Ecological effects and pre-emption of land use or capability would largely be reversible following closure of the site. The cumulative land production permanently relinquished as a result of disposal centre construction would be minimized by siting in an area of low land use capability or mineral resource potential.

The quantities of excavated rock to be disposed are significant, but not unprecedented by any means. A nuclear fuel disposal project would have much in common with a mining development for example. However, the toxic runoff effects from rock disposal areas which sometimes occur with mining developments are not expected to occur in this case because site selection is expected to avoid areas with mineral potential. Any negative effects would be reduced if there were a market for this rock (e.g., as aggregate). Furthermore, prudent siting and adherence to environmental design and construction procedures for Ontario mining developments will eliminate or minimize to within acceptable levels any potential adverse effects.

Sensitive environmental areas (i.e., those having features of conspicuous ecological, geological, historical or cultural value) are normally avoided through careful siting of facilities. However, should any of these features be found on a site, protection measures and experience are available to ensure that the features are preserved. This is largely a matter of environmental policy and procedures.

Non-radiological emissions could not be fully quantified or analysed for potential toxic effects based on the current reference design (e.g. fumes from immobilization with lead, emissions from steam/heat generation, liquid wastes, etc.). However, effective technology and experience are known to be available for controlling the types of emissions which have been identified.

If lead is retained as the matrix material in the disposal container design, the total lead requirement will have a significant effect on Canadian lead supplies and reserves depending on the projected fuel disposal rate. However, ongoing research into alternative matrix materials may well lead to a different container design

involving more abundant resources. No other material resource requirements were found to be potentially critical, although several require further investigation, e.g. titanium alternative for disposal containers.

Social and Community Impacts

The objective of social impact assessment is to evaluate potential changes which may affect individuals and communities as a result of development activity. Social impact assessments focus on the ways in which these changes affect communities and the means of minimizing disruptions to the community and of maximizing benefits.

The major results of the social impact assessment of a disposal centre and of used fuel transportation are summarized in the following. It should be noted that the results are not considered conclusive owing to the limitations and generic nature (i.e., non-site-specific) of the assessment. The major limitation in this assessment is that public involvement, which is an important component of the impact assessment process, could not be incorporated in this assessment. These results do, however, serve to illustrate the wide range of social impacts, beneficial and non-beneficial, which could result from a disposal centre project. Social impact studies conducted at the site selection phase, when communities are known and public involvement is part of the study, will identify the most probable impacts. If appropriate, mitigation measures can be taken to eliminate or minimize these impacts. Once a site is chosen, the establishment of a monitoring and review process will enable unforeseen impacts to be identified and mitigation actions taken before serious impacts occur.

A nuclear fuel waste disposal centre, like any major energy project, will have a wide range of socio-economic impacts. Some of the impacts would generally be desirable, e.g. employment, income distribution, etc., and could be expected to occur in any community affected by a disposal centre. Although the number of local residents that could be employed at a disposal centre is difficult to estimate in a generic assessment, being dependent upon site and project specific factors, local residents may comprise 40 percent to 50 percent of the operating staff based on Ontario Hydro's generating station experience in northern Ontario (Table 2).

TABLE 2

DIRECT EMPLOYMENT POTENTIAL

A. Estimated Total Direct Employment (man-years)

Construction	2500
Operation (excl. transportation)	21400
Decommissioning	<u>1900</u>
Total	25800

TABLE 2 (cont'd)

<u>B. Estimated Local Employment (man-years)</u>	
Construction (30-70%)	750-1750
Operation (40-50%)	8550-10700
Decommissioning (30-50%)	570-950
Total	9870-13400
<u>C. Estimated Jobs at Peak Construction/Operation</u>	
Peak Total	800
Peak Local (30-70%)	240-560

Other impacts would be considered negative, e.g. increased demands on community services, changes in lifestyles and social interactions, etc. The assessment analyzed a wide range of such potential impacts for each of the reference community types. While most of the impacts are not unique or unfamiliar, compared to those of other large energy projects, the affected public may perceive some impacts as unfamiliar and perhaps serious. The assessment indicates that health and safety concerns, as well as benefit expectations, are likely to remain dominant factors in public attitudes.

The assessment of used fuel transportation identified a number of potential social/community impacts. These are concerned with (a) traffic, (b) employment and (c) social aspects. Of the potential effects identified, (a) is considered to be of a local nature, while (c) is considered likely to be more pervasive. With respect to employment, transportation is a linear, non-centralized activity and is unlikely to have much effect on employment in any one area. The potential effects of used fuel transportation on the social aspects of communities will mainly be influenced by the concern for harmful health effects which are perceived by the public to be associated with this activity. The influence of risk perception is discussed in greater detail in a paper by B.G. Rogers⁽⁴⁾, presented at this conference.

Occupational Safety

The objective of occupational safety assessment is to analyze and assess the risk to workers due to both radiation exposure and conventional hazards. The results of the assessment are summarized in the following.

The total radiological risk to workers is estimated to be 1.9 fatalities/10⁸ manhours worked, including fuel transportation, immobilization and disposal operations. While this risk is low, significant reduction in dose to workers appears feasible with additional design and coordination effort, e.g. integration of container systems for transportation and immobilization/disposal. It should be noted that Ontario Hydro, in fact, has not had any fatal accidents among nuclear workers in over 80 million manhours worked.

The risk to workers due to conventional operational hazards (excluding vault excavation and expansion) is estimated to be 2-4 fatalities/10⁸ manhours worked. The total occupational risk for operation of the disposal centre is therefore estimated as 4-6 fatalities/10⁸ manhours. This compares favourably with risks in other industries known to have high safety standards.

For other activities (including vault excavation, construction of surface facilities and eventual demolition), it is assumed that occupational risks will be no greater than the average risks associated with comparable industries in Ontario or Canada.

Radiological Effects of Abnormal Operations and Postulated Accidents

The objective of the safety assessment is to analyze the radiological risk to the public due to abnormal operations or postulated accidents at a disposal facility and during transportation of used fuel. The analysis incorporated a review of the conceptual design with particular regard to protective and safety features as well as security and safeguards and an analysis of the consequences of abnormal operations and postulated accidents during fuel transportation, fuel handling, immobilization, storage and emplacement in the disposal vault initiated by extreme natural phenomena (e.g. floods, earthquakes, etc.) equipment failures and operator error. The key results of the safety assessment are summarized in the following.

Safety in transportation of used nuclear fuel is considered from the following perspectives:

1. Principal design safety features
2. Demonstration of transport cask integrity
3. Transportation accident statistics

The radiological impact of postulated accidents in transportation was evaluated by considering various accident environments (including five stresses tested at the Sandia Laboratories: fire, impact, crushing, immersion and puncture) and identifying potential release mechanisms. The role of contingency plans in mitigating the consequences of an accident is also addressed in the safety analysis. The results of the analysis indicate that radiation dose to the public would be much less than the emergency dose limit of 250 mSv/person recommended by the ICRP and specified by the AECB and that the probability of severe accidents occurring is very low (the frequency of accidents of a severe nature is estimated to be less than 1.3 in 10⁵ per year). The results indicate that the overall radiological risk of used fuel shipments does not constitute an unacceptable hazard to the public.

Possible abnormal occurrences during disposal centre operation, including fuel handling, immobilization, surface-to-underground transfer and emplacement, were reviewed and assessed for radiation exposure. The analysis of the entire fuel handling sequence at a disposal centre indicated that the safety design features will

limit the radiological consequences from abnormal operations to a low level. The consequences, if any, would be within established regulatory limits.

The following postulated accidents or natural phenomena at a disposal centre have been assessed for public safety:

1. Accidental dropping of a fuel container down the vault shaft;
2. A handling accident in the Fuel Immobilization Building resulting in the rupture of fuel bundles, coupled with extreme meteorological conditions (causing loss of power, ventilation and air treatment at the site);
3. Extreme natural phenomena such as floods, earthquakes and fires including forest fires;
4. External events such as an aircraft crash.

Overall, the assessment did not identify any credible abnormalities or accidents which would result in significant consequences to the public.

INTERIM CONCLUSIONS

The preliminary conclusion of the pre-closure environmental and safety assessment is that the concept relies upon technology which is already available or appears to be economically achievable and that the conceptual design can probably be refined and optimized, including practical environmental protection measures, such that no unacceptable effects or risks would result to man or his environment. Despite this expected compliance with regulatory criteria for health and environmental protection, public acceptance cannot be presumed at this time. A large-scale disposal undertaking, using this concept, will produce a number of socio-economic benefits as well as undesirable impacts which have to be compensated for.

More detailed conclusions, covering all essential aspects of this multidisciplinary assessment, are as follows:

1. The conceptual design⁽³⁾ would allow a nuclear fuel disposal centre to be operated such that no worker or public would receive a radiation dose exceeding limits specified in the Atomic Energy Control Regulations.
2. Using the given design information and incorporating many conservatisms in the interim source terms, the radiological effect of normal disposal centre operations and fuel transportation are, with the exception of aquatic emissions to small waterbodies, estimated to be a small fraction of natural background radiation dose. Excluding small waterbodies, these dose estimates are considered to represent a negligible impact on human health.
3. The non-radiological effects on the biophysical environment of construction, operation, used fuel transportation and decommissioning of a disposal centre are generally consistent with the effects which

would be expected from the development of any large industrial facility in the Shield region. The disposal of waste rock from the vault excavation would be similar to mining operations but without the potential for toxic runoff effects. Many of the potentially adverse effects can be avoided or minimized through careful siting of the facility. Control technology is available to ensure that atmospheric and aquatic emissions comply with environmental protection criteria. Although some effects will be clearly evident, such as the loss of vegetation and displacement of wildlife as a result of site clearing and grading during construction, these are not unique or unusual and site planning and implementation of appropriate controls will reduce these effects to acceptable levels.

If lead is retained as the matrix material in the disposal container design, the total lead requirement will have a significant effect on Canadian lead supplies and reserves depending on the projected fuel disposal rate.

4. A nuclear fuel disposal centre, like any major project, will have a wide range of community impacts. Some of the potential impacts would generally be desirable (e.g., employment, income distribution etc.) while others might be undesirable (e.g., increased costs of community services, changes in lifestyles and social interactions, etc.). Although this interim assessment has not identified any unique or unfamiliar impacts, compared to those of other large energy projects, the affected public may perceive some impacts as unfamiliar and perhaps serious.

Some impacts will occur (although their magnitude may vary) regardless of the type of host community while others will be dependent upon the specific characteristics of the host community (e.g. availability of housing, adequacy of municipal services, etc.). Where project activities would have some negative impacts on a local community, despite overall net benefits to the region or province, suitable offsetting compensation is assumed to be provided. Staged development from demonstration, through half-scale to full-scale operation would have less socio-economic impact than immediate full-scale development.

Despite predicted compliance with regulatory criteria for health and environmental protection, public acceptance cannot be presumed at this time. Public perception of risk will continue to be an important consideration in assessing the acceptability of the nuclear fuel waste disposal program. Continuing to provide information about the program should contribute to reducing people's fears about the unknown and unfamiliar.

5. A substantial energy resource of great potential value may be forfeited through direct used fuel disposal without reprocessing to remove the useable material it contains, and subsequent disposal of the remaining waste in the form of an insoluble glass or ceramic material.

Extended storage of used fuel at reactor sites (along with further studies of reprocessing) could be a suitable way to give more time for a decision on the disposition of this energy resource, before it would be irretrievably disposed of. The next pre-closure assessment will include a generic study of extended storage to determine its possible environmental effects.

6. The total occupational risk (radiological and conventional) from operation of a disposal centre compares favourably with that of other industries known to have high safety standards. With additional design effort, significant reductions in radiological dose to workers appear feasible.
7. The preliminary safety assessment of the conceptual disposal centre design indicates that the impacts of abnormal operations and postulated accidents during handling, storage, immobilization and emplacement would not result in unacceptable radiological consequences.

The safety assessment of used fuel transportation indicated that the radiological consequences are within acceptable limits. It is, therefore, concluded that the overall risk of used fuel shipments, from a safety perspective do not constitute an unacceptable hazard to the public.

8. The benefits of a nuclear fuel waste disposal project would include: (a) permanent isolation of hazardous materials from man and his environment; (b) direct, indirect and induced employment associated with construction and operation of the facility as well as supply of materials, equipment and services; and, (c) tax/grant revenue to the local community. Approximately 75 percent of total expenditures would remain in Ontario, generating close to one percent of Gross Provincial Product at maximum expenditure.

The economic costs of facilities, operation (including transportation), decommissioning, security and surveillance would be substantial. However, Ontario Hydro accounting policy provides for the necessary revenues by requiring that rates paid by

electricity consumers be sufficient to cover the future costs of irradiated fuel management. The fraction of electricity rates paid by consumers for future costs of irradiated fuel management is very small. Further evaluation of the costs and benefits on a local, regional and provincial scale should be undertaken when the conceptual design is developed further.

OUTLOOK TO THE NEXT ASSESSMENT ITERATION

The preliminary environmental and safety assessment is considered to represent a sound and comprehensive basis for the next interim pre-closure assessment which is planned for 1986. The results and conclusions of this assessment have indicated a number of areas which can be refined and improved. These include, refinement of the reference environment approach to more systematically incorporate environmental conditions and their variation in the assessment; refinement of the radiological pathways models and source terms; and incorporation of the fuel recycle waste disposal option into the assessment.

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