ON ESTABLISHING WASTE CONCENTRATION LIMITS FOR LOW-LEVEL RADIOACTIVE WASTE DISPOSAL

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ABSTRACT

Screening models are often used as a tool to obtain a conservative estimate of the potential radiological impacts of releases from a facility used for the processing or disposal of low-level radioactive wastes. Screening analyses were used for performance assessments of several U.S. Department of Energy facilities to reduce relatively large lists of radionuclides (up to 100 or more) to more manageable lists of 20 or less radionuclides for consideration in more detailed analyses. Based on the results of these calculations, the DOE's Performance Assessment Task Team has recently considered the benefits of using screening analyses in the process of determining waste concentration (or inventory) limits for LLW disposal facilities.

A number of benefits can be obtained through the use of screening calculations to establish an initial set of "trigger levels" for radionuclides at a given site. Trigger levels provide waste generators and facility operators with an indication of what constitutes a potentially significant concentration (or inventory) for a given radionuclide in a given disposal facility in regard to meeting performance objectives for protection of public health and the environment. If the concentration (or inventory) of a radionuclide in the incoming wastes is expected to be below the trigger level, then no additional calculations or data collection activities are necessary for that radionuclide. However, if the concentration (or inventory) of a radionuclide is expected to be larger than the trigger level, then more detailed calculations and (or) data collection activities would be required for that radionuclide. Such an approach emphasizes the need to clearly communicate the conservative basis for a set of trigger levels and subsequent waste concentration (or inventory) limits based on more detailed analyses.

INTRODUCTION

Screening models have been used for a number of years to obtain initial conservative estimates of potential doses to the public from facilities processing or disposing of radioactive materials. The most common use has been for assessing atmospheric releases at operating facilities; however, with the increasing efforts related to performance assessments (PAs) for design of waste disposal facilities and risk assessments for clean-up decisions at contaminated sites, broader applications for screening analyses have become apparent. The U.S. Department of Energy (DOE) Performance Assessment Task Team (PATT) has started to consider this issue with respect to PAs for DOE disposal facilities. This paper will focus on the use of screening models to establish conservative radionuclide concentration (or inventory) limits, hereafter termed trigger levels, for use by waste generators and operators at a given low-level radioactive waste (LLW) disposal facility.

The primary objectives of this paper are to discuss the benefits of using screening analyses to establish conservative trigger levels for radionuclides to be placed in a disposal facility and to present an approach for establishing the trigger levels. Another important objective is to emphasize the need for analysts and PA managers to *clearly state* the underlying assumptions for the analysis on which a set of trigger levels or waste concentration (or inventory) limits are based. Background material discussing DOE and U.S. Nuclear Regulatory Commission (NRC) approaches to PA is provided first. This is followed by a discussion of the benefits of using screening models. A third section presents example screening approaches for intruder and groundwater analyses. This is followed by a summary of the more important conclusions from the paper.

BACKGROUND

DOE Order 5820.2A requires that each site establish Waste Acceptance Criteria for materials to be disposed of in a LLW disposal facility. Typically, as part of these criteria, each site establishes concentration limits of radionuclides for acceptable waste disposal based on PA calculations. Although the current approach is logical and defensible, a more efficient approach has been considered based on experiences in PAs at DOE sites and discussions at PATT meetings. Experience has shown that the use of a screening approach increases the cost-effectiveness of PAs.

An underlying basis for the use of screening analyses is the iterative nature of PA calculations. The iterative nature of PA has been recognized in DOE requirements, DOE sponsored guidance, and NRC sponsored guidance. DOE Order 5820.2A specifically addresses the iterative nature of PA by stating that "each site shall prepare and maintain (emphasis added)" a PA for the purpose of demonstrating compliance with the performance objectives. DOE sponsored guidance (1,2) and NRC sponsored guidance (3) have also identified the iterative nature of PAs. Recognition of the iterative nature and the need to maintain a PA is a key element in the basis for the increased use of screening analyses. Use of screening analyses would help optimize the expenditure of resources and avoid unneeded efforts on evaluating trivial aspects of facility performance.

Understanding the purpose of a PA also contributes to the basis for the use of screening analyses. DOE (1) and NRC (3) sponsored guidance have emphasized that a PA is a compliance calculation, the purpose of which is to demonstrate that the potential dose will be below a given performance objective, rather than a calculation to provide best estimates of actual doses that might occur. This is an important distinction that greatly affects the manner in which a PA is conducted. Since the goal is to demonstrate that the dose is below a given performance objective, the tendency is to use conservative assumptions as long as the performance objective is met. The cost of collecting data and defending assumptions for a conservative model can be much less than for a more realistic model.

These two concepts have a large impact on the way PAs are conducted and how the results of PAs need to be interpreted. Because of the iterative and conservative nature of PAs, concentration (or inventory) limits may change over time as new data are obtained and new analyses are conducted. The fact that PAs tend to be biased toward conservative assumptions, rather than actual predictions of dose, suggests that limits based on PA results are not actually requirements that must be met to protect public health and the environment, but are targets that are very dependent on the conservative assumptions made in the PA models. Nevertheless, the public may view these as actual concentration (or inventory) limits which if exceeded would result in doses in excess of allowable levels. Benefits of using screening models and proposed approaches for screening analyses are provided in the following paragraphs.

BENEFITS OF USING SCREENING MODELS

The use of screening models to establish conservative trigger levels provides a number of benefits over the short and long term. The two items discussed in the previous section directly suggest potential benefits from a public perception perspective. If firm limits are established based on conservative models, outsiders may feel that any wastes in excess of the limits are not safe for disposal, when in reality the wastes can be demonstrated to be safe for disposal with an investment of time and funding to use less conservative assumptions. This also leads to benefits from a cost-effectiveness perspective that can also be realized by using screening models. These benefits are discussed below.

As stated previously, it is well recognized that PA is an iterative process. A logical way to conduct the iterations is to start with simple models with minimal requirements for site-specific data. In this regard, screening offers a simple and straightforward approach to obtain a set of conservative trigger levels for radionuclides. The trigger levels are used to identify which radionuclides need to be considered in more detailed analyses (i.e., the next iteration). Experience to date with PAs at DOE LLW disposal sites suggests that up to 90% or more of all radionuclides reported in waste inventories can be eliminated from further consideration using simple spreadsheet or hand calculations based on bounding values for site parameters.

Cost-effectiveness can be significantly increased by using screening calculations. As stated previously, screening calculations can remove as many as 90% of the radionuclides in an inventory from consideration in detailed analyses. The cost of conducting screening calculations is relatively small in terms of time to conduct, check, and document the calculations. Additional savings are recognized in terms of defending the results as well as obtaining data necessary to defend results. Data costs should be minimal given that very conservative assumptions are used. After the first round of screening calculations, the analyst will be able to identify the radionuclides of concern in the inventory. Thus, detailed data collection and analysis efforts will only be directed at the potentially important radionuclides.

A less tangible but critical long-term benefit relates to perception of results. A baseline set of trigger levels obtained with a clearly conservative and easy to understand model will hopefully encourage assumptions used for subsequent results to be considered more carefully. This will help to emphasize the dependence of concentration (or inventory) limits based on the more detailed calculations on the assumptions used. It is important to recognize that limits simply reflect the conditions that were modeled. For example, new containers may be developed in the future that provide a large increase in isolation capability. Limits based on calculations using assumptions for lesser containers would likely be too restrictive if the new containers were used.

The above paragraphs have identified some benefits of using screening analyses to establish an initial set of trigger levels as an interim step before setting waste concentration (or inventory) limits using more detailed calculations. Cost savings and improved efficiency are important benefits that can be appreciated by all parties, but a less tangible benefit may be more important in the long term. Given the large amount of public scrutiny to waste disposal projects, the need to clearly identify the basis for conclusions cannot be ignored. It is important to understand that limits obtained by conducting a PA usually are based on conservative analyses conducted within budget and time constraints. In many cases, some additional data collection and (or) more detailed analysis could demonstrate that it is indeed safe to dispose of larger concentrations (or inventories). However, in the interest of cost effectiveness, expenditures on additional analysis or data collection should not be made unless there is a forecasted waste form that would require a larger limit.

PROPOSED APPROACH

Performance objectives for LLW disposal facilities at DOE sites address protection of off-site members of the public, inadvertent intruders into the disposal site following loss of active institutional control, and groundwater resources. The groundwater pathway is generally expected to be the most important for off-site releases. A requirement for protection of groundwater in accordance with drinking water standards is expected to be more restrictive in regard to determining allowable releases than the requirement for protection of off-site individuals from all exposure pathways. Thus, the simplified approach discussed in this paper focuses on the drinking water pathway. Intrusion scenarios generally address exposures to average concentrations of wastes brought to the surface due to excavation of a basement into the waste or drilling a well through the waste.

The primary emphasis of the approach is the use of simplified intruder and groundwater pathway screening to identify trigger levels that result in acceptable performance without the need for any detailed analysis. Rather than limits, screening analyses would provide a set of waste concentration (or inventory) trigger levels below which safe performance is virtually assured. The derived trigger levels could be used to provide guidance for operators of disposal facilities on waste concentrations (or inventories) of any radionuclides that would require re-evaluation in a detailed PA. The primary benefit is the ability to identify readily acceptable wastes based on screening, while judging the acceptability of wastes with activity in excess of the trigger values on a generator-specific basis (i.e., inventory, waste form, and container) and avoid a large expenditure on analysis and data collection for wastes that could not contribute significantly to the overall performance of the disposal facility.

Three approaches for screening are discussed in this section. The first approach is for intruder dose analyses and the second and third approaches are for analyses of releases to groundwater. The intruder case is presented in a form such that no analyses would even be required. Early decisions on acceptability of wastes can be made based on a simple criterion. The groundwater pathway is slightly more complicated but still can be done on a spreadsheet. A number of different approaches can be used. The two approaches presented here are provided as examples. The general rule of thumb is that the approaches should require minimal data and should be unquestionably defensible in regard to the conservative nature of the assumptions used in the calculations.

Intruder Pathway

At many sites, an agriculture scenario will be used to set concentration limits for radionuclides that would provide protection of inadvertent intruders. Previous experience with PAs at DOE sites has indicated that the dose to an inadvertent intruder from any radionuclide will be a small fraction of the dose limit (generally less than 10% and in most cases much less than 10%) if the average concentration in the waste is less than 1 μCi/m^3. Thus, an initial trigger level to identify radionuclides requiring more detailed consideration for intrusion scenarios would simply be a concentration of 1 μCi/m^3.

It is important to note that the trigger level given above is an average concentration, and the facility operator can interpret the trigger level in two ways. The first and simplest option is for the facility operator to assume that this is a package limit (i.e., any packages with radionuclides present in quantities less than 1 μCi/m^3 need not be considered in subsequent analyses). A second option is to apply the trigger level to the average concentration in all waste packages. This option requires that the facility operator keep track of the concentrations in individual waste packages, but it would permit concentrations in individual packages to be above the trigger level while still not requiring more detailed analysis. In this case, radionuclides with average concentrations in all wastes less than 1 μCi/m^3 need not be considered in subsequent analyses.

The approach to screening is particularly simple for the case of intruder dose analyses, because the total dose to an intruder is just the sum of the predicted doses from all radionuclides. Thus, the sum-of-fractions rule can be applied to mixtures of radionuclides in a straightforward fashion.

Groundwater Pathway

Two general approaches essentially based on the assumption that an individual consumes 2 liters/day of pore solution in the waste are envisioned in the screening analysis for the groundwater pathway. The fundamental difference between the two approaches is the time period for radionuclide decay prior to consumption by a potential receptor. Each approach would consider a combination of inventory, half-life, radiotoxicity (i.e., the dose per unit intake by ingestion), and environmental mobility (in the form of a retardation coefficient and (or) solubility). In either approach, the results would be readily obtainable using a spreadsheet that requires minimal time to be revised for numerous radionuclides. Thus, the approaches could readily consider changes in the inventory or account for the addition of a radionuclide to the inventory.

One equation can be used to conduct the screening calculations for both approaches by using the parameter t to represent the time after disposal at which consumption of contaminated water occurs. The appropriate values for t depending on the particular approach are discussed in the following paragraphs. An equation that can be used for determining trigger levels for the groundwater pathway is:

$$T_i = \frac{D_{std}\,\theta\,R_d}{D_{ing} C_r e^{-\lambda t}} \qquad \text{(Eq. 1)}$$

where

T_i = Trigger level for radionuclide i (Ci/liter),
D_{std} = Dose limit, typically assumed to be 4 mrem/yr,
D_{ing} = Ingestion dose conversion factor for radionuclide i (mrem/Ci),
C_r = Consumption rate, 730 liters/yr,
λ = Decay constant for radionuclide i (1/yr),
t = Time at which consumption takes place (yr),
θ = Porosity of aquifer (-), and
R_d = Retardation coefficient for radionuclide i in the aquifer (-).

The first approach assumes the radionuclides are consumed at the time immediately following institutional control. That is, the entire waste inventory at 100 years is assumed to be dumped in the same volume of aquifer at the disposal site, with no releases assumed to have occurred before that time. Thus, the screening concentration in groundwater would be obtained by allowing decay for the time up to institutional control and considering solid/solution partitioning in the aquifer; e.g., t from Eq. 1 is set equal to 100 yr. Distribution coefficients or solubilities for radionuclides should be selected conservatively to ensure that the possible concentration in groundwater is bounded. Also, if multiple radionuclides are present in quantities close to but not exceeding the trigger levels, then the analyst will need to either consider the radionuclides in the next phase of the PA or provide further justification prior to not considering the radionuclides in the next iteration.

The second approach assumes that the radionuclides are consumed at the time based on the radionuclide-specific travel time to a well 100 m downstream from the facility; e.g., t from Eq. 1 is set equal to a conservative groundwater travel time multiplied by the retardation factor for the radionuclide of concern. Concentrations would be calculated in the same way as in the previous approach except for the different decay time. In this case, conservative assumptions must be made regarding the groundwater travel time and the distribution coefficients assumed for the radionuclides. Selection of a conservative distribution coefficient for determining the concentration will also result in a conservative value for determining the radionuclide travel time.

A critical consideration when specifying a delay time is defensibility and justification of the assumptions. Potential sources of delay include: institutional control, groundwater travel time, retardation, and containment by engineered barriers. The emphasis during screening should be placed on making conservative bounding assumptions for all inputs used to determine the delay time and radionuclide concentrations in the aquifer. This will be necessary because of the lack of data during the early stages of the analysis. It is also advisable because the intent of screening is to minimize the need for detailed justification and defense of models and inputs.

When using the approach based on radionuclide travel time to the downstream well, some special considerations exist. For example, for short-lived radionuclides, a larger dispersion coefficient may be more conservative, because the contaminant arrives earlier (i.e., a radionuclide may decay completely at the time of arrival for plug flow, but may not decay completely when the front edge of the dispersed plume arrives). Thus, the travel time should address possible dispersion. However, it should be noted that if a travel time based on dispersion is used, then the concentration at the front of the plume should also be adjusted for dispersion. Thus, a concentration lower than that used for a plug flow calculation should be used commensurate with the amount of dispersion assumed. Justification for a given retardation factor is also critical in this case. Daughter products are generally assumed to travel with the parent. However, the analyst will need to determine the adequacy of this assumption on a radionuclide-specific basis.

The institutional control period approach has less chance for misuse given the considerations discussed in the previous paragraph. However, the travel time based approach incorporates some features that must be addressed in the more detailed calculations. This can provide some early insight into the factors that will affect the detailed calculations. Both approaches have been used at DOE sites with success. Other approaches can and have been successfully applied. The approaches discussed in this section are provided as examples; however, selection of an approach to be used at a given site is at the discretion of the analyst. However, analysts must use caution to ensure defensibility and conservatism of results.

SUMMARY

In conclusion, it is recommended that the results of screening analyses be taken seriously. Screening analyses can be used to establish a set of trigger levels that are not intended to be limits but are intended to indicate a concentration (or inventory) above which more detailed analyses will be required to demonstrate compliance with the performance objectives for LLW disposal. Three approaches for establishing trigger levels based on the results of screening analyses were provided. The calculations are simple enough to be conducted with a spreadsheet or hand calculations.

The use of screening calculations is consistent with the iterative nature of a PA and tends to increase the cost-effectiveness of data collection and analysis in support of a PA. This is also consistent with the DOE requirement that each site must prepare and maintain a PA. Use of screening analyses may also help to place the results of PAs in better perspective. It is important to recognize that PAs are conservative by nature. Whenever limits are established it is critical to emphasize the conservative assumptions used in the calculations, and thus, the conservative nature of the limits. For example, recognition that limits are a function of the assumptions on which they are based will help people to understand that limits may change if future waste forms or containers can be shown to provide additional isolation capability for certain radionuclides.

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