# CONSIDERATIONS IN REVIEWING THE WASTE VOLUME REDUCTION PROGRAM IN A LARGE UTILITY

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## ABSTRACT

A program is underway at Ontario Hydro to establish a desirable future scheme for central processing/volume reduction of solid radioactive Low-Level Wastes (LLW) prior to their placement into the centralized storage, and in the future into a disposal facility. The approach being investigated is to furnish the current Waste Volume Reduction Facility (WVRF) with state-of-art processes, reclassify the waste categories and segregate the wastes such that each volume reduction (VR) process is then applied where it would be most effective. This "optimized" approach is then compared with other, specific schemes, which basically differ in that each scheme omits one of the major VR processes, thus allowing the next most effective process to take over its role. Each scheme is assessed quantitatively from the viewpoint of cost and VR effectiveness, and qualitatively from the viewpoint of resultant waste form. The economic assessments take into consideration the long term (20 year) impact of selected VR schemes on the overall waste management cost, including construction and operation of the storage facility. This paper highlights the overall study, includes the major results, and identifies aspects that need to be addressed in the selection of a desirable combination of VR processes in absence of knowledge of future waste disposal costs.

## BACKGROUND

Ontario Hydro is presently operating 10,250 MW(e) of CANDU Pressurized Heavy Water reactors. An additional 4,400 MW(e) is under construction. The nuclear program currently generates about 6,000 $m^3$ (before processing) of solid Low-Level Waste (LLW) per year and this quantity is expected to increase to approximately 8,000 $m^3/y$ by 1993. All of Ontario Hydro's solid low level waste is segregated at the source (nuclear stations) and transported to the Bruce Nuclear Power Development (BNPD) Reactor Waste Operations Site (RWOS) for centralized processing and storage. (1)

Initially, the wastes were stored directly in concrete, in-ground storage structures (trenches) without processing. Due to the relatively high costs of such first generation engineered storage, there has been a strong economic incentive to both reduce the waste volume to a minimum and also decrease the cost of waste storage by development of more economical storage structures. While the former resulted in construction of the Waste Volume Reduction Facility (WVRF), which was commissioned in 1977, the latter lead to development of above-ground bulk storage facilities. The current processes employed at the WVRF include incineration and mechanical compaction. The total waste volume received at the RWOS between 1978 and 1985 was on the order of 33,000 $m^3$.

The waste processing performance of the WVRF has been quite satisfactory, with the overall cycle reasonably optimized. However, the technological advances in volume reduction equipment that have occurred in the last decade, combined with the substantially increased volumes of incoming wastes expected at the maturity of the committed nuclear program in early 1990s, and the fact that the current incinerator has been approaching the end of its useful life and is already marginal in capacity, dictated a review of the present scheme. A study has been initiated addressing the feasibility of guaranteeing the continuity of the present situation, and the possibility of introducing a set of strategic plans that could improve it.

## CURRENT SCHEME

In the current scheme, incineration and mechanical compaction are used for reduction of waste volume. To facilitate this, all solid LLW generated is segregated at the source (e.g., nuclear power plants) into incinerable, compactible, and non-processible packages, and transported to the WVRF.

Incinerable waste, comprised mainly of paper, cloth, cardboard and non-halogenated plastic items, wood, vermiculites and floor cleaning materials, with fields up to 0.6 mSv/h (60 mR/h), is processed in a batch type pyrolyzing incinerator. (2) The resultant ash is placed into storage in metal containers, directly without immobilization. On average, about 65 percent of the incoming solid LLW is incinerated.

Twenty-two percent of incoming LLW, comprised mainly of PVC material, light metal objects, neoprene, and discarded $D_2O$ drums, with fields of up to 2 mSv/h (200 mR/h) on contact, is classified as compactible. While the empty $D_2O$ drums are volume reduced by a drum crusher (a modified drum compactor), the balance of the compactible waste is processed by a hydraulic compactor/baler. Crushed drums and plastic-wrapped bales are placed into storage arranged on self-stacking storage racks.

The remaining 13 percent of waste is categorized as non-processible, and is placed into storage in polyethylene bags or metal drums arranged on self-stacking racks or in bins.

The overall volume reduction factor (VRF) achieved by these management practices, has been approximately 4:1, taking ineffectiveness of containerization and storage method into consideration.

## PROJECTED ALTERNATIVE SCHEMES

Obviously, the most effective volume reduction scheme would engage state-of-art processes, which complement each other when processing respective waste categories for which they are most VR effective. Since incineration, representing the method of highest possible volume reduction, has already been utilized at the WVRF, it was mainly supercompaction that needed to be assessed and incorporated into the alternative schemes. The processes selected for consideration were, therefore, incineration, supercompaction, and compaction. Since the two former are both (although not to the same degree) capital intensive, the principal question was whether both processes would be warranted, and affordable, in one management scheme.

Since the WVRF already utilized a marginal incinerator, it was necessary to investigate the economic impact of installing a higher capacity system, in comparison to a life extension of the existing system by replacement of its modular components. Also of interest was to investigate consequences of a "do nothing" approach, where the incinerator would be phased out at the end of its projected useful life (1992) and all waste would be processed thereafter by an existing non-capital intensive method - baling. Thus, five site-specific schemes have been identified for assessment, representing alternative but realistic and logical courses of action, taking into account the actual site conditions, expected acquisition dates for new equipment, and well tuned waste generation forecasts for all waste categories. Care was taken to cover all practical combinations of the VR processes such that their analyses would provide a satisfactory background for the subsequent decision-making process. The following is the definition of these alternative schemes, Cases 0 to 4, with the dominating combination of processes (e.g., after 1992) in brackets.

### Case 0 (Baler and Drum Crusher)

Existing incinerator operative until end of 1992, when it is decommissioned but not replaced. Baler and drum crusher operative (with refurbishments as necessary) until 2005, processing all generated waste, including incinerables after 1992. In essence, a "do nothing" scenario.

### Case 1 (Old Incinerator, Baler, and Drum Crusher)

Existing incinerator maintained in operation by major component replacements until 2005. Baler and drum crusher operative throughout with refurbishment, processing their respective waste categories plus portion of incinerable waste in excess of incinerator capacity. A scenario maintaining the status quo.

### Case 2 (New Incinerator, Baler, and Drum Crusher)

Existing incinerator operative until 1992, when it is replaced by a higher capacity system. Baler and drum crusher operative throughout with refurbishment, processing their respective waste categories.

### Case 3 (Supercompactor)

Existing incinerator operative until end of 1992, when it is decommissioned but not replaced. Supercompactor operative since 1991, eliminating subsequent needs for baling and drum crushing. After 1992, incinerable waste is also supercompacted.

### Case 4 (New Incinerator and Supercompactor)

Existing incinerator replaced in 1992 by a higher capacity system. Supercompactor operative since 1991, eliminating subsequent needs for baling and drum crushing.

## WASTE GENERATION FORECAST AND WASTE CATEGORIES

To assess realistically the alternative waste management schemes, reliable information was needed on future volumes of generated waste. A waste generation forecasting method for low and medium level radioactive waste was developed specifically for this purpose. Historical waste generation data from the period 1978 to 1985, resulting from operation of Pickering GS A and B, Bruce GS A and B, Douglas Point GS, and related supporting facilities were compiled and analyzed by using a computerized statistical method. This method was verified and utilized to create a mathematical model for waste generation forecasting, which was then used throughout the study as needed.

Obviously, not only the total waste volumes but also the projected breakdowns by waste categories were needed for the assessment. While the current waste management scheme requires segregation into incinerable, compactible, and non-processible categories, the waste processing options under assessment necessitated identification of a new category of "supercompressible" waste, and an adjustment of the other categories. For the purpose of the study, a reclassification of the waste categories was made, with the definition of the new categories as follows:

| | |
|---|---|
| incinerable | - waste with overall combustible characteristics, suitable for incineration (equivalent to waste currently incinerated); |
| compressible | - waste suitable for conventional compaction, e.g., by the existing baler, drum crusher (equivalent to waste currently compacted, including discarded $D_2O$ drums); |
| supercompressible | - waste suitable for supercompaction but not conventional compaction (equivalent to portion of current "non-processible" category that could be supercompacted); |
| non-processible | - waste not suitable for processing by any of the above (equivalent to the balance of the waste). |

As apparent, the new category of supercompressible waste comprises part of the category defined as non-processible under the current mode of operation. To quantify this portion, a thorough characterization and analysis of the current non-processible waste was necessary. The quantitative results of this effort are shown in Fig. 1. The new supercompressible category constitutes approximately 13 percent of the total solid LLW generated (or 84 percent of the current non-processible category; such waste is currently stored without processing in plastic bags or drums). The portion of waste that cannot be volume reduced by any of the above processes constitutes approximately 2.5 percent of the total LLW (reduced from the 15.5 percent for the currently defined non-processible waste category).

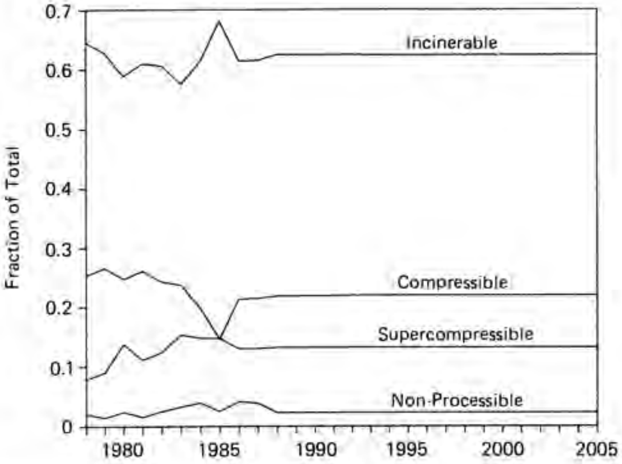

Fig. 1. Fractional Distribution by Waste Categories of Annual Waste Generated (Actual and Forecast).

Figure 2 depicts the annual waste volumes by the individual waste categories for the period 1978-2005, containing both the historical data and the forecast. It can be seen that the supercompressible category reaches annual volumes of approximately 1000 $m^3/y$ after 1993, when the total volumes of waste generated approach 7500 $m^3/y$. At that time, the annual volumes of the new non-processible waste category do not exceed 200 $m^3/y$.

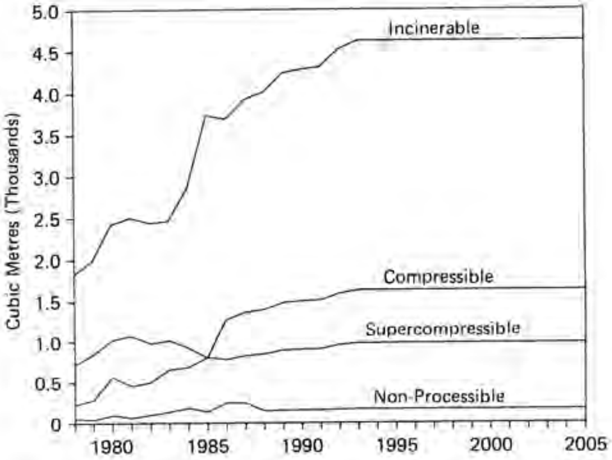

Fig. 2. Annual Waste Volumes Generated, by Waste Categories (Actual and Forecast).

WASTE STORAGE

It was assumed that all waste considered in the study, would be stored, after processing and appropriate packaging, until at least 2005 in above-ground storage structures identical to the existing Low Level Storage Buildings (LLSB) Nos. 1 and 2. These buildings are now being used for storage of solid LLW with radiation fields of less than 10 mSv/h (1 Rem/h). (1)

The LLSB design is based on a pre-fabricated, pre-stressed concrete superstructure (Fig. 3), consisting of concrete roof columns with 0.38 m thick concrete walls and a 0.16 m thick concrete roof. The approximate building dimensions are 50 m long by 30 m wide by 8 m high and can store about 6,600 $m^3$ of packaged wastes. The LLSB is designed as an unheated building; however, the design includes: a $CO_2$ (gas) fire extinguishing system, smoke detection equipment, a modest forced air ventilation system, internal fixed lighting, and an internal drainage system. All wastes are stored in self-stacking metal containers or racks to a height of 6.25 m. Loading of the wastes is accomplished by a front end loading vehicle similar to a forklift. To facilitate future expansion, the LLSB is designed as a module whereby successive LLSBs can be added to existing buildings utilizing a common wall and the fire protection system.

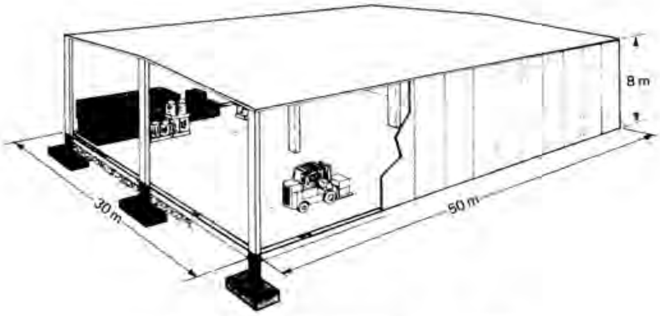

Fig. 3. Low Level Storage Building.

ASSUMED VR FACTORS

For the purpose of this assessment, the overall volume reduction factor (VRF) for each of the waste categories and VR processes were calculated, taking into consideration the VRF of the process, packaging efficiency, and the storage space utilization efficiency. The data used, shown in Table I, are based on the experience with the current processing, packaging and storage practices, except those concerning supercompaction, which were based on the experience of others.

## TABLE I

### Volume Reduction Factors for Processes and Waste Feed Categories

| Process | Waste Feed Category | Resultant Waste Package | Process Volume Reduction Factor | Packaging Efficiency (%) | Storage Space Utilization (%) | Overall Volume Reduction Factor |
|---|---|---|---|---|---|---|
| Incineration | incinerable | ash container | 75 | 78 | 85 | 50 |
| Compaction | compressible | bale | 6.3 | 100 | 63 | 4 |
| Drum Crushing | empty $D_2O$ drums | crushed drum | 7.4 | 70 | 77 | 4 |
| Supercompaction | incinerable | drum | 12.5 | 75 | 75 | 7 |
| Supercompaction | compressible | drum | 10.6 | 75 | 75 | 6 |
| Supercompaction | supercompressible | drum | 4.2 | 75 | 75 | 2.4 |
| None | non-processible | bag | - | - | 70 | .7 |
| None | non-processible | drum | - | 75 | 75 | .55 |

## COST ASSUMPTIONS

All cost estimates shown below, are in Canadian Dollars (1986).

Waste Storage Structures

| | |
|---|---|
| Low Level Storage Building (construction between 1986 and 2002): | K$ 1,840 |
| Low Level Storage Building (construction beyond 2002): | K$ 1,932 |

Incinerator (Capital Cost)

| | |
|---|---|
| Process Equipment | K$ 4,000 |
| Building and Auxiliary Systems | 1,260 |
| Construction | 840 |
| Indirects, Engineering, Contingencies, etc. | 4,215 |
| Total Cost[a] | K$ 10,315 |

[a] does not include interest and corporate overheads.

Supercompactor (Capital Cost)

| | |
|---|---|
| Process Equipment | K$ 2,430 |
| Building and Auxiliary Systems | 650 |
| Construction | 450 |
| Indirects, Engineering, Contingencies, etc. | 2,368 |
| Total cost[a] | K$ 5,898 |

[a] does not include interest and corporate overheads.

Baler (Capital Cost)

| | |
|---|---|
| Process equipment installed | K$ 142 |

Operation and Maintenance

The estimates of operating costs include operating labour, routine equipment maintenance (but not major refurbishment) labour and materials, and operating consumables.

| | |
|---|---|
| Incineration (existing system): | 591,000 $/y |
| Incineration (higher capacity system): | 348,750 $/y |
| Baling and drum crushing: | .93 man-hr/$m^3$ |
| Supercompaction: | 1.25 man-hr/$m^3$ |
| Packaging (containerization) including cost of storage racks, bins, etc.: | |
| - baled waste | 60 $/$m^3$ |
| - non-processible waste | 77 $/$m^3$ |
| - incinerator ash | 476 $/$m^3$ |
| - supercompactor pucks (including pre-packaging drums, storage drums, and racks): | 300 $/$m^3$ |
| Transfer to storage (all categories): | 1.0 man-hr/$m^3$ |

Decommissioning

The estimate of the decommissioning costs includes decontamination and storage costs.

| | |
|---|---|
| Incinerator: | $ 244,000 |
| Baler: | $ 14,000 |

### Incinerator Life Extension

Life extension of the existing incinerator is assumed to cost a total of 1,231 K\$ (1986), spread over the period 1992 to 2004, with major expenditures occurring in 1992 (427 K\$), and 1996 (277 K\$) due to replacements of the primary combustion chamber and the afterburner.

### Common Costs

To simplify the economic assessment of the alternative waste management schemes, various expenditures that are common to all schemes could be removed and calculated separately. These were typically: operation and maintenance of the existing incinerator until end of 1992; operation and maintenance of the drum crusher in a common time period; design and construction of a new waste receiving facility; baling of excess incinerables until end of 1991; labour costs associated with receiving and sorting of the wastes; supervision, administration, and overheads; and other. The calculated present worth (1986\$) of the common costs for the period 1986-2005 is 14.5 M\$.

## OTHER ASSUMPTIONS

There was a number of general assumptions made to facilitate a fair comparison of the alternative schemes from the viewpoint of economics and VR effectiveness. Typically, January 1, 1987 was selected as a date of approval for implementation of the alternative schemes, and the various in-service dates were established accordingly. The existing incinerator was assumed to be successfully modified by January 1, 1987, with the average yearly capacity increased from 2650 to 4000 $m^3$/y. The backlog of unprocessed waste was also assumed to be eliminated by January 1, 1987. All construction of the new facilities and/or addition of new equipment would be achieved without disrupting the operation and throughput of the existing equipment. A new waste receiving and segregation facility would be constructed to accommodate the projected increase in waste receipts.

## ASSESSMENT OF VR EFFECTIVENESS

The consequences of implementation of the five waste management schemes (Cases 0 to 4) are shown in Fig. 4. The intercepts of the curves with the coordinate of the year 2005 represent the cumulative values of resultant waste volumes stored during the 1986 to 2005 period. The total volume of waste processed in that period is 140,000 $m^3$.

As expected, Case 0 and Case 4 constitute the extreme ends of the processing spectrum since they represent the minimal, and the most complete volume reduction scenarios respectively. The minimum resultant total waste volume of 20,000 $m^3$ is obtained for Case 4, and this increases to 47,000 $m^3$ for Case 0. While the scenario of extended incinerator life (Case 1) indicates a final cumulative waste volume of 35,000 $m^3$, a timely replacement of the same equipment with a new, higher capacity system would reduce this total to 33,000 $m^3$ (Case 2). The difference of 2,000 $m^3$ is attributed to the fact, that some incinerable waste will have to be compacted in Case 1 due to insufficient capacity of the existing incinerator. Finally, a replacement of the incinerator with a supercompactor (Case 3) indicates a stored waste volume of 27,500 $m^3$.

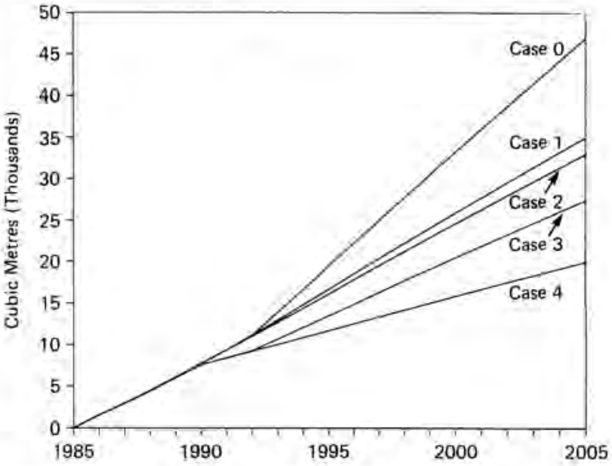

Fig. 4. Comparison of Storage Space Requirements for Waste Processed in the Alternative Waste Management Schemes (Cases 0 to 4). Cumulative Data.

If the results for the extreme Cases 0 and 4 were expressed in term of the facility overall volume reduction factor (VRF), they would be 3 and 7 respectively. An overview of the overall volume reduction factors, together with the resultant waste volumes requiring storage for all five schemes, and the numbers of additional LLSBs required, are shown in Table II.

## IMPACT ON STORED WASTE MIXTURE

The choice of the waste processing scheme obviously effects not only the stored waste volumes but also the stored waste form and the package form. In the current waste management scheme, the processed waste is stored in the following package form: (a) 3.5 $m^3$ containers, containing incinerator ash; (b) 0.5 $m^3$ bales, containing compacted trash, on self-stacking storage racks; and (c) drums or bags, arranged on storage racks, or in bins, containing unprocessed (non-processible) waste. Introduction of supercompaction creates a new, additional package form: (d) 208 l drums, containing supercompacted drums (pucks).

Obviously, the fractional distribution of the above identified four types of waste packages would vary substantially with each waste processing scheme examined. Typically, Fig. 5 depicts cumulative fractional distribution of the waste package form for the event that the current waste processing scheme continues (Case 1), and Fig. 6 the same for a scheme employing incineration and supercompaction (Case 4). While under the current scheme 68 percent of the stored waste would consist of non-processed waste by 2005, the incinerator/supercompactor scheme would decrease this category to a mere 12 percent of the total.

TABLE II

Comparison of Volume Reduction Effectiveness for the Alternative Waste Management Schemes (Cases 0 to 4)

| Case | Key Processes | Overall Volume Reduction Factor | Resultant Waste Volume ($m^3$) | Additional Number of LLSBs Required |
|---|---|---|---|---|
| 0 | Baler, Drum Crusher | 3 | 47,000 | 6 |
| 1 | Old Incinerator,<br>Baler, Drum Crusher | 4 | 35,000 | 4 |
| 2 | New Incinerator,<br>Baler, Drum Crusher | 4.2 | 33,000 | 4 |
| 3 | Supercompactor | 5.1 | 27,000 | 3 |
| 4 | New Incinerator,<br>Supercompactor | 7 | 20,000 | 2 |

NOTE: Waste Volume Before Processing - 140,000 $m^3$

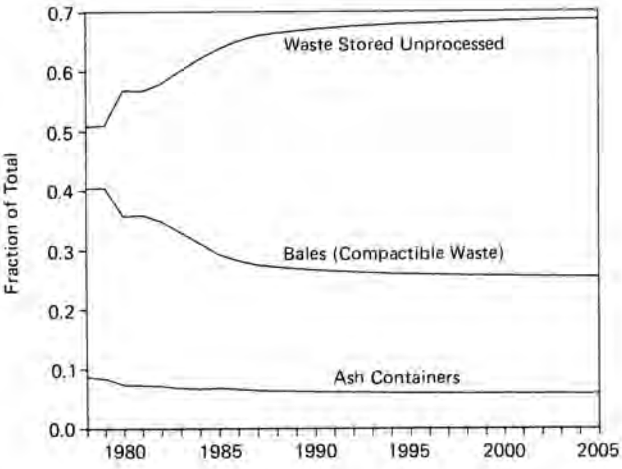

Fig. 5. Fractional Distribution by Package Form of Processed Waste when Current Waste Processing Scheme Continues (Case 1).

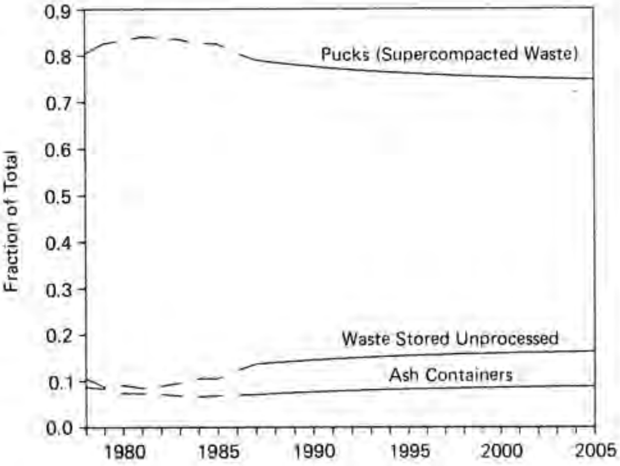

Fig. 6. Fractional Distribution by Package Form of Processed Waste for Incineration/ Supercompaction Scheme (Case 4).

A graphical display of the accumulated and stored waste volumes by the year 2005 for the five alternative waste management schemes, together with a breakdown by the individual waste categories and corresponding package forms, is shown in Fig. 7. It appears that, for instance, 49.4 percent of the total volume (after processing) in Case 0 is baled waste, which is not a preferred waste and package form. Bales constitute, however, only 9.1 percent of the total volume (after processing) in Case 4.

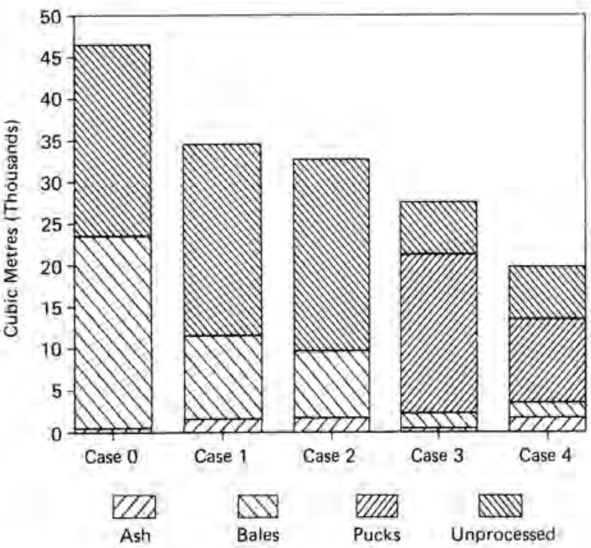

Fig. 7. Comparison of Cumulative Stored Waste Mixtures and Corresponding Package Forms for the Alternative Waste Management Schemes (Cases 0 to 4).

## ECONOMIC ASSESSMENT

The overall costs of the five alternative schemes, including all capital and operating/maintenance costs associated with volume reduction, packaging and storage of the waste in the period 1986-2005, have been determined in both constant (1986) Canadian dollars and present worth (1986) Canadian dollars. Ontario Hydro corporate financial discount rates and escalation factors have been used to determine the costs in present worth dollars. The expenditures common to all schemes were removed and calculated separately; they may be used to compute any or all of the schemes' overall costs when waste management normalized costs are to be determined or in an attempt to rank the options (Table III).

TABLE III

Summary of Overall Costs (1986-2005) of the Alternative Waste Management Schemes

| | | Present Worth (1986 M$) | | |
|---|---|---|---|---|
| Case | Key Processes | Case Specific Cost | Common Cost | Total Cost |
| 0 | Baler, Drum Crusher | 12.5 | 14.5 | 27 |
| 1 | Old Incinerator, Baler, Drum Crusher | 13 | 14.5 | 27.5 |
| 2 | New Incinerator, Baler, Drum Crusher | 19 | 14.5 | 33.5 |
| 3 | Supercompactor | 16 | 14.5 | 30.5 |
| 4 | New Incinerator, Supercompactor | 22.5 | 14.5 | 37 |

The definition of a "do nothing" scheme (Case 0) allowed identification of the scenario below which it would not be conceivable to operate. It represents a waste management option based on incinerable waste being incinerated until the end of the equipment useful life (e.g., 1992) after which waste compaction is the only processing method practiced. The consequences of this practice are a storage capacity requirement equivalent to 6 (six) additional Low Level Storage Building (LLSB). The estimated total cost in present worth dollars for this option is 27 M$ of which approximately 14.5 M$ constitute expenditures common to all alternatives. Although the economics of this option are the most favourable of the five cases, the waste volume reduction obtained is the lowest (VRF = 3).

The results of the Cases 1 and 2 evaluation are discussed together because both cases are based on a similar waste management strategy (incineration plus compaction). The major difference between the two cases is the introduction, in Case 2, of a large capital expenditure related to the procurement of a new incinerator. In fact, Case 1 has been introduced to create a specific reference for Case 2 rather than to indicate a desirable condition. Life extension of the current incinerator to the year 2005 (13 years beyond the expected expiry date) is considered only a theoretical condition. The two cases require 4 (four) additional LLSBs. The resulting volume reduction factor of 4 would ensure the current waste management performance to be extended to the year 2005. The economic assessment indicates that while Case 1 is only marginally more expensive than Case 0, Case 2 represents an additional expenditure of 6.5 M$ in present worth over Case 0.

Cases 3 and 4 share a common feature of a supercompactor as the processing equipment for compressible (and supercompressible) waste. Case 3 indicates that an overall volume reduction factor of 5 can be obtained even though the incineration equipment is decommissioned in 1992 without replacement. The consequences are that only 3 (three) additional LLSBs are required for this option.

Case 4 constitutes the "optimized" waste management scenario under the tenets of minimization of the impact on the storage, and the future disposal phases through maximization of the waste volume reduction. Under these conditions, the benefit of processing at a VRF = 7 is better expressed by this option's requirement for only 2 (two) new LLSBs by the year 2005. A difference of 10 M$ over the reference Case 0 represents the cost of this optimization in present worth dollars.

## CAPITAL COST SENSITIVITY

The major capital expenditures in the alternative waste management schemes are those of the waste storage structures and the processing equipment. While the schemes with low overall VRFs (e.g. Case 0 and 1) are characteristic with their capital expenditures associated with storage structures, the schemes with higher VRFs require more substantial capitals for the processing equipment. In order to have a fair comparison of the alterative schemes, it is necessary to explore to what degree the capital expenditures (and their variability) affect the ranking of the schemes.

It is believed, that the cost of the storage structures (LLSBs) at M$ 1.84, used in the assessment, is quite realistic due to the fact that two such structures were constructed recently and the costs are known. The costs of the supercompaction facility at M$ 5.898 and the incineration facility as M$ 10.315 are evidently more variable, depending on the selection of the types and makes of the process equipment, and on the degree of required sophistication and automation of the facilities. While the estimated costs used represent fairly complete state-of-art processing facilities, the cost of supercompaction hardware could be reduced from M$ 2.43 to M$ 1.5, and that of incineration hardware from M$ 4 to M$ 2, if "economic" versions are acceptable. The impact of the cost reduction (e.g., after adjustment, a supercompaction facility at M$ 4.15, and an incineration facility at M$ 7.155) on the overall costs of the alternative schemes is shown in Fig. 8, where Cases 2A, 3A, and 4A represent economic versions of the basic Cases 2, 3 and 4. Cases 0 and 1 are not effected by the cost reductions. The overall costs of Cases 2A, 3A and 4A in present worth (1986) dollars are M$ 31, M$ 28.5, and M$ 33 respectively (including the common costs).

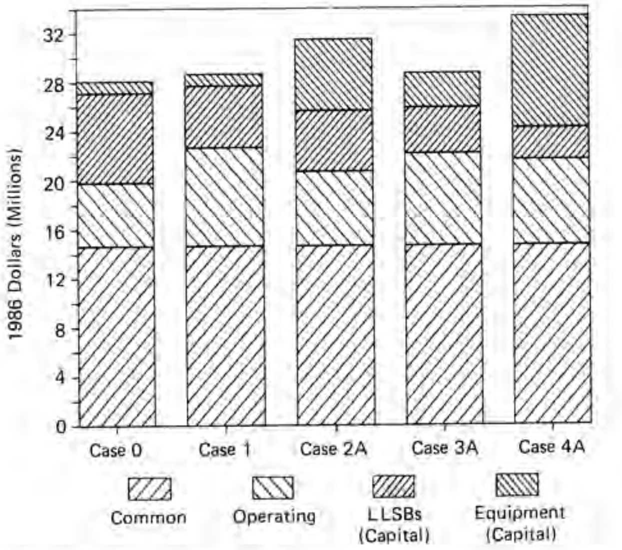

Fig. 8. Comparison of Cost Segments in Present Worth Dollars (1986) for the Alternative Waste Management Schemes. Basic Options 2, 3, and 4 are Substituted by their "Economic" Versions 2A, 3A, and 4A.

## IMPACT ON FINAL DISPOSAL

It is assumed that, after year 2005, certain portions or all of the waste stored in the LLSBs, would be transferred to an, unspecified at this time, disposal facility. Since timing, costs, and magnitude of this action are unknown, only a sensitivity assessment was prepared for informative purposes. Fig. 9 depicts the present worth of the overall waste management costs (including disposal) for each analyzed option as a function of "disposal cost" ranging from 500 to 3500 $/m$^3$. The "disposal cost" is defined for the purpose of this study as an actual cost of waste retrieval, re-packaging (as appropriate), transportation and placement into a final disposal repository, inclusive of all fees and surcharges to the disposal facility. As Fig. 9 indicates, Case 4 (incineration/supercompaction) is the most economical waste management scheme when "disposal costs" are in excess of 880 $/m$^3$.

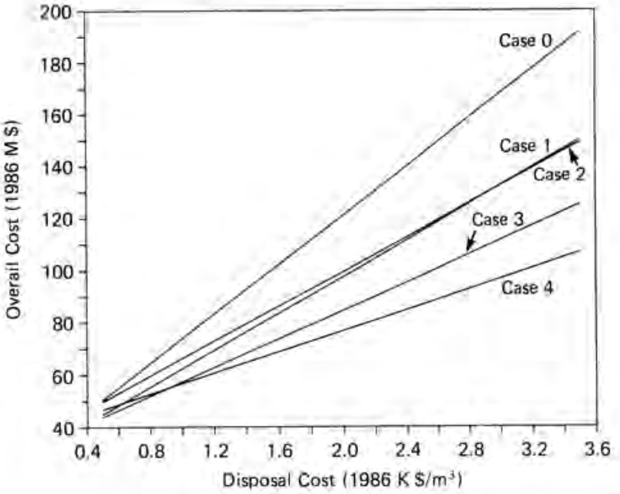

Fig. 9. Present Worth Costs (1986$) of VR, Storage and Disposal of Waste for the Alternative Waste Management Schemes (Cases 0 to 4) as a Function of Variable "Disposal Cost".

## DISCUSSION AND CONCLUSIONS

Rather than a selection of an optimal waste management scenario for immediate implementation, the objective of this phase of the study was exploration of what volume reduction can be achieved, at what cost, by utilization of various combinations of the state-of-art technologies. While the individual scenarios were defined as realistically as possible, taking all existing conditions into consideration, the implementation timing and the study period were approximate and arbitrary (e.g., 1986-2005). A different timeframe (e.g., deferral of implementation by two or three years), however, was not expected to substantially change the outcome of the study and, most importantly, the relationships between the individual scenarios.

It has been generally known that volume reduction by simple means (e.g., compaction), yielding low overall VRFs (e.g., up to 2) is cost effective, both for intermediate storage as well as final disposal of the waste, when compared to management of original volumes of waste without volume reduction. Achieving higher VRFs, however, requires more sophisticated processing technologies or their combinations, which is increasingly capital intensive as the resultant VRF increases. When processed waste is directly forwarded to disposal, with all costs and disposal criteria known, a selection of an efficient VR scheme can be done relatively simply on purely economic grounds. The situation is different, however, when a disposal site is unavailable, and the processed waste has to be stored on-site for an unspecified (long term) period. Reliable data on availability and costs (in

$\$/m^3$) of the future disposal are unknown in such a case, and consequently an economic assessment is no longer the only consideration in the selection of an optimal volume reduction scenario.

The study clearly indicated that, in the given conditions, the overall waste volume reduction efficiency of this central processing and storage facility would range between 3 and 7 (both values representing extreme practical limits), depending on the selection of a processing scheme. While the overall cost of the basic "do nothing" scheme (VRF=3) was calculated at M$ 27 (present worth), the cost of the most technologically advanced scheme (incineration/supercompaction, VRF=7) appeared to be 37 percent more expensive, or only 22 percent in its "economic" version. However, due to their respective resultant waste volumes, the final disposal of the waste from the "do nothing" scheme would be over 100 percent more expensive than that from the technologically advanced scheme. In general, the cost differences between the individual schemes are not significant enough to warrant a selection of a scheme on purely economic grounds without assessment of other inherent aspects specific to each scheme.

When selecting a volume reduction scheme in a waste management plan that includes an interim storage period and a rather uncertain final disposal, all relevant aspects of the storage of the waste, and its surveillance need to be carefully considered. Unfortunately, some, if not most, of these aspects are intangible, which may necessitate a qualitative rather than a quantitative assessment. While such assessment was not a subject of this study, it may be useful to list some of the aspects, that need to be considered, as a minimum, and not necessarily in that order:

- Characteristics of waste after processing, in each category, including its stability during storage and disposal, and fractional distribution of categories;
- Form of waste packages, including assessment of their packaging/storage space efficiency, containment of radionuclides, uniformity, durability, ease of handling, surveillance, and transportation;
- Redundancy in VR capacity/capability, with a specific focus on prevention of waste accumulation due to temporary unavailability of a process;
- Regulatory constraints including environmental release limits and licensing;
- Storage site expansion limitations;
- Labour requirements versus automation;
- Radiological safety;
- Anticipated disposal criteria;
- Future growth of generating capacity (e.g., nuclear versus fossil);
- Citizenship and public image.

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