System analysis for radwaste management

An overview of the decision-making framework for low- and medium-level wastes

by William L. Lennemann

Radioactive waste management can be considered as the barrier between the uses of nuclear energy and the potential detrimental effects of radioactive waste arisings on man and his environment. Among the various skills and/or disciplines that are required for qualified and acceptable management and disposal of radioactive waste are technical competence in such areas as engineering, chemistry, biology, geological sciences, health physics, cost and risk/benefit analysis, economics or cost effectiveness, feasibility and environmental assessments, and systems analysis, as well as good knowledge of communications, public relations, and an understanding of political processes and social and political climates.

Neither all the skills nor all the disciplines will reside in any one individual. That is why radioactive waste management should be a group effort.

At this time, economics, cost effectiveness, and risk/benefits in radioactive waste management usually are given little consideration by the public. One does what one has to do because of political and societal pressures. In all countries, radioactive waste management and disposal has come under political control and surveillance and bureaucratic regulation where, at times, decisions are influenced more by societal pressures than by technical requirements. Nevertheless, it is the responsibility of radioactive waste managers to present the cost effectiveness and risk/benefits of various alternatives and systems for handling radioactive waste to the political and regulatory decision makers, so that they are not unaware of the implications of their decisions regardless of what these decisions may be.

The selection of a radioactive waste management process or equipment should not rely solely on the advice of a seller or, as the saying goes, let the buyer beware. A generator or processor of radioactive waste should have competent in-house expertise for radioactive waste management or obtain the consultation of appropriate and unbiased independent experts. Tens of millions of dollars have been spent needlessly in the nuclear industry from not adhering to this tenet.

The most logical approach to evaluating radioactive waste management processes and their options is to consider radioactive waste management, handling, and disposal as a complete and complex system from the waste arisings (or generation) to their disposition. The system can be logically compartmentalized or divided into operational components. What is done in one component can impose constraints or flexibility on one or more of the other components of such a system.

Radwaste management system

Physically speaking, radwaste can be classified into the following five generic categories for treatment and packaging:*

- Liquids, including thin slurries
- Wet solids, including thick slurries
- Dry solids
- Compactable trash
- Gases

Gaseous radionuclides that currently are of some concern are krypton-85, carbon-14, hydrogen-3 (tritium), and iodine-129. Generally speaking, these gaseous radionuclides are being released to and diluted by atmospheric processes. Their capture and acceptable disposition in the gaseous form is controversial. On the other hand, it is technically possible to capture and convert these gaseous radionuclides to solid forms that can be more acceptable forms of disposal. Consequently, it is assumed that this is the case to the extent that capture and confinement of these radionuclides become necessary.

Each component of a radwaste management system has two or more options, requiring decisions on objectives, technology, and criteria that can affect what is being done or will be done — namely, other decisions,

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* As used in this article, the term "radwaste" means levels of radioactive waste in low and medium, or intermediate, categories that contain insignificant levels of long half-life transuranium (TRU) radionuclides. Some countries also have restrictive levels on long half-life fission and activation products. For purposes of a definition, long half-life is in excess of 50 years.

with respect to the options available for the other components in the system. For example, the selection of the disposal site and/or disposal method may significantly influence the treatment or packaging of the radwaste, and vice versa.

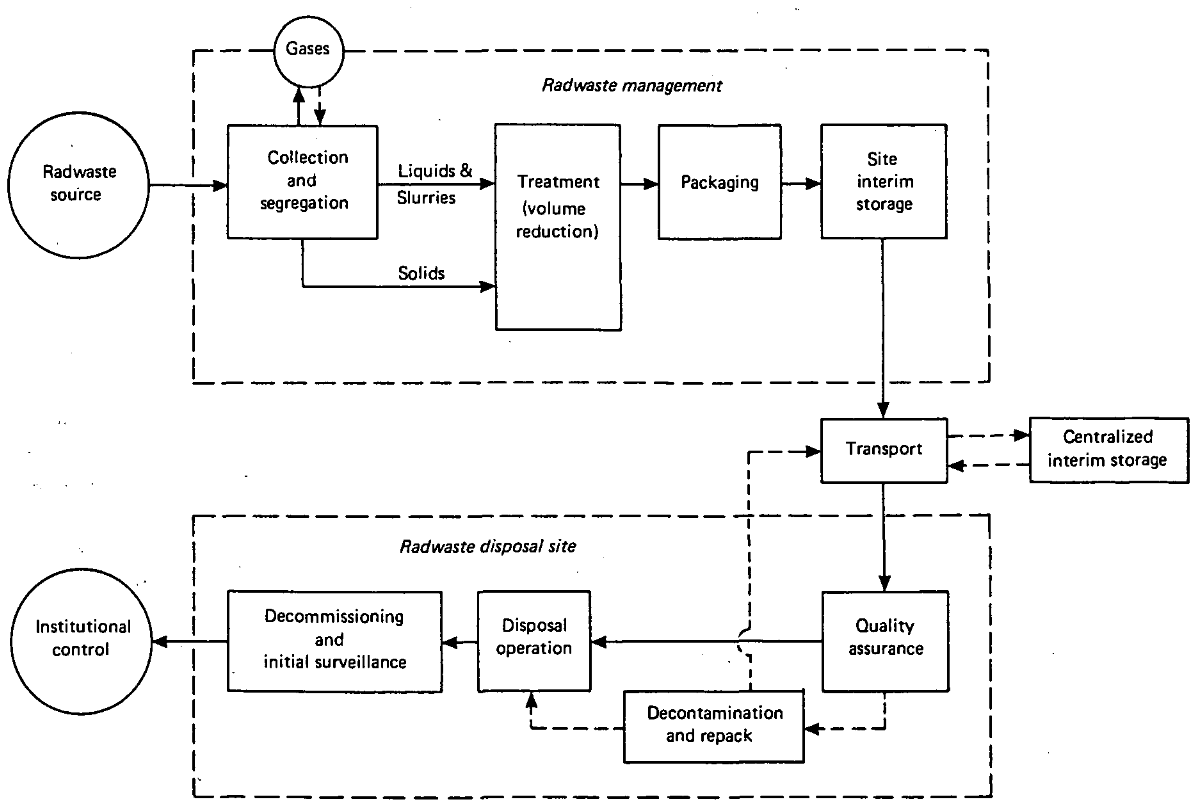
The components of a radwaste management system can be referred to as ''decision places'' for purposes of discussion and illustration. If at all possible, the decision-making process involving radwaste management should survey and consider the effects of a decision on all components of the system rather than being limited mainly to the component involved and perhaps one or two others. *(See figure below.)*

A somewhat obvious but often overlooked decision concerns an early standardization of the radwaste packages. A waste package consists of its content and the containment or container. The benefits of standardized radwaste treatment and waste forms can depend on the local and/or national situation at the time. On the other hand, obvious benefits can be obtained from the standpoint of handling, transporting, and disposing of the radwaste packages by standardizing the sizes, shapes, and handling aids of the containers. Having several standardized packages, essentially dependent on the radwaste form and radiological hazard, also facilitates batching a multiple number of identical packages into a larger container or frame for their unitized handling and disposition.

Management options

Current options and technologies are available for the various components or elements of a radwaste management system. Volume reduction of radwaste essentially involves the removal of the non-radioactive components — namely, water, air, and combustible organics. Packaging usually involves stabilizing a liquid or solid waste form into a solid matrix. On the other hand, if the radionuclides and solid waste forms are not readily dispersable or the radionuclides are intrinsically well-contained within the waste form itself (for example, a metal matrix in which induced radioactivity is fixed) packaging may be unnecessary.

The decision-making process involves making management decisions regarding those options and/or technologies, or a combination of them, to utilize for each component of the radwaste management system. Consequently, the total system should be examined to determine to what extent a decision within the system is compatible with the other components in the system, including the detrimental and/or beneficial effects of any



Each component of a radwaste management system has two or more options, requiring decisions on objectives, technology, and criteria that can affect what is being done or will be done. These components can be referred to as "decision places". The dotted flowlines indicate alternatives that should be taken into account.

adjustments in the system that may be necessary as a result of the decision.

By systems analysis, it is possible to optimize packaged radwaste volumes and handling with respect to both costs and detrimental effects, such as risks and radiological exposures. A simple example involves the segregation of radioactive waste from non-radioactive waste, or the segregation of radioactive waste into various groupings for either treatment or disposal which, in some cases, can be considered a way of volume reduction. One should weigh the possible benefits from this sorting with the associated detriments, which would include the sorting costs and the occupational risks of the sorting operation. (*See the accompanying chart.)*

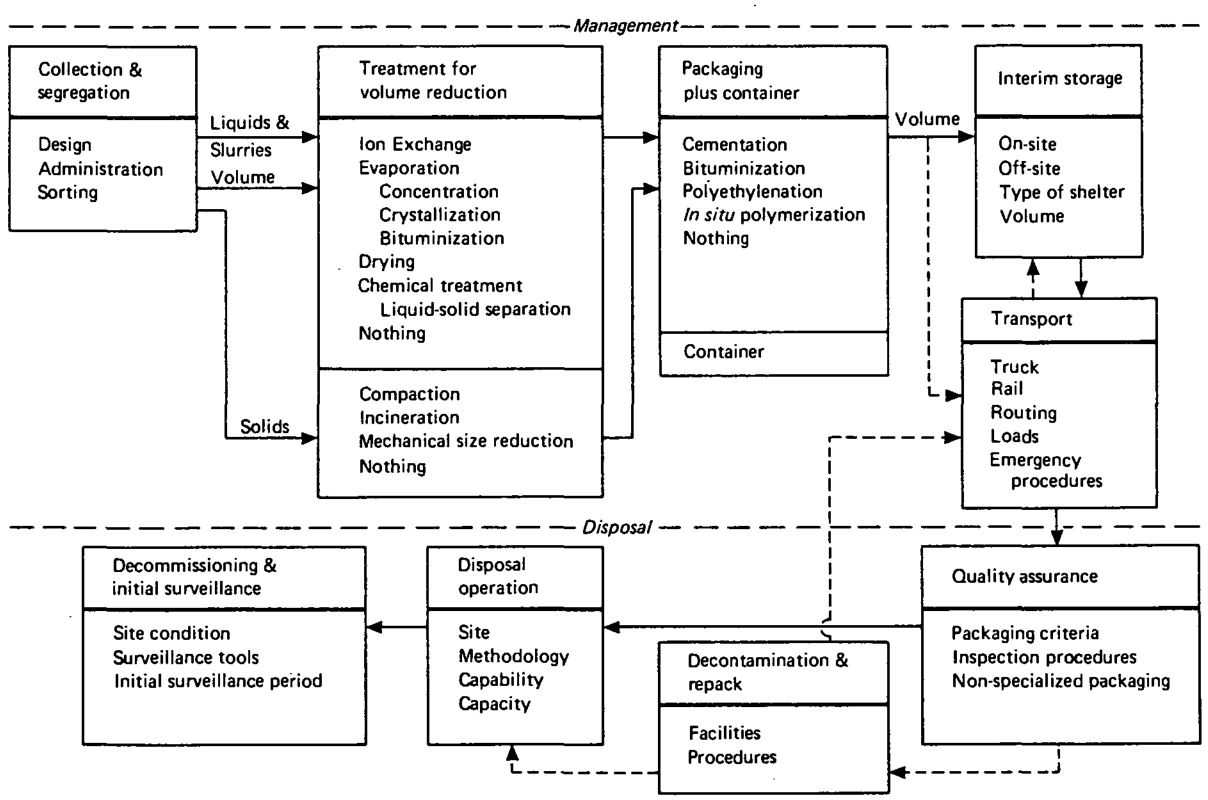
System optimization

The principal elements that should be considered or taken into account when making a decision involving one or more components of a radwaste management system essentially concern radiation doses or detriments — both radiological and industrial safety (hazards and risks) and both capital investments and operating costs. (*See accompanying table.*) An evaluation of the detriments, the overall safety, and the costs involved in operating the system under one set of decisions or options,

Radwaste management system decision elements

Considerations involving decision places	• Radiation protection • Radiation exposure Workers Individuals Population groups • Magnitude of hazard Radiological Industrial • Probability of risk Radiological Industrial • Costs
	• Totals for system • Trade-offs • Cost effectiveness
ALARA principle	

Options and technologies for a radwaste management system



as compared to under one or more other sets of decisions, can be provided by totalling the elements — using a common basis of evaluation or the units of a ranking method with any adjustments — for the system components. In this way, one can arrive at a radwaste management system that is optimized for obtaining the desired objectives.

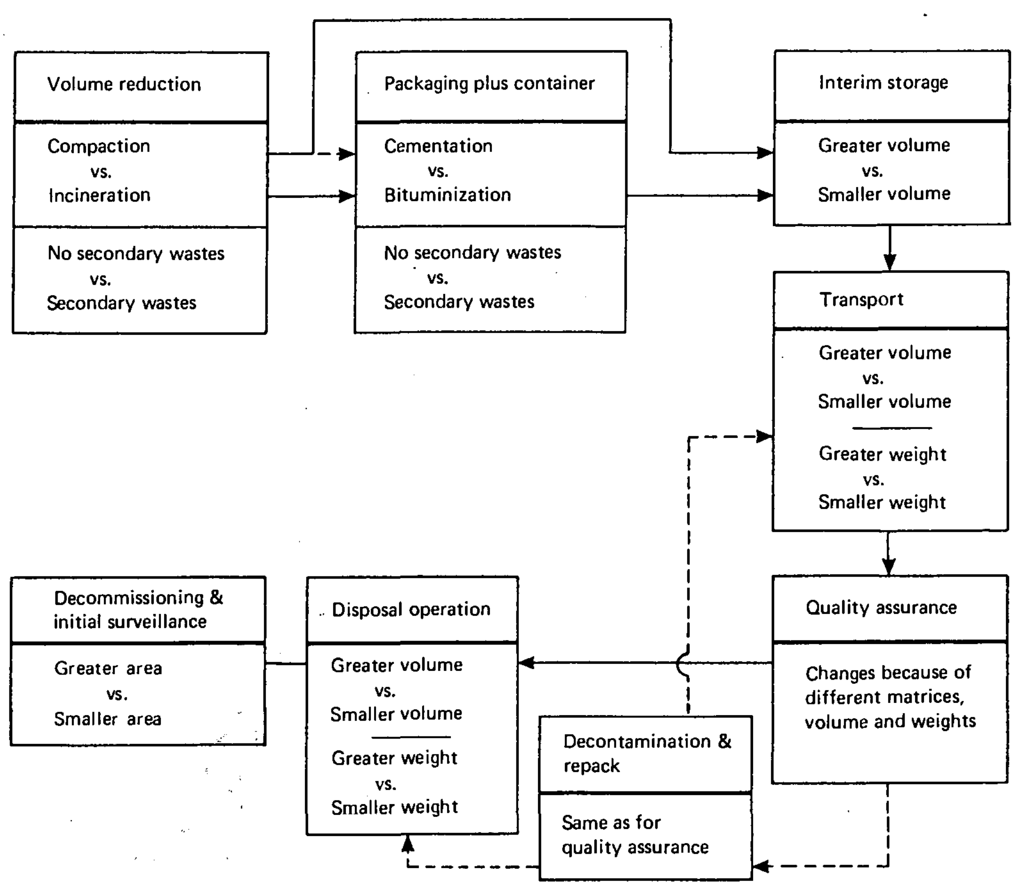
Trade-offs are involved in optimizing a system — namely, where improving the operation and benefits of one component of the system could be done by relaxing the objectives of one or more of its other components. In other words, where can the money best be spent in a system to obtain the maximum overall benefit? For example, money spent to reduce individual radiation exposures in the radwaste management system might be more prudently spent in reducing an element of risk.

Money is a resource both in private and in national undertakings. Cost effectiveness involves a decision as to whether an expenditure or saving is really worthwhile or whether spending the money somewhere else might result in greater private or public benefits. For example, money spent to reduce radiological exposure levels to population groups might be more effectively spent on medical research (concerning cancer, for example), or on alleviation of other hazards resulting in serious health effects to population groups. The point is that presumably the value of a human life in a country is the same regardless of the cause of debilitating illness or death.

In countries having economies with limited financial resources, expenditures to protect the health of population groups should be directed to where there is the greatest benefit, despite but including radiological exposures. Also, a greater reduction in radiological exposure levels might be obtained by spending the same amount of money in another component of the radwaste management system or even somewhere else in a nuclear energy programme. The ALARA principle of the International Commission on Radiological Protection (ICRP) does provide certain flexibility in the objectives for radiological exposure, since social and economic considerations to be taken into account by the regulatory authorities can vary considerably from country to country and can be adjusted to suit the circumstances or situation.*

ALARA means "as low as reasonably achievable", social and economic considerations being taken into account.

Examples of systems analysis



Comparison of volume reduction techniques

*Cementation versus Bituminization**
*Compaction versus Incineration***

Obvious pluses

- Decrease unit volumes
- Decrease storage requirements
- Decrease transport requirements
- Decrease disposal area needed
- Bitumen more water resistant

Obvious minuses

- More complicated process
- Greater capital cost
- Greater operating cost
- Greater unit cost per reference volume
- Less shielding
- Higher radiation
- Secondary waste streams
- Small fire risk

Some trade-off considerations

- Value of land area saved greater than additional cost
- Risks of volume reduction vs. risks of reference process
- Radiological exposures for volume reduction vs. radiological exposures for reference process

* For thin slurries and evaporator bottoms.
** For combustible solid waste.

Some considerations that are involved in the respective systems analyses of two examples of opposing volume reduction techniques for radwaste are shown in the accompanying diagram. The two examples are:

- Cementation versus bituminization for thin slurries and evaporator bottoms
- Compaction versus incineration for combustible solid waste.

While compacted waste is already packaged, incinerator ashes are readily dispersable and would probably have to be immobilized and packaged either by cementation or bituminization. The principal impact considerations are volume and weight reductions and secondary radwastes resulting from the volume reduction operations. These impacts are translatable into exposures, risks, and costs for systems analysis.

Some obvious benefits and disadvantages (pluses and minuses) of bituminization over cementation and of incineration over compaction that should be taken into account in a systems analysis are summarized in the table above. There certainly are other possible benefits and disadvantages, but those listed are sufficient for purposes of illustration and brevity. The pluses and minuses are more or less the same for bituminization and for incineration, with the exception that bitumen is more water resistant than cement or concrete.

The table also lists several trade-offs that should be considered with respect to achieving a decrease in the volume of waste for disposition. From a cost effectiveness point of view, one might consider the questions:

- How does the additional cost of the volume reduction equate to the savings in handling, transport, and disposal costs, plus the value of the land that no longer is required for terrestrial disposal of the packaged waste?
- Where else could this additional cost be used to a better advantage in nuclear energy, such as for training or the improvement of roads and other transport facilities for the safer transportation of nuclear materials including radioactive waste, or possibly to a better national advantage (for example, research and development, construction of medical facilities, reclamation of land for agriculture, or public housing)?

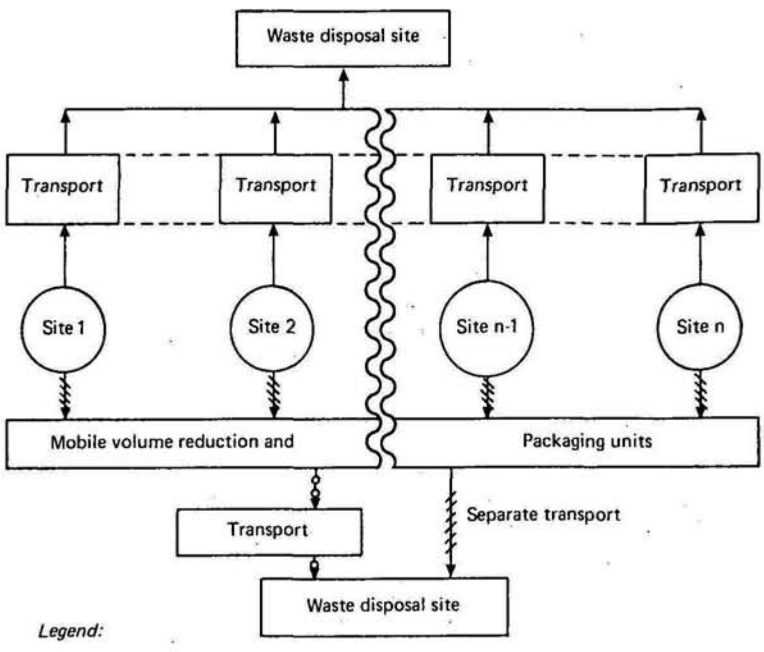
Optional systems

Of the options that could be considered for a national or regional radwaste management system, the usual one selected is for each respective nuclear power plant or other radwaste generator to arrange for and have its packaged radwaste transported to a national or regional disposal operation; for example, a land burial site.

A second option that probably would save costs, management, and risk would be for a consortium of electrical utilities (perhaps including other licensees for the possession and handling of nuclear materials) to establish a jointly owned or co-operative organization for handling and transporting the packaged radwaste to the national or regional burial operation, or to have a governmental radwaste collection agency that would provide such a service.

A third option is for the nuclear power plants to have interim storage facilities for their evaporator bottoms, ion-exchange resins, compactable and combustible radwaste, etc., which would be treated and packaged periodically by mobile units. This option would provide economies by preventing the duplication of expensive radwaste treatment and packaging facilities at each site, which are usually used only periodically, along with

Options for national or regional radwaste management system



eliminating the training, personnel, and inconvenience at each site for the periodic operations. It also would eliminate the additional element of risk that is inherent in the operation of multiple facilities (radwaste treatment and packaging in this case) for the same purpose. In other words, it probably would be a safer option. It might be especially attractive where nuclear power plants are situated on a sea coast or navigable waterway and are accessible to a large floating radwaste management facility.

A fourth option is an extension of the third option where the floating radwaste management facility, having an interim storage capability for packaged radwaste, would periodically deliver the packaged waste to a disposal site, presumably easily accessible to the floating facility. A mobile radwaste management land unit could not accomplish the fourth option for obvious reasons.

Mr N.I. Ryzhkov, Chairman of the Council of Ministers of the USSR, (left) and Dr Blix in Moscow. (Credit: APN, Moscow)