COHERENT AND CONSISTENT DECISION MAKING FOR MIXED HAZARDOUS WASTE MANAGEMENT: THE APPLICATION OF QUANTITATIVE ASSESSMENT TECHNIQUES

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ABSTRACT

This paper focuses on predictive modelling capacity for post-disposal safety assessments of land-based disposal facilities, illustrated by presentation of the development and application of a comprehensive, yet practicable, assessment framework. The issues addressed include:

- land-based disposal practice,
- the conceptual and mathematical representation of processes leading to release, migration and accumulation of contaminants,
- the identification and evaluation of relevant assessment end-points, including human health, health of non-human biota and eco-systems, and property and resource effects,
- the gap between data requirements and data availability,
- the application of results in decision making, given the uncertainties in assessment results and the difficulty of comparing qualitatively different impacts arising in different temporal and spatial scales.

The paper illustrates the issues with examples based on disposal of metals and radionuclides to shallow facilities. The types of disposal facility considered include features consistent with facilities for radioactive wastes as well as other types of design more typical of hazardous wastes. The intention is to raise the question of whether radioactive and other hazardous wastes are being consistently managed, and to show that assessment methods are being developed which can provide quantitative information on the levels of environmental impact as well as a consistent approach for different types of waste. such methods can then be applied to mixed hazardous wastes containing radionuclides as well as other contaminants. The remaining question is whether the will exists to employ them.

The discussion and worked illustrations are based on a methodology developed and being extended within the current European Atomic Energy Community's cost-sharing research program on radioactive waste management and disposal, with co-funding support from Empresa Nacional de Residuous Radiactivos SA, Spain.

INTRODUCTION

The need for safety assessments of waste management systems stems not only from the implementation of regulations requiring the assessment of environmental effects, but also from the more general need to justify decisions on protection requirements. As disposal methods have become more technologically based, through the application of more highly engineered design concepts and through more rigorous and specific limitations on the types and quantities of waste disposed, it follows that assessment procedures also must become more sophisticated. How else will the sufficiency of waste management proposals be demonstrated, relative to regulatory protection requirements and the general desire to optimize the allocation of resources?

Waste management practice in different industrial and commercial contexts has developed in a complicated patchwork, largely as a matter of historical accident. This patchwork is reflected in many countries, in the history of regulatory control and in the nature of the extent and scope of the corresponding safety assessment studies. However, more recently and to varying degrees in different countries, a more strategic attitude is being taken to environmental protection and to controls of waste management practices. Such a strategic approach requires comparisons of environmental impacts deriving from alternative management options and a comprehensive evaluation of all the impacts associated with each option. This in turn predicates the need for quantitative assessment methods. The decision maker, whether operator, regulator or a voter, needs to know what the alternatives are, how much protection he or she is getting and at what outlay.

LAND BASED DISPOSAL PRACTICE

Waste disposal practices have been broadly reviewed in Ref. (1) for all types of radioactive, toxic and mixed hazardous wastes. For that study, since toxicity is determined only in the dose, 'toxic waste' was interpreted broadly to include any kind of waste which could give rise to a detrimental environmental impact post disposal.

A variety of land-based options is practiced, including different forms of shallow and deep disposal involving different degrees of man-made or natural containment according to the geological setting and the number of and type of engineered barriers. Emplacement techniques also vary considerably, from simple tipping of trash (which nevertheless can contain significantly hazardous components) to highly controlled and engineered emplacement of radioactive waste in purpose built repositories deep underground. It is not obvious why some techniques are necessary for some wastes and not for others. For example, deep injection for radioactive waste has been abandoned, whereas it continues for other hazardous waste disposal. Some concepts are concerned with absolute containment as well as the option of retrievability. Others more readily acknowledge absolute containment as an engineering impossibility, and so involve designs ensuring that releases are delayed and occur at only slow rates, giving rise only to low environmental concentrations of contaminants, i.e., so-called dilute and disperse concepts. The timescale of operative effectiveness of the barriers also varies considerably, from very long term requirements in some concepts for radioactive waste disposal to, apparently, a need for the barrier but no time specification for its effectiveness for other types of waste disposal. A related issue is the long term management plan for completed sites. How long should monitoring be carried on and with what objectives? What post-closure management or controls should be in place? Again, considerable variations arise.

The fact that these differences in practice arise does not of itself indicate either inadequate protection or an imbalance in protection. However, as discussed more fully in Petts (2), it is in this regard that various forms of environmental, engineering and/or risk assessment have a key role to play.

ASSESSMENT REPRESENTATION OF PROCESSES

Many assessment methods have been developed and applied to the different types of disposal systems referred to above. Sometimes the focus is on a single issue, such as performance of a single barrier, for example the liner to a landfill. In other cases, some overall picture of the disposal system and its effects is provided through the assessment, as illustrated in Fig. 1 (3).

It can be argued that determining the appropriate level of detailed representation of particular processes is difficult enough, but greater concern arises about the expression of the level of confidence in model predictions due to conceptual uncertainties. Classical approaches to uncertainty analysis provide insight into the effects of parameter variation and various verification checks can be employed to check mathematical algorithms. However, other difficulties arise concerning whether the mathematical equations (to which the algorithms are applied) are sufficiently representative. For example, is an assumption of equilibrium distribution valid in the particular circumstances, or is an assumption of linear dynamics appropriate? More difficult still, are the appropriate scenarios for the evolution of the disposal system adequate? Have all the relevant degradation and migration processes been identified? How can you tell? What about the possibilities for human interference with disposal sites? Given a particular model (for example, a model approved by a regulatory authority) how much is the assessment result influenced by the user's application of the model?

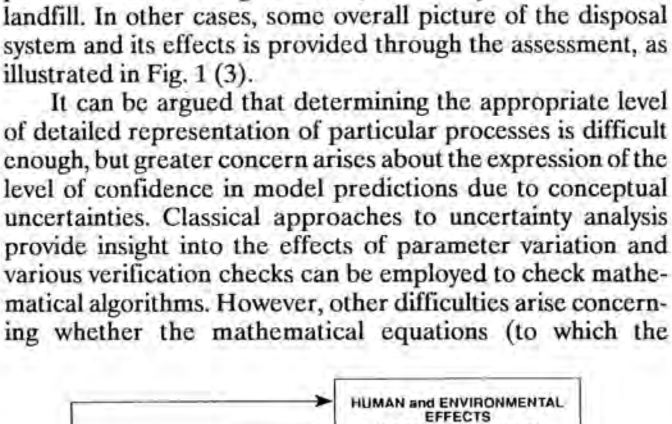

Fig. 1. Generic conceptual model of release and dispersion from a disposal facility.

These questions are intrinsically difficult to answer. The same level of detailed scrutiny is not applied to all types of disposal, and ultimately, this may not be necessary. The background justification of generic answers to these types of question is being provided in part through exercises such as those described in Refs. (4-6). However, the emphasis so far has been predominantly on radioactive wastes, and experience is still relatively limited.

ASSESSMENT END POINTS AND CRITERIA

Important among the reasons for differences in assessments is that regulatory requirements differ for different types of waste. However, it need not be assumed that existing regulations are adequate for the level of protection and types of decision that have to be made. Commonly, the types of pollution and other hazards of interest, whether to people, ecosystems or property, are hard to specify, either as criteria or as relevant end points for assessments. All sorts of queries arise, for example, as asked by EPA (7), such as how should additive risks be handled? Ranking methods can be useful but do not provide the level of quantitative information which is possible with more quantitative techniques. The advantages and disadvantages of these approaches are discussed in the context of radioactive, toxic and mixed hazardous wastes in Ref. (1) and in summary in reference (8).

DATA AVAILABILITY

One of the problem areas for any kind of assessment, but particularly if a more quantitative approach is adopted, is the availability of suitably reliable data. The number of specialized sites for radioactive waste is small compared with other types of waste disposal sites, and, for better or worse, they tend to be better characterized. Perhaps this is a reflection of the 'environmental myth' that 'if you are radioactive you are in big trouble' (9). That is, the radioactive waste sites are better characterized because it is thought they need to be.

Apart from needing data on how contaminants move through the environment and accumulate in various media such as foodstuffs, data are also required on how such concentrations affect, say, human health. Complications arise because of the different types of effect, such as acute and chronic effects, and effects which can occur with or without exceeding a threshold of exposure or dose. A valuable contribution is provided in the regular publication (10) of the Health Effects Assessment Summary Tables (HEAST). Use of these or similar tables permits the effects of different kinds of contaminants to be put onto at least some kind of equal footing, in terms of assessed impacts on human health. For other types of end point, such as may reflect a broader measure of environmental health, environmental quality standards (EQS) may be used as indicators of the actual level of impact which could occur. It is to be hoped that EQSs, as for example proposed in (11) for different media and different contaminants will continue to be developed on an even handed basis.

ILLUSTRATIVE RESULTS

The examples considered are of disposal of waste containing Fe Zn and Pb to a simple trench facility, typical of a municipal solid waste (MSW) disposal site and of radionuclides, Cs-137 and Th-230, to the same type of trench and to an engineered vault, typical of the type now used for low level radioactive waste disposal. The assessment code used is SACO, described in reference (3) and the modelling assumptions are described in detail in reference (12). The release, dispersion and exposure scenarios are illustrated in Fig. 2. The site characteristic assumptions are broadly realistic (13), but the inventory and all other assumptions are not intended to reflect any particular site or circumstances.

Table I shows the results for maximum metal concentrations in soil, water and air and compares them with corresponding EQSs. These sorts of results, compared to EQSs, are useful but provide less insight than those in Table II which shows the individual human intakes which might arise as a result of the environmental concentrations. Guide levels for intake are also shown for Pb and Zn, but it would be straightforward to apply the HEAST type data (10) to convert the intakes to health risks.

Figure 3 shows the rate of Cs-137 release from the trench and vault facilities. The advantage arising from the extra degree of containment provided by the vault is reflected in the lower and later peak release rate. (The radioactive half-life of Cs-137 is 30 y). Note, however, that the corresponding doses would not be reduced the same extent, since delay in the geosphere and accumulation of activity in biosphere compartments during the period of release are also important factors in the dose assessment. (see Fig. 2).

Figure 4 shows the annual individual dose from the Th-230 releases from the trench and vault. Th-230 has a much longer half-life but is also rather less mobile in the environment, which results in much delayed releases. The advantage of the vault in terms of reduced dose has been quantified, at least within the context of the release scenarios considered. Use of the HEAST tables would allow comparison of the health risks due to the metals with those from the radionuclides. Reference (12) provides further illustrations for other types of disposal facility and contaminants.

When comparing the impacts and interpreting the model results various factors have to be taken into account, such as the level of confidence in the model results. Where peak risks, doses or concentrations appear to be similar, then different options may be differentiated by the area contaminated, the size of exposed population, the likelihood of the release scenario and/or the time before the peaks arise. These additional factors are especially important if the end points relate to EQS quantities for different media/containment combinations which are less directly comparable. Further worked examples of this problem are provided in reference (14).

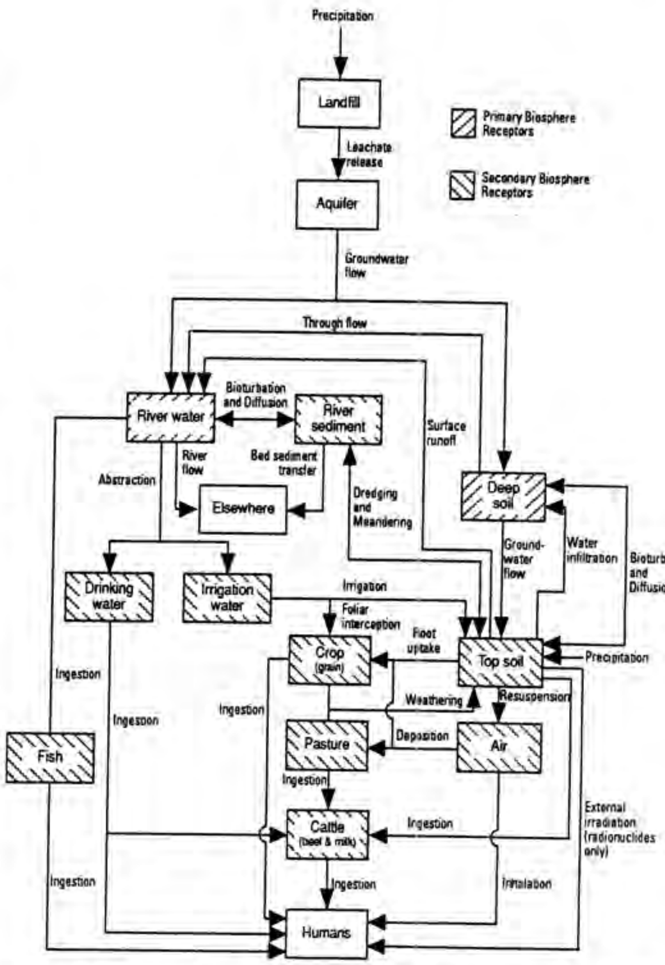

Fig. 2. Exposure scenarios analysed in illustrative calculations.

CONCLUDING REMARKS

The assessment illustrations suggest that quantitative assessment is becoming increasingly practicable for a range of waste types and that it is possible to apply a single assessment procedure to both radioactive and other hazardous wastes, thus contributing to coherent environmental and resource management. Some of the difficulties have been illustrated

TABLE I
Heavy Metal Peak Concentrations from the Trench Disposal of MSW Compared with Illustrative Environmental Quality Standards (EQSs)

	Top soil conc. mg kg^{-1}	Soil EQS mg kg^{-1}	Groundwater conc. mg l^{-1}	Riverwater conc. mg l^{-1}	Water EQS mg l^{-1}	Air conc. mg m^{-3}	Air EQS mg m^{-3}
Fe	1E-9	1E+3	2E-2	1E-11	2E-1	3E-14	1E+0
Zn	2E-6	3E+2	4E-1	2E-11	5E+0	4E-11	5E+0
Pb	3E-7	2E+3	2E-2	2E-12	5E-2	7E-12	2E-1

TABLE II
Heavy Metal Intake from the Trench Disposal of MSW

	Peak intake, mg d^{-1}	Time of Peak, y	Guide Level, mg d^{-1}
Fe	4.4E-10	1.2E+5	No level
Zn	2.0E-6	2.0E+4	1.4E+1
Pb	3.3E-10	8.0E+4	5.0E-1

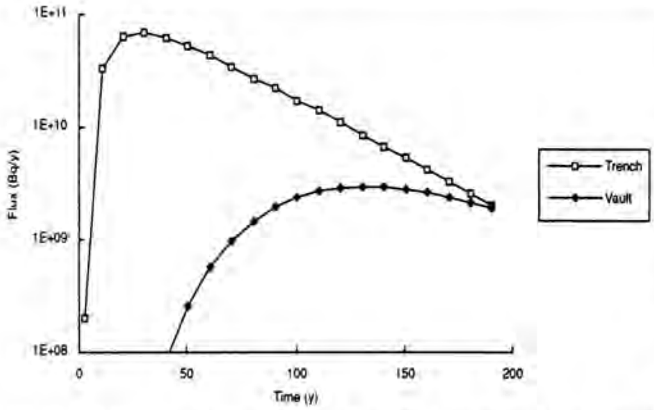

Fig. 3. Cs-137 release rate to the aquifer from trench and vault disposals.

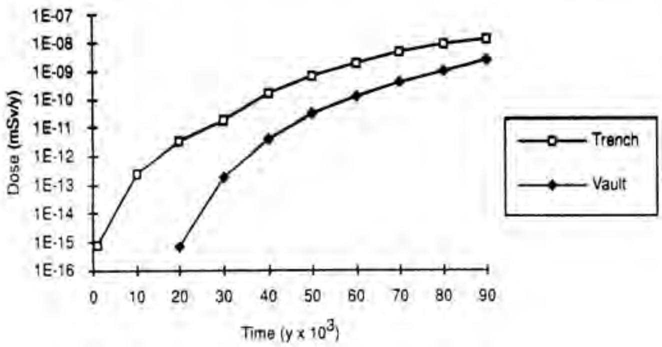

Fig. 4. Individual dose from Th-230 from trench and vault disposals.

and corresponding suggestions for their resolution can be summarized as follows.

A hierarchy of criteria needs to be developed, with general principles at the top applicable to any kind of disposal, supported by technical expressions of dose, risk and other protection objectives still of general applicability, further supported by engineering requirements and limitations which are derived from the protection objectives using assessment models applied on a waste and/or site specific level.

A wide range of improvements in the quality of data is required to improve the precision of and confidence in assessment results. Further improvements in handling and presentation of uncertainties, particularly conceptual uncertainties, are also required. As a contribution to handling conceptual uncertainties, methods need to be extended for developing release, transport and exposure scenarios representative of the long term aspects of the problem.

Assessment models and the interpretation of the results then have to be kept up to date in line with these criteria and methodological developments. Work is ongoing in these areas, and perhaps the most interesting question is when these techniques will become generally applied to support waste management decisions.

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