POSTER SESSION
PART I

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POTENTIAL

RADIATION CRITERIA FOR ONTARIO HYDRO'S

REACTOR WASTE DISPOSAL PROGRAM

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ABSTRACT

A ranking procedure developed by Ontario Hydro to assist in the selection of potential reactor waste disposal concepts from a radiological safety viewpoint is presented. This process includes the defining of objective radiological disposal concept ranking criteria and the testing of disposal concepts against the criteria using radiological pathway models. The results of applying the proposed criteria are presented in the assessment and ranking of several example disposal concepts.

BACKGROUND

Ontario Hydro is the publicly owned electric utility in the Province of Ontario in Canada. Ontario Hydro currently has 12 nuclear reactor units in-service and 10 units under construction. By the 1990's, Ontario Hydro will have 13,500 MWe of CANDU generation in-service as base load.

Reactor waste consisting of discarded protective clothing, contamination control floor coverings, rags and mopheads, wood, vermiculite, solidified liquid waste, piping, valves, tools, ion exchange resins and filters are routinely generated from the maintenance and purification of CANDU reactor systems. The projected accumulated reactor waste volume to the year 2000 in Ontario Hydro is illustrated in Fig. 1. Irradiated fuel and decommissioning wastes are outside the scope of this analysis.

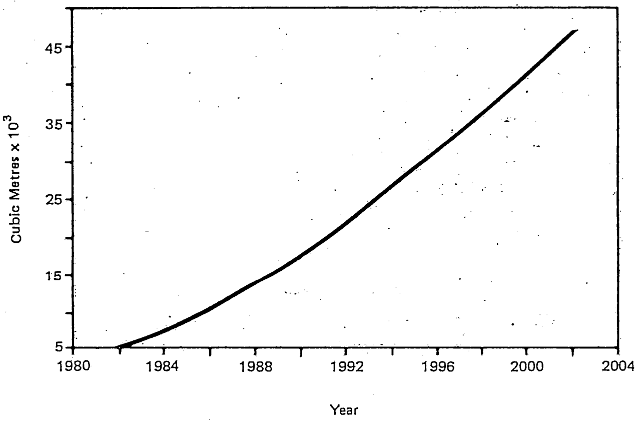

Fig. 1. Projected accumulated reactor waste volume in Ontario Hydro.

Reactor waste is currently transported and stored by Ontario Hydro at the Radioactive Waste Operations Site located at the Bruce Nuclear Power Development in Ontario. Processible waste is volume reduced by incineration or compaction (baling). Reactor waste is stored in four types of retrievable-waste storage facilities; concrete trenches, tile holes, quadricells and a low level storage building (1).

Purpose of Study

Reactor waste disposal in Ontario Hydro is under study because of the need for a safe, permanent waste management solution. Disposal will minimize costs associated with waste storage such as incinerator capital equipment costs, storage facility capital costs and costs associated with the double handling of wastes. Eliminating double handling of wastes would also reduce occupational radiation exposure.

The methodology of selecting a preferred reactor waste disposal concept from a radiation safety viewpoint is the focus of this paper. In order to objectively evaluate and rank several different disposal concepts, a set of quantifiable concept ranking criteria were developed. Criteria were also developed by others in the areas of site geotechnical features, disposal concept technical feasibility, public impact and cost, but these areas are outside the focus of this paper.

The proposed radiation criteria for ranking reactor waste disposal concepts are presented in the following section, followed by examples of applying the criteria to assess landfill, trench, borehole, rock cavern and deep disposal techniques at three different generic sites typical in Ontario.

RADIOLOGICAL CRITERIA

Proposed radiological criteria to be used in the assessment and ranking of alternative reactor waste disposal concepts are presented below. Two types of criteria are presented, "must" and "should" criteria. These are defined such that all "must" criteria are to be satisfied in an acceptable disposal concept or else the disposal concept is deemed not acceptable. "Must" criteria are usually quantified by an upper limit legislated by the federal and provincial governments. "Should" criteria are defined such that it is preferable that they be satisfied, and, the "should" criteria are weighted as to importance with respect to each other. Each "should" criterion is quantified on a rating curve. Table I contains a summary of the radiological criteria for assessment of reactor waste disposal concepts.

The radiation criteria are divided into two areas, "performance" and "technical" criteria.

PERFORMANCE CRITERIA

The four general radiation protection performance criteria for reactor waste disposal are:

1. Protection of the public from releases of radioactivity during site operation;
2. Protection of workers during site operation;
3. Protection of the public from releases of radioactivity after site closure;
4. Protection of the public from inadvertent intrusion.

Detailed performance criteria were developed for each of the above general criteria, as discussed below.

Protection of the Public from Releases of Radioactivity During Site Operation

The AECB regulates the management of radioactive wastes in Canada with general regulations and site-specific licenses (3). The general framework by which the AECB is proposing to assess the radiological impact of any waste management practice is contained in the following three radiation protection principles (4):

1. The dose limits specified in the Atomic Energy Control Regulations shall be observed.

2. The collective dose arising from a radioactive waste management practice shall be kept as low as reasonably achievable (ALARA), economic and social factors taken into account.

3. There are some doses arising from radioactive waste management practices which are so small that, for regulatory purposes, they may be neglected (trivial dose).

TABLE I

Radiological Criteria for Assessment of Reactor Waste Disposal Concepts

PERFORMANCE CRITERIA

Protection of Public During Site Operation

- must limit dose to < 5 mSv/a per person
- should apply ALARA principle
- should comply with MOE water quality targets

Protection of Workers During Site Operation

- must limit dose to < 50 mSv/a per person
- should apply ALARA principle
- must limit dose rate to < 0.025 mSv/hr at 1 meter above final covering (under review)
- must limit dose rate to < 3 mSv/hr for receiving facilities (under review)

Protection of Public After Site Closure

- must limit dose to < 5 mSv/a per person
- should have the option to impose an institutional control period if required
- should have defense-in-depth barriers to sufficiently limit radionuclide releases

Protection of Public from Intrusion

- must limit dose levels consistent with nuclear safety risk standards applied to other nuclear facilities
- should have intruder control

TECHNICAL CRITERIA

Radiological Protection Site Design Criteria

- site should be located away from population and industrial growth
- site should not be located over potentially valuable natural resources
- site should have hydrogeological characteristics such that radiological consequences are minimized
- site should have redundancy in barriers
- design lifetime of engineered barriers should be relative to the radiotoxicity lifetime of the waste
- site should have a buffer zone
- site should have a baseline survey
- site should be monitored during its operational period
- site should be monitored during institutional control period
- site should have a contingency plan
- site should not require maintenance after site closure

Waste Classification Criteria

- waste should be compatible with surrounding medium
- waste should be stable
- waste should have low specific surface area with low leach rate
- waste should be solid form
- waste should not contain a high content of non-degradable toxic chemicals

The basis for the first AECB radiation protection principle (2) is currently undergoing review and change (5) based on ICRP 26 methodology (6). It is expected that the following annual dose limits for Atomic Radiation Workers (ARW) will be implemented by the AECB (7):

1. The committed effective dose equivalent from radionuclides that enter the body plus the dose equivalent received from external sources of radiation shall not exceed 50 mSv/a.

2. The committed dose equivalent to any organ or tissue from radionuclides that enter the body plus the dose equivalent received by that organ or tissue from external sources of radiation shall not exceed 500 mSv/a except for the dose to the lens of the eye which shall not exceed 150 mSv/a.

The dose limits for any member of the public shall be one tenth of the limits specified above for ARW's except the dose equivalent to the lens of the eye shall be limited to 50 mSv/a.

Provincially, the Ontario Ministry of the Environment (MOE) assists the AECB in radioactive waste management. The MOE regards the surface water as potential drinking water and has applied ICRP 26 dose-response relationships in setting water quality objectives to limit dose to the population (8). The surface water quality at the boundary of the disposal site should comply with the MOE water quality objectives (9) given in Table II.

TABLE II

MOE Surface Water Guidelines

Radionuclide	Becquerels/Litre
Cesium-137	50
Iodine-131	10
Radium-226	1
Strontium-90	10
Tritium	40,000

Note: The radionuclide targets are based on the total concentration of an unfiltered water supply. If two or more radionuclides affecting the same organ or tissue are found to be present, the following relationship based on ICRP26 should be satisfied:

$$\frac{c_1}{C_1} + \frac{c_2}{C_2} + \ldots\ldots\ldots \frac{c_i}{C_i} \leqslant 1$$

where c_1, c_2 and c_i are the observed concentrations, and C_1, C_2 and C_i are the maximum acceptable concentrations for each contributing radionuclide. Radionuclide concentrations exceeding the maximum acceptable concentrations may be tolerated provided that the duration of the increase is short and that the annual average concentrations remain below this level and meet the restriction for multiple radionuclides.

For comparison, in the United States, the Nuclear Regulatory Commission (NRC) in 10 CFR 61 limits dose as a result of reactor waste disposal to 0.25 mSv/a (25 mrem/a whole body) (10). In Sweden, a design criterion for waste disposal states that dose should not exceed 0.1 mSv/a (11).

In the United Kingdom, the proposed risk limit to an individual from waste disposal should not exceed 10^{-4}/a, and in those situations where doses would be incurred over periods exceeding ten years, the risk to an individual should not exceed 2×10^{-5}/a (12). The risk limits are based on the 5 mSv/a dose limit and, in cases where prolonged exposures are involved, 1 mSv/a dose limit, and the probabilities based on the linear dose-effect relationship that an individual will contract a fatal cancer (10^{-2}/Sv) or that there will be serious genetic effect in any of an individual's descendents (8×10^{-3}/Sv).

In Canada, our approach to radiation protection in waste management is to have a broad region of acceptability below the primary dose limits. The ALARA principle is applied to minimize dose below the limits.

Protection of Workers During Site Operation

Operations at the reactor waste disposal facility must be conducted such that the AECB regulations for occupational radiation dose are adhered to, as discussed in the previous section.

Ontario Hydro has corporate regulations for radioactive waste management. Although these regulations were developed for reactor waste storage, they are being applied here as interim criteria for disposal facilities. The gamma dose rate from waste management facilities must not exceed 0.025 mSv/hr at one meter above the final covering in areas generally accessible to the operating staff. The gamma dose rate from facilities which are receiving radioactive waste must not exceed 3 mSv/hr. (In addition to limiting radiation doses, conventional safety practices must be adhered to. The occupation safety guidelines currently applied at nuclear facilities should also be applied at a disposal facility.)

Protection of the Public from Releases of Radioactivity After Site Closure

An institutional control period should follow the operational period of the disposal facility. Institutional control refers to passive control of a closed out disposal site by a responsible agency such that use of the site is regulated by the controlling authority, the site can be monitored and no site maintenance is required. An institutional control period of up to 100 years is being considered for near-surface, reactor waste disposal. Longer institutional control periods may be required depending on the waste's hazardous lifetime and disposal technique used. During this period, it must be possible to detect, intercept and manage any released radioactive material before it appears in undesirable concentrations in the environment. The disposal site would have to be precluded from certain future uses until such time that "unrestricted" use of the site does not jeopardize public safety. There may even be a need for perpetual restricted use of the waste site.

Chemical and physical properties of the waste, immobilizing materials, waste containers, engineered barriers, buffer/backfill materials and the geologic host media should be of the quality to provide the multiple barrier, defense-in-depth-necessary to limit the release of radioactive materials into the environment. Human intervention into controlling the waste site should not be necessary after institutional control of the disposal site has been terminated.

Protection of the Public from Inadvertent Intrusion

Design, operation and closure of the waste disposal facility must provide for protection of any individual inadvertently intruding into the disposal site. This may include building on the site, farming the site, mining the site or any other activities which may lead to contact with the wastes at any time after institutional controls over the disposal site are removed.

The maximum allowable dose to any member of the public must be consistent with nuclear safety risk standards applied to other nulcear facilities. It should be noted that the number of people involved in an intrusion event is expected to be small and the probability of an intrusion event is also very small.

Protection of intruders should be available by providing two principal controls:

1. Control of site use.

2. Disposing of waste in a manner that provides a form of intruder barrier to prevent inadvertent contact with the waste.

TECHNICAL CRITERIA

Technical criteria which affect radiation protection in reactor waste disposal are presented in this section. It is likely that the Performance Criteria will be met if the Technical Criteria are achieved.

The technical criteria, which have similarity to current U.S. requirements (10) are subdivided as follows:

1. Radiation protection site design criteria.

2. Waste classification criteria.

Radiation Protection Site Design Criteria

Radiation protection design features of a reactor waste disposal site are presented below. The emphasis here is describing site features which limit radiation dose without specifying a specific disposal technique (e.g., trenches, landfill, deep disposal, etc.).

1. A disposal site should be located so that population and industrial growth would not interfere with meeting the dose performance criteria.

2. A disposal site should not be located in an area of known natural resources such that the dose performance criteria would not be met if recovery of the resources was attempted.

3. The hydrogeological characteristics of the disposal site should be such that radiological consequences are minimized.

4. The disposal site should have redundancy in natural and engineered barriers such that failure of a single barrier will not result in unacceptable radionuclide release.

5. The engineered barriers in a disposal facility should have a design lifetime relative to the radiotoxicity lifetime of the waste.

6. A disposal site should have a buffer zone between wastes and the site boundary such that environmental monitoring and mitigative measures can be carried out in the buffer zone.

7. The disposal site should have a radiation baseline survey sufficient in scope and duration to allow a before and after comparison of radiation levels in and around the disposal site.

8. During site operation, a radiation monitoring program should be maintained to provide data to evaluate the potential health and environmental impacts and to provide early warning of significant radionuclide releases.

9. During the institutional control period, a radiation monitoring program should be maintained to provide early warning of significant releases of radionuclides from the site.

10. A contingency plan should be available for implementation during site operation and institutional control period if the performance criteria are not met.

11. Disposal site design should not require site maintenance after site closure.

Waste Classification Criteria

Reactor waste should be classified to determine its potential hazard within the environment. Waste with a similar classification can be disposed of in a common facility. The disposal option chosen must safely dispose of the most hazardous waste placed in it.

Factors which affect waste classification are: radionuclides present, specific radioactivity, decay half life, waste container, waste form and chemical content.

The following waste classification criteria are intended to facilitate safe handling and disposal (13):

1. Waste should be compatible with surrounding medium at the disposal site.

2. Waste should have adequate chemical, mechanical, biological, thermal and radiation stability to meet the facility specific requirements.

3. Waste should have low specific surface area (i.e. high volume to surface area ratio) with low leach rate of radionuclides.

4. Waste should be solid as opposed to liquid or gaseous form.

5. Waste should not contain a high content of non-degradable toxic chemicals.

RANKING PROCEDURE

The goal of the ranking procedure is to assess and rank disposal concepts in an objective and quantifiable manner, wherever possible. The following procedure was developed.

A checklist was made up containing the "must" criteria which all have to be satisfied for an acceptable disposal concept. The "must" criteria have quantified limits to enable a YES/NO objective decision of compliance with each criterion.

The "should" criteria were expressed on quantified rating curves (example shown in Fig. 2). The axes for the curves are the Level of Concern (LOC) axis versus range of criteria values axis. The LOC axis ranges from -5 to 0 corresponding to very large to minimal concern. Of course, it is preferable for a disposal concept to have minimal concern for each criterion. The criteria values range from the accepted limit (where LOC = -5) to the most preferable value (where LOC = 0).

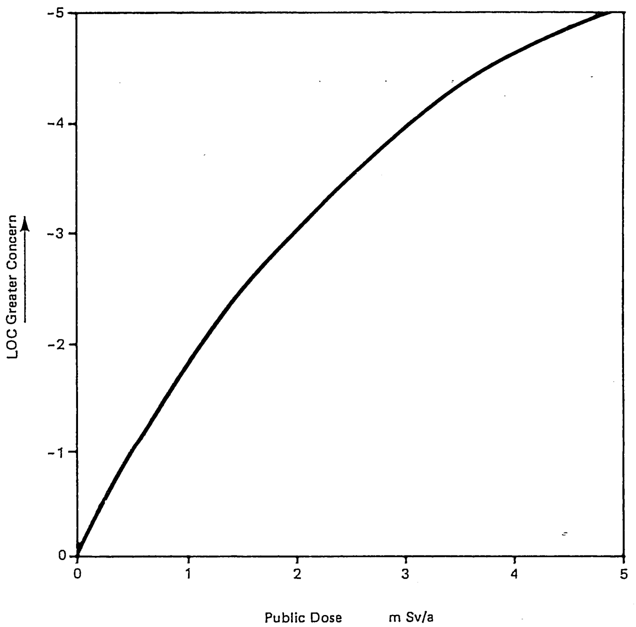

Fig. 2. Example rating curve.

A relative weight was assigned to each radiological "should" criterion. The LOC for each criterion obtained from the rating curve multiplied by the weighting factor give the score for that criterion. The sum of scores for all criteria is the total score for a given disposal concept. A perfect score would be zero points.

APPLICATION OF CRITERIA

An example application of the criteria and ranking procedure is presented below. Landfill, trench, borehole, rock cavern and deep disposal techniques were ranked at three different generic sites labelled A, B and C. The generic sites have typical hydrogeology representative of Ontario. The primary differences among the three sites are composition of subsurface strata (e.g. clay, till, limestone), depth to aquifer and groundwater velocity.

Low level reactor waste projected to the year 2000 in Ontario Hydro, as characterized in Table III, was used as the source term. Note that ion exchange resins and filters are considered intermediate level wastes and are not included in this source term.

TABLE III

Low Level Reactor Waste Source Term

Radionuclide	Total Activity (Bq)
H-3	1.85×10^{15}
C-14	1.85×10^{9}
Co-60	2.04×10^{13}
Sr-90	1.70×10^{11}
Cs-137	1.70×10^{13}

Two pathway models were used in the analyses of disposal concepts. The first model, Subsurface Transport (SST), is an analytical model for evaluating the relative importance of various hydrogeological and engineering parameters which affect the radiation dose to man as a result of the leaching of radionuclides from a waste repository (14). The second model, Intrusion Exposures (INTEX), is an analytical model for estimating human exposures from inadvertent intrusion activities into a near-surface repository or from upward migration of radionuclides from a deep repository via exploratory boreholes or cracks (15).

All "must" criteria were shown to be satisfied for low level reactor waste disposal for each of the example disposal concepts. Note that the AECB principles of ALARA and trivial dose have not been applied in this example, but would be applied in future site-specific assessments.

The "should" criteria were applied to rate each disposal concept using the rating curves discussed previously. A preliminary sensitivity analysis consisting of varying the input parameters to the pathway models resulted in a distribution of dose results with a measured variance. The distribution of dose results corresponds to a distribution of LOC for each criterion as obtained from the rating curves.

The results from the rating curve for each criterion (LOC, variance, distribution) were entered into a computerized decision model for the purpose of complex decision making. The ranking results of the example disposal concepts are presented in Table IV based on the output of the computer decision model.

TABLE IV

Ranking of Example Disposal Concepts

Rank No.	Site-Disposal Option
1	A - Deep Disposal
1	B - Deep Disposal
1	C - Deep Disposal
2	A - Intermediate Depth Rock Cavern
3	C - Trench/Borehole
4	B - Trench/Borehole
5	C - Landfill
6	A - Landfill
6	B - Landfill

Site A: 35 m depth of Till over Limestone
Site B: 17 m depth of Clay/Till over Limestone
Site C: 45 m depth of Clay over Limestone
Deep Disposal: 200-500 m below surface
Rock Cavern: 60 m below surface
Trench/Borehole: 10-20 m below surface
Landfill: at surface

SUMMARY

Radiation criteria for objectively and quantitatively ranking reactor waste disposal concepts have been presented. The results of applying the criteria in the assessment and ranking of several disposal techniques (landfill, trench, borehole, rock cavern and deep) at three different generic sites have been presented. The ranking results and methodology are preliminary because further waste and site specific characterization data would be required to complete a more detailed assessment of disposal concepts. The performance and technical criteria and rating assessment curves require further development to improve the reliability of ranking results. However, the ranking results in Table IV indicate a pattern in that deep disposal concepts rank the best and landfill concepts rank the lowest.

The radiation criteria and ranking methodology presented in this paper will be finalized and applied to assess and recommend, from a radiation safety viewpoint, reactor waste disposal technique(s) and site(s) for implementation in Ontario.

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