A COMPARATIVE ECONOMIC ANALYSIS OF LOW-LEVEL RADIOACTIVE WASTE DISPOSAL IN CANADA

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ABSTRACT

Conceptual designs have been prepared which cover the range of facilities which might satisfy Canada's needs for low-level radioactive waste disposal. Their siting at various hypothetical locations has been considered. Ten major scenarios have been developed, and some of these include alternative design concepts or multiple sites. Capital and operating cost estimates have been analysed for sixteen hypothetical facilities and in most cases transportation costs have been analysed. The results of these analyses are presented and compared.

INTRODUCTION

The Low-Level Radioactive Waste Management Office of Atomic Energy of Canada discharges the responsibilities and initiatives of the Government of Canada in the field of low-level radioactive waste management. It also provides advice to the government and performs studies to support development of national policy. A recent paper (I) summarizes a series of studies performed to evaluate the options which might be considered to establish a national waste management system. The analysis included surveys of waste production, conceptual design of disposal facilities, waste transportation studies, economic analysis of alternatives and a review of socio-political factors which must be taken into account in the facility siting process. Whereas the previous publication covered all of these areas very generally, it is the objective of the current paper to deal specifically and in some detail with the comparative cost analysis of alternatives and to revise these studies, using up to date costing data. Therefore, the information necessary to support the cost analyses, such as waste volumes and characteristics, is presented here with the minimum of discussion.

It should be recognized that Canada, at present, has no licensed low-level radioactive waste disposal facilities. All wastes are being stored, mainly by the waste producers, although Atomic Energy of Canada Ltd. does provide a commercial waste storage service for users of radioisotopes, such as hospitals and universities. The responsible minister of the government has appointed a task force to examine issues primarily associated with the disposal of about 880,000 cu.m. of waste resulting from the refining of uranium in the Port Hope area of Ontario, and to recommend a process to secure a disposal site for these wastes using community acceptance as the basis of the process. Although the task force will be primarily concerned about the Port Hope area wastes, it will likely consider the related issue of ongoing waste production, which has been the main focus of our economic analyses. No decision will be made concerning a national waste disposal system until after the task force has completed its deliberations. Therefore, the cases presented here are hypothetical, although AECL has at various times (II - III) indicated its intention to establish disposal facilities at its Chalk River Nuclear Laboratories. This intent is reflected in the choice of some of the cases in our analysis. AECL's plans are consistent with the government's current policy, which allows waste producers to develop their own disposal solutions to their waste management problems (IV). In some of our examples a disposal site is contemplated at Ontario Hydro's Bruce Nuclear Power Development. These analyses were performed at our initiative and do not indicate a position taken by Ontario Hydro.

WASTE VOLUMES

Sources and volumes of low-level radioactive waste in Canada were estimated (I). Canada has large volumes of accumulated LLRW, mainly derived from uranium processing and nuclear research and development activities. However, only relatively small volumes of waste are produced at this time. Table I shows the current estimate of annual production, broken down by general source of production. There are over 1,000,000 cu.m. of LLW already in existence in Canada. The majority are wastes from uranium and radium refining operations and contaminated soils associated with these wastes. Most result from activities which took place decades ago. However, there are also inventories of LLRW at the nuclear utilities and AECL's research sites. It should be noted that uranium mining and milling wastes and large volume wastes derived from the processing of mildly radioactive minerals, such as phosphate rock, are excluded from this analysis.

The estimate of future waste volumes is inexact because it depends to a large extent on the amount of processing applied to the waste. In estimating annual production it has been assumed that only compaction of the compactible fraction at a volume reduction ratio of 4:1 is used. It should be noted that AECL and Ontario Hydro currently both use incineration. An additional source of uncertainty is the expectation that producers will create less waste when faced with a system which recovers the full cost of disposal in contrast to the current system under which some producers are shielded from this economic burden.

DISPOSAL SCENARIOS

Our first economic analysis was performed before the full study of waste volumes was completed and assumed annual production of 10 000 cu.m. per annum. Because of the uncertainty in estimating future volumes it was justifiable to retain this figure for additional studies of a disposal facility intended to handle all of Canada's continuing waste production. This was, therefore, one case studied in detail. Another case analysed was to dispose of a fraction of the accumulated backlog of wastes during the first 10 years of operation in a facility also designed to handle all of the continuing waste production. It was assumed that an arbitrary volume of 325,000 cu.m. of bulk stored wastes would be sent to the disposal facility. At the time these studies were performed it was believed that Eldorado Resources Ltd. would dispose of their own stored wastes in a facility dedicated to this purpose. Therefore, no allowance was made for Eldorado's wastes in our analyses. Because government policy allows waste producers to dispose of their own wastes in their own facilities, and because some other producers may adopt this option, a small facility, designed for only the wastes of small producers unlikely to follow this route, was also analysed.

Because the vast majority of LLRW in Canada is located in (or will be produced in) Ontario, it was assumed that these facilities would be located at a greenfield site in Ontario. This province has varied geology and could host facilities based on shallow land burial or disposal in rock caverns (the intermediate depth geologic or IDG concept). Conceptual designs were prepared for both options and costed.

Design was based on a 30-year operation, but it was assumed that land was acquired sufficient for 50 years of disposal. It was assumed that higher activity wastes corresponding to category B and C wastes would be placed in large diameter boreholes, backfilled with concrete, in a fraction of the trenches or caverns. Figures 1 and 2 show an overview of the facilities designed for disposal of 10,000 cu.m. per year for 30 years. For the case where bulk wastes from current accumulations, such as contaminated soils, were included, they were assumed to be placed in larger-sized designated trenches or caverns. A feature of these caverns is that they would be filled with the bulk wastes through large diameter boreholes, extending from the cavern to the surface, thus avoiding human entry into the caverns, which could then be excavated using an inexpensive open-stoping technique.

It was considered uneconomic to apply the cavern concept to the disposal of wastes in the small volume case. Therefore, a design was costed which achieves the same degree of isolation, but at less expense, by sinking large diameter boreholes into a suitable rock formation, filling their lower portion with waste, and then backfilling to the surface with concrete.

Although a centralized facility located in Ontario probably represents the most economic option for a national disposal system, it is important, because economics alone are unlikely to dominate strategy, to analyse credible alternatives. Three alternative greenfield facilities were identified and analysed.

Many people consider remoteness as a very desirable characteristic of any hazardous waste disposal facility, and Canada does have large amounts of relatively uninhabited land. Therefore, a disposal facility in Northern Ontario was analysed. However, taking the wastes to Northern Ontario is not sufficient to achieve true remoteness because wherever there are transportation routes suitable for movement of the waste there are centres of population, although they are spaced further apart than in the south. A truly remote option was costed by considering a site separated by about 160 km from the nearest centre of population. This separation would be achieved by driving a high quality gravel road into the bush for a distance of about 125 km from a major route such as the Trans-Canada Highway. To take into account transportation distance, separations of 1000 and 2000 km. from the major waste production centres in Ontario were assumed.

Although a single central facility will be the most economic to operate it will involve high transportation costs for waste producers who are located far from the facility. Therefore, the concept of regional facilities located in the West, Ontario and the East was investigated. The western site was assumed to be located in Alberta and the eastern site in New Brunswick for the purpose of this analysis. The Ontario facility was again assumed to be at a greenfield site located centrally to the major centres of production. Because so little waste is produced in the west and east, the

TABLE I

Estimate of Current Low-Level Radioactive Waste Production in Canada† 1985-2025

Source	Volume m^3
Licensed users of radioisotopes, nuclear fuel fabrication and uranium processing*	92,720
Generation of nuclear electricity	156,480
Use of naturally radioactive minerals and elements in conventional industry**	57,160
Atomic energy research and development	61,187
TOTAL	367,547

† It is assumed that all compactible wastes are reduced in volume by a ratio of 4:1, but that no additional processing of solid wastes takes place.

* Eldorado Resources Ltd., through its uranium processing activities, would produce about 70% of this volume.

** This estimate includes only wastes which might be relocated for disposal. For example, phosphogypsum residues are excluded, but filters from phosphate processing plants are included.

volume of waste consigned to the Ontario facility would not change significantly and disposal costs at the Ontario site would not change very much.

A third alternative was selectd on technical grounds. In Western Canada there are regions which are quite dry compared with the humid environment of Central Ontario. In these regions water tables may be more than 100 m below the surface. Because the public is greatly concerned about the potential contamination of groundwater supplies, an arid site may be perceived as more appropriate.

The options considered to this point all assume that facilities are located at greenfield sites. However, major producers could establish their own facilities and they are most likely to do this on properties which they already own, providing they are technically suitable. The populations around sites with existing nuclear installations also tend to be less sensitive to the prospect of waste disposal facilities (V). Therefore, options were costed which assumed that a facility to handle all continuing waste arrisings would be located at an AECL or an Ontario Hydro site, or that AECL and Ontario Hydro might each establish sites for their own wastes with Ontario Hydro accepting wastes from the other Canadian utilities and AECL accepting the remaining waste production from all other Canadian sources. In addition a case was analysed in which AECL would establish facilities for its own use and would accept the wastes of only small institutional producers such as hospitals and universities. Finally, a case which considered disposal of all continuing waste production at an Ontario uranium mine was costed.

SURFACE SITE LAYOUT (140 ha)

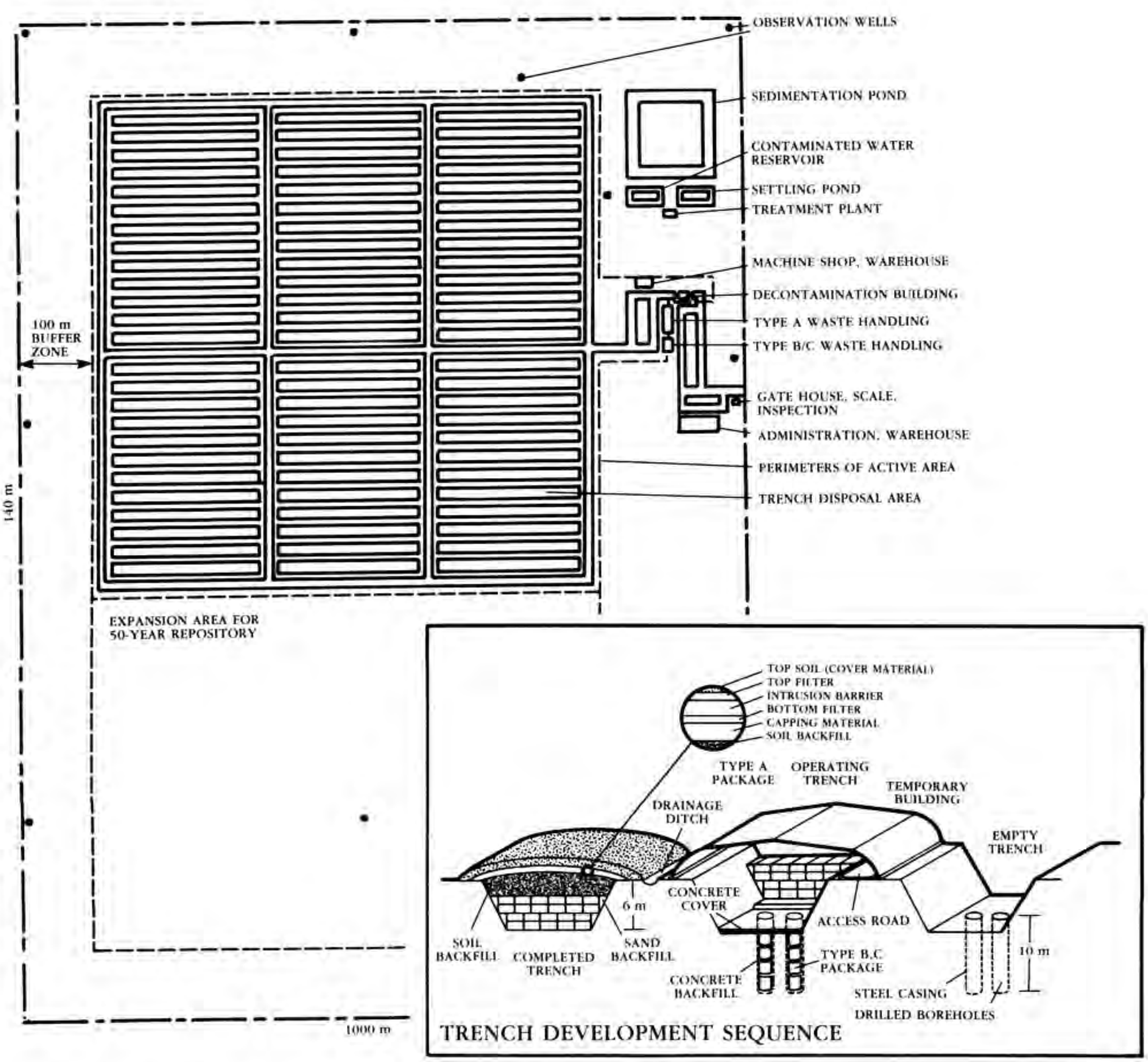

Fig. 1. Plan and Design Detail of the Trenches for the Shallow Land Burial Concept.

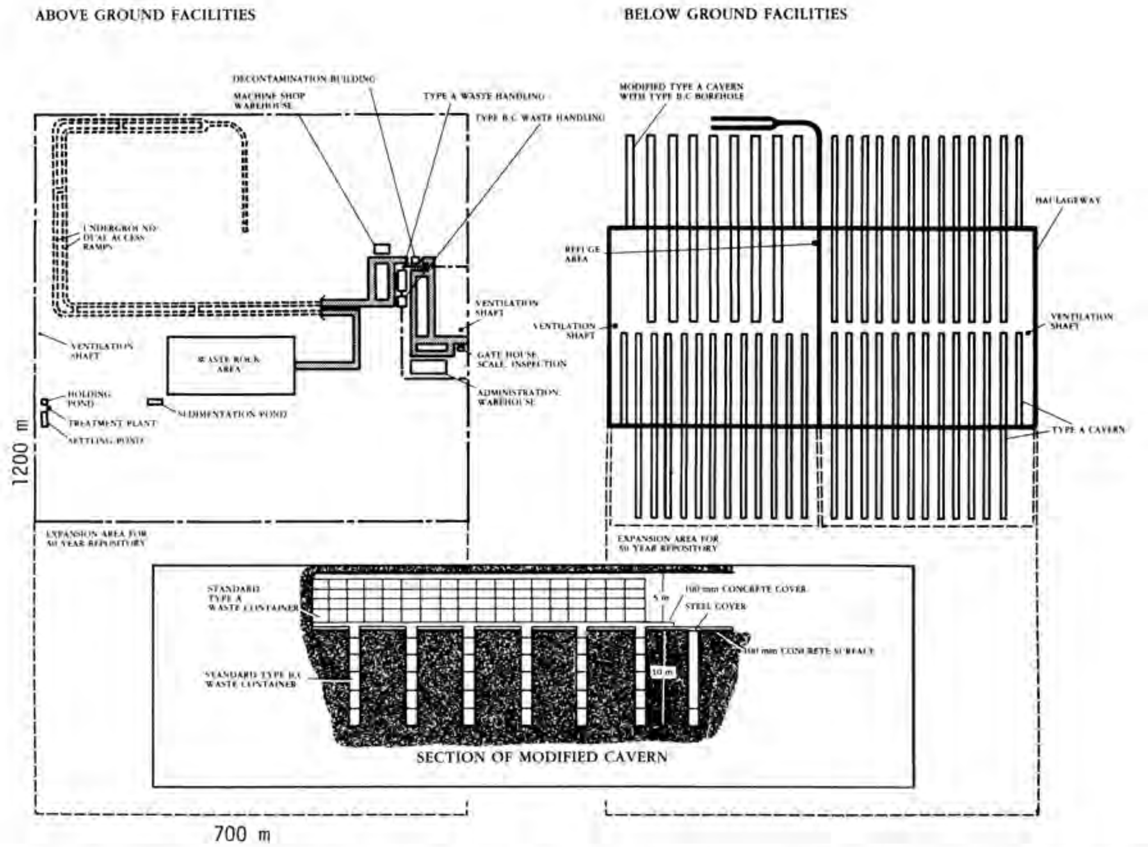

Fig. 2. Plan of Surface Facilities, Cavern Layout and Design Detail of Caverns for the Shallow Rock Cavern (or IDG) Concept.

TABLE II

Index to Disposal Scenarios

Case	Description	Waste Volume cu.m. per year	Technology	Assumed Location
	Greenfield Site Options			
1.	Disposal of all continuing production	10,000	(a) SLB (b) IDG	Central Ontario
2.	Disposal of all continuing production and an additional 325,000 m^3 of bulk wastes during the first 10 years	42,500 and then 10,000	(a) SLB (b) IDG	Central Ontario
3.	Disposal of wastes from small producers only	600	(a) SLB (b) IDG	Central Ontario
4.	Disposal of all continuing production at an arid site	10,000	SLB	Alberta/Sask. border
5.	Disposal 160 km from nearest population centre	10,000	IDG	Norther Ontario 1000 and 2000 km from centres of production
6 (a)	Regional site for Western Canada	300	SLB	Alberta
6 (b)	Regional site for Eastern Canada	380	SLB	New Brunswick
	Co-Located Facilities			
7.	Disposal of all continuing production at one existing nuclear facility	10,000	SLB	CRNL or BNPD
8.	Disposal of wastes from small producers and AECL	1,400	SLB	CRNL
9 (a)	Disposal of all wastes from nuclear utilities	5,200	SLB	BNPD
9 (b)	Disposal of all remaining wastes	4,800	SLB	CRNL
10.	Disposal of all continuing production at a uranium mine	10,000	(a) SLB (b) IDG	Elliot Lake

The various scenarios considered are summarized in Table II and are identified by the number used in Table II in some of the subsequent tables.

COSTING OF FACILITIES

Basis of the Cost Analysis

Costing data used in the estimates for the selected options were obtained from contractors, equipment suppliers, engineering studies, and literature sources. For some items lump sum allowances based upon judgement or experience on other projects were used. All costs are expressed as 1987 Canadian dollars and are expected to be accurate within ±35%.

The cost estmates were divided into capital and operating cost components. The capital cost component reflects the front-end costs required to get the facility into operation, while the operating cost component reflects the continued costs, such as labour and utilities, which would be incurred during the facility's operation. It was assumed that capital costs would be amortized over 30 years of operation of the facility. However, it was assumed that enough land is purchased to allow operation for as long as 50 years.

In the development of the estimates the following assumptions were made:

i) Initial development costs were kept to a minimum to reduce the requirement for large amounts of development capital.

ii) Disposal space would be developed, where practical, on an ongoing basis in advance of the actual requirement for disposal space, and as such would be treated as an operating expense rather than a capital cost.

iii) The design assumed the use of standardized containers to facilitate waste handling. The cost of these containers was not included in the estimates since this cost would be directly applied to user disposal fees.

iv) Because the regulations and requirements for the decommissioning of the facility at the end of its operational lifetime are uncertain, a cost of perpetual care was not included in the estimates.

v) Because of the high variability associated with the costs of siting and environmental studies an order of magnitude allowance has been assumed.

vi) No allowance for profit was provided in the estimates.

vii) The analysis is by necessity generic in nature and assumes that a site with appropriate characteristics exists in the specified region(s) of the country.

viii) It was assumed that the facility is financed by money borrowed at an interest rate of 10%.

A description of the capital and operating cost items follows, and Tables III and IV present our estimates for each item for all of the cases studied except for Cases 2 and 3. The detailed cost breakdown for these cases was not available for this publication, but overall costs are discussed later.

Capital Costs

Site Preparation

Site preparation costs include allowances for stripping and stockpiling top soil, grading, shaping and drainage of the site, paving access roads, haul roads construction, and fencing. For all cases, a sufficient area of the site was cleared, shaped and graded to permit the construction of buildings, roads and disposal units sufficient to allow initial operation of the facility. Following this initial construction it was assumed that additional areas of the site could be prepared by the on-site personnel. Fencing was provided for the entire facility. Site preparation costs are substantially lower for the intermediate depth cavern disposal concept, the small scale regional facilities and for the co-located facilities.

Sedimentation Pond

The sedimentation pond would be an unlined storage reservoir designed to settle suspended material contained in runoff from the site. The pond would be excavated below grade with the excavated material stockpiled on site for future use. The side slopes would be stabilized with a 0.5 m thick layer of rip rap. It was assumed that sedimentation ponds would not be required at current sites.

Water Treatment Plant

A water treatment plant would be provided to handle any contaminated water from active waste trenches and from decontamination facilities. A lump sum allowance for a lined storage reservoir and treatment plant was provided.

Buildings and Accessories

Items and costs for this component include lump sum allowances for a gate house, weigh scale, waste compactor, laboratory equipment, truck wash and for the SLB concept a storage dome for the backfill. Because of the small size of the regional facility, it was assumed no laboratory would be required. Any laboratory work could be contracted.

The buildings were sized and a unit rate was applied to cover the cost of construction. Because the Type B, C waste handling building and decontamination building require more specialized services, shielding and handling equipment, a higher unit rate was applied.

Construction and Handling Equipment

Current costs were obtained for all of the major pieces of equipment except the waste transporters. An allowance was provided in the cost estimates for these non-standard pieces of equipment.

TABLE III

Capital Cost Estimate

Cost Item	Disposal Scenario 1 (a)	1 (b)	4	5	6 (a) & (b)	7	8	9 (a)	9 (b)	10 (a)	10 (b)
1. Site Preparation	$624,000	$395,500	$623,700	$395,000	$278,000	$243,000	$78,000	$168,500	$155,500	$243,000	$146,500
2. Sedimentation Pond	626,500	626,500	626,400	626,500	119,000	-	-	-	-	-	-
3. Treatment Plant	378,000	378,000	378,000	378,000	76,000	108,000	32,500	75,500	75,500	378,000	378,000
4. Buildings/ Accessories	3,091,500	1,903,500	2,011,500	1,903,500	1,085,000	1,237,000	308,000	718,000	675,000	2,230,000	1,042,000
5. Construction, Handling Equipment	1,722,500	1,636,000	1,722,600	1,852,000	189,000	1,722,500	462,500	544,500	536,000	1,722,500	691,000
6. Trench/Cavern Construction	807,000	12,879,000	806,760	12,879,000	-	807,000	116,000	419,500	387,000	807,000	1,728,000
7. Monitoring Wells	259,000	453,500	270,000	454,000	130,000	259,000	173,000	216,000	216,000	259,000	453,500
8. Land	378,000	216,000	378,000	216,000	108,000	-	-	-	-	-	-
9. Engineering (15%)	1,183,000	2,773,000	1,022,500	8,142,000	298,000	656,000	175,500	321,500	307,000	846,000	666,000
10. Studies	3,348,000	3,348,000	3,348,000	3,348,000	2,700,000	2,268,000	2,052,000	2,160,000	2,160,000	2,268,000	2,268,000
11. Contingency (25%)	3,104,500	6,152,000	2,797,000	16,443,000	1,246,000	1,825,000	849,500	1,156,000	1,128,000	2,188,500	1,643,000
12. Access Road	-	-	-	33,750,000	-	-	-	-	-	-	-
13. Additional Support Facilities	-	-	-	540,000	-	-	-	-	-	-	-
14. Construction Premium	-	-	-	1,286,000	-	-	-	-	-	-	-
Total Capital	15,522,000	30,761,000	13,984,500	82,215,000	6,229,000	9,126,000	4,247,000	5,779,500	5,640,000	10,942,000	9,216,000
Amortized Cost/ Year (30 yrs @ 10%)	1,607,000	3,184,500	1,448,000	8,511,000	645,000	944,500	439,700	598,300	583,900	1,133,000	944,500

TABLE IV

Operating Cost Estimate

Item	Disposal Scenario 1 (a)	1 (b)	4	5	6 (a)	6 (b)	7	8	9 (a)	9 (b)	10 (a)	10 (b)
1. Labour	$1,004,500	$1,076,000	$1,004,500	$1,111,000	$267,500	$267,500	$855,500	$338,800	$475,200	$475,200	$855,500	$784,000
2. Utilities	108,000	108,000	108,000	108,000	16,000	16,000	106,000	24,800	61,500	57,100	108,000	108,000
3. Operations/ Maintenance	372,500	402,000	237,500	406,000	82,000	82,000	372,500	74,200	183,000	171,300	372,500	186,500
4. Equipment Replacement Allowance	172,000	163,500	172,000	185,000	19,000	19,000	173,000	90,600	214,200	201,500	173,000	83,000
5. Fuel/ Lubrication	86,000	82,000	86,000	92,500	9,500	9,500	86,000	23,100	27,200	26,800	86,500	41,500
6. Trench/Cavern Construction	640,000	181,000	640,000	181,000	-	-	640,000	92,000	332,600	307,200	640,000	181,000
7. Trench/Bore-hole Constr. By External Contractor	-	-	-	-	120,000	96,000	-	-	-	-	-	-
8. Borehole Construction	210,500	189,000	210,500	189,000	-	-	210,500	30,200	109,500	110,100	210,500	189,000
9. Effluent Treatment	54,000	54,000	-	54,000	11,000	9,500	54,000	21,600	37,800	37,800	54,000	54,000
10. Environmental Monitoring	324,000	324,000	324,000	324,000	216,000	216,000	324,000	243,000	286,200	286,200	324,000	324,000
11. Sundries	100,500	108,000	100,500	111,000	27,000	27,000	85,500	34,000	47,500	47,500	85,500	78,500
12. Engineering	85,000	37,000	85,000	37,000	12,000	10,000	85,000	12,200	44,300	40,800	85,000	37,000
13. Contingency (25%)	789,000	681,000	742,000	1,025,500	195,000	188,000	748,500	246,000	455,000	438,000	749,500	516,500
14. Remote Camp Operation	-	-	-	243,000	-	-	-	-	-	-	-	-
15. Road Maintenance	-	-	-	1,012,500	-	-	-	-	-	-	-	-
16. Construction Premium	-	-	-	37,000	-	-	-	-	-	-	-	-
17. Utilities Premium	-	-	-	11,000	-	-	-	-	-	-	-	-
18. Transferred Amortized Capital	-	-	-	-	-	-	274,500	39,500	142,700	131,600	126,500	126,500
Grand Total	3,946,000	3,405,500	3,710,000	5,127,500	975,000	940,500	4,017,000	1,270,000	2,416,700	2,322,300	3,870,500	2,709,500

Trench/Cavern Construction

For each of the facilities a few trenches or caverns would be initially constructed by contracted work forces to get the facility into operation. One of these trenches or caverns would be provided with boreholes for the disposal of Type B, C wastes. The cost associated with the construction of these initial disposal units has been listed as a capital cost item. Once in operation the construction of the disposal units would be undertaken by on-site personnel, and would, therefore, be an operating cost item. For the small regional facility, the cost of providing all disposal space was considered an operating cost.

Unit rates for soil and rock excavation were based upon recent costs provided by contractors. Costs to auger and case boreholes were also supplied by contractors.

Monitoring Wells

The costs for monitoring wells will depend upon a number of factors including depth, soil conditions, and type of instrumentation. A unit rate per shallow well and per deep well was assumed, based on the nominal number of wells required to monitor each facility.

Land

The surface land requirements were estimated based on a potential 50-year operating life. A unit rate per hectare was assumed for land purchase. It was assumed that there would be no cost for land at the co located facilities.

Engineering

An engineering allowance of 15% of the total cost for items 1 to 8 was applied for the design and construction of the facility. For the remote northern site the allowance was also applied to items 12, 13 and 14.

Studies

There would be several major studies required for the licensing of the facility. These would include a site selection study, a baseline environmental monitoring study, and an environmental impact statement (E.I.S.). The requirements could be highly variable depending not only on the technical aspects of the site and the disposal concept, but also on the prevailing social/political climate. Allowances for these studies have been provided; however, it is important to note that the actual costs could be several times those included in this estimate.

Contingency

A contingency and estimating allowance of 25% has been provided. Given the level of the conceptual design, this allowance should provide for minor modifications to scope and changes in costing data.

The total capital costs (sums of items 1 to 11) were amortized at 10% over 30 years for most scenarios. For the cases where large volumes of bulk waste would be emplaced during the first 10 years (disposal scenarios 2 (a) and (b)) the additional capital costs required were amortized over the first 10 years of operation.

Access Road

On reviewing the maps of northern Ontario it is apparent that a new road at least 125 km in length would be required to obtain the remoteness objective.

Additional Support Facilities

The additional capital cost items required for the remote northern Ontario site would be:

- bunkhouse and support facilities to house operations staff
- diesel generator power supply
- water supply
- sewage work
- fuel storage

Construction Premium

An allowance of 10% of item 6 (cavern construction cost) was included because of the remote location of the site.

Operating Costs

Table IV presents a summary of the operating cost items used in the preparation of this cost analysis.

Labor

The single largest item in the operating cost is the annual labor allowance. For each facility the potential labor requirements were estimated and reasonable salaries for level of responsibility and job qualification were applied. Potential staff positions are as follows:

administrator
office and operation managers
security
clerical, accounting
health physics technician
quality assurance
lab technician
equipment operator, miner
maintenance
warehouse, waste handler, truck driver
site engineer
surveyor/draftsman

The number of positions depend on the size of the facility. Staffing requirements are estimated in Table V for cases 1, 2 and 3. To cover fringe benefits a payroll burden of 10% was added to the total of the annual salaries.

Utilities

A lump sum charge for utilities such as hydro, water, and telephone was estimated.

Operations and Maintenance

Three operating costs were considered under operations and maintenance. The annual general maintenance cost for major equipment was

TABLE V

Employment at Disposal Facilities

Disposal Scenario	Employment
1 (a)	28
1 (b)	30
2 (a)	33
2 (b)	35
3 (a) and (b)	7

considered to be 5% of the capital cost. This cost would be in addition to replacement allowances, mechanics salaries, and fuel. The maintenance costs for mining equipment were increased to reflect the more complex maintenance required for such sophisticated equipment. Building maintenance, cleaning and repairs were assumed to be 5% of the capital construction cost. The third operating cost item was the cost associated with the relocation of the temporary shelters used to cover the trenches during the filling operation. A cost of $10/sq.m. of trench surface covered was applied for this item.

Equipment Replacement Allowance

All major construction/handling equipment was assumed to require replacement after an average life span of 10 years. Therefore, an annual replacement allowance of 10 percent of the capital cost of the equipment was included in the annual operating cost estimate.

Fuel and Lubrication

Fuel and lubrication requirements for on-site equipment was estimated as 5 percent of the equipment capital cost.

Trench and Cavern Construction

The items included under this operating cost component are the purchase of the cap materials for the trenches, and floor and bulkhead material for the caverns. The costs for labor and equipment involved in the disposal unit construction have been dealt with in operating cost components 1 to 5.

Trench Construction - External Contractors

Because of the small annual quantities of material to be disposed of at small regional sites, external contractors would be retained on an as-required basis to construct the disposal trenches.

Borehole Construction and Concrete Costs

The construction costs for disposal boreholes in either trenches or caverns for type B, C wastes were estimated for soil and for rock. Concrete backfill for boreholes was costed.

Effluent Treatment

An annual lump sum allowance for chemicals and miscellaneous costs was provided for effluent treatment.

Environmental Monitoring

An annual lump sum allowance for environmental monitoring was provided. Labor associated with monitoring would be provided by on-site staff.

Sundries

An annual allowance of 10% of the labour cost was provided to cover sundry items such as protective clothing, office supplies, etc.

Engineering

A 10% allowance for the engineering involved in the construction of the trenches and caverns was applied to items 6, 7 and 8. This would provide for ongoing design modifications. Additional engineering services and site inspection would be provided by the on-site engineer.

Contingency

An estimating allowance and contingency of 25% has been allowed. Given the level of the conceptual design, this allowance should account for minor modifications to scope and changes in costs.

Remote Camp Operation

An annual lump allowance for an outside contractor to operate the remote camp has been included. The contractor would supply food, lodging, maid service and miscellaneous camp supplies. A four-day week for all staff was assumed for this option.

Road Maintenance

A provision for annual road maintenance was included, based on an annual allowance of 3% of the capital cost for the road.

Construction Premium

A construction premium of 10% of items 6 and 8 was included in the estimate.

Utilities Premium

Because of the remoteness of the site an electrical power generation unit will have to be constructed and operated at the site. A utility premium of 10% of item 2 was included in the cost estimate to account for this special site-specific requirement.

Transferred Annualized Capital

Some capital cost items already exist at the co-located sites (e.g. machine shops, administration, waste handling, decontamination.) Such facilities can be made available to the disposal facility on an as required basis. It is assumed that the charge for use of these facilities will include an amortized capital cost component. However, as these facilities are now being provided as a service, rather than on a dedicated basis, the charge will be proportional to annual volume of waste.

TRANSPORTATION COST

For several of the cases analysed the hypothetical disposal facilities are located far away from the major waste producers. Therefore, transportation costs are an important component of comparative economic analysis. A transportation model was constructed which took into account the volumes and geographic locations of waste production and was applied to each scenario analysed. It was believed that rail transportation would probably be applicable only to the large volume bulk wastes, and even then, only if the disposal site is adjacent to a railway line. Therefore, only road transportation was analysed. It was assumed that low specific activity wastes would be packaged but not shielded during transportation, that wastes corresponding to 10 CFR 61 Class B and C wastes would be in transportation casks and that the bulk soil-type wastes would be transported in tandem-pup dump trailers. The number of waste shipments required per year can be determined by either the physical space available on the vehicle or by weight limitations. In this regard it was recognized that Manitoba has lower weight limits than Ontario, thus imposing a transportation cost penalty on the western disposal site options. Table VI shows the volumes of various types of waste per shipment. Table VII lists the unit transportation costs for the different waste types to three assumed destinations.

TABLE VII

Average Unit Transportation Costs For Different Types of Waste Sent To Three Assumed Disposal Sites $/cu.m. km

Waste Type	Central Ontario	Northern Ontario	Western Canada
Unshielded	0.115	0.126	0.145
Shielded	2.354	2.432	3.807
Bulk Soils	0.137	0.155	0.233

COST SUMMARY AND DISCUSSION

Table VIII sums the annualized capital costs and operating costs. The first feature of note is the strong dependence of disposal cost on through-put of the facility. This is best illustrated by the very high cost of regional disposal (scenario 6 (a) and (b)), due to the small volume of waste production in Western and Eastern Canada and the significantly reduced cost for the high volume cases 2 (a) and (b).

Development of a truly remote disposal site raises capital costs dramatically because of the need for new road construction to achieve the remoteness objective. Also, it is necessary to transport the waste fairly large distances from the centres of waste production to reach regions where separation from people of at least 160 km can be achieved.

TABLE VI

Vehicle Payloads

Waste Form	Volume per Shipment Eastern Site, cu.m.	Western Site Penalty Factor
Compacted Bales	32	1.7
Drums	21.6	1.2
Incinerator Ash	19.6	1.7
Non-processible	20.7	1.0
IX Resins	2.8	1.7
Filters	0.8	1.7
Bulk Soil Wastes	20	1.5

Similarly, use of an arid Western site imposes a very large cost penalty because of the need to transport wastes over even greater distances.

For disposal at an existing nuclear facility, capital costs are significantly reduced, because components such as fencing, water treatment facilities and laboratories are assumed to already exist and to be capable of handling the demand which would be placed upon them by the disposal facilities. However, in performing the cost analysis it is assumed that the fee which is paid for these services will have a component which reflects the capital cost of the facilities being used. Credit is only taken for items which are required at a greenfield site but which are truly redundant at a co-located facility; for example, the gate house. Therefore, contrary, perhaps, to superficial expectations, it would not be significantly less expensive to dispose of Canada's entire continuing waste production at an existing nuclear facility.

However, it is important to note that the actual new capital investment would be significantly reduced at such a site. Because of this, disposal costs would be less sensitive to volume than at a greenfield site because some services would be provided for a fee based on volume of waste disposed of at a co-located facility, whereas the service would have to be provided on a dedicated basis at a greenfield site. Because of this reduced dependency of cost on volume a commercial disposal operation would be less risky (in the business sense) than it would at a greenfield site, because a major component of the business risk is in the uncertainty of volume estimates.

Another important conclusion is that at the same scale of operations there does not seem to be a major cost difference between shallow land burial and intermediate depth geologic disposal as disposal technologies. It is more expensive to create space in rock rather than in soil materials, but this is offset to some extent by the materials and effort required to create an effective trench cover and cap in the shallow land burial case.

Because, by most waste management standards, the volume of LLRW produced in Canada is quite small, disposal cost (on a unit volume basis) is very sensitive to the capital cost of the facility. It is not too difficult to estimate the cost of the physical facilities, but it is almost impossible to estimate the cost of site selection, because this is so dependent on the process employed, which is in turn dependent on public attitudes and the response of government to these attitudes. In these studies a cost of between $2,052,00 and $3,348,000 has been assumed for site investigation, hearings and licensing. This estimate could be very low, and process-driven costs could be the largest capital cost component in most cases.

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TABLE VIII

Cost Summary

Disposal Scenario	Annual Volume (m^3)	Annualized Capital	Annual Operating	Unit Disposal Cost ($/$m^3$)	Unit Transportation Cost ($/$m^3$)	Total Unit Cost ($/$m^3$)
1(a)	10,000	$1,607,000	$3,946,000	556	142	698
1(b)	10,000	$3,184,500	$3,405,500	660	142	802
2(a)	42,500	$1,876,000	$5,655,500	177	N/C	N/C
2(b)	42,500	$3,627,500	$6,052,500	228	N/C	N/C
3(a)	590	$ 645,000	$1,045,000	2,874	N/C	N/C
3(b)	590	$ 601,500	$1,932,000	4,309	N/C	N/C
4	10,000	$1,448,000	$3,710,000	516	1,220	1,736
5	10,000	$8,511,000	$5,127,500	1,364	254-508	1,618-1,872
6(a)	380	$ 645,000	$ 975,000	4,263	324	4,587
6(b)	300	$ 645,000	$ 940,500	5,285	87	5,372
7	10,000	$ 944,500	$4,017,000	496	170	666
8	1,438	$ 439,700	$1,270,000	1,189	170	1,359
9(a)	5,200	$ 598,300	$2,416,700	580	49	629
9(b)	4,800	$ 583,900	$2,322,300	606	170	776
10(a)	10,000	$1,133,000	$3,870,500	500	206	706
10(b)	10,000	$ 944,500	$2,709,500	366	206	572

N/C = Not calculated