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Applied Exposure Modeling for Residual Radioactivity and Release Criteria

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ABSTRACT

The protection of public health and the environment from the release of materials with residual radioactivity for recycle or disposal as wastes without radioactive contents of concern presents a formidable challenge. Existing regulatory criteria are based on technical judgment concerning detectability and simple modeling. Recently, exposure modeling methodologies have been developed to provide a more consistent level of health protection. Release criteria derived from the application of exposure modeling methodologies share the same basic elements of analysis but are developed to serve a variety of purposes. Models for the support of regulations for all applications rely on conservative interpretations of generalized conditions while models developed to show compliance incorporate specific conditions not likely to be duplicated at other sites. Research models represent yet another type of modeling which strives to simulate the actual behavior of released material. In spite of these differing purposes, exposure modeling permits the application of sound and reasoned principles of radiation protection to the release of materials with residual levels of radioactivity. Examples of the similarities and differences of these models are presented and an application to the disposal of materials with residual levels of uranium contamination is discussed.

1.0 INTRODUCTION

Modeling studies of the fate of radioactive materials released to the environment have been performed over the past forty years. Within the past decade, they have been applied to the establishment of regulatory criteria and standards. Models are a useful means for examining the consequences of the release of radioactive materials because they provide a consistent presentation of the significant release and transport mechanisms and exposure pathways affecting human health and the environment. ICRP [1,2] has provided the basis for evaluating doses on a consistent basis with the application of constant risk from exposure to radiation. This has allowed models to examine scenarios for the exposure of workers and members of the public and compare the relative doses providing a technically defensible basis for establishing regulatory standards. Maximum individual doses and collective doses to larger groups of people can be addressed by models on an equivalent basis to provide consistent levels of protection appropriate to the waste management practice being considered. Exposure models include doses received from external exposure, inhalation, and ingestion pathways and are typically tailored to the specific management practice and radioactive materials being evaluated. The application of exposure modeling to residual radioactivity and recycle provides a means for addressing many of the unresolved issues in current regulations, such as the criteria for the release of materials with bulk activity compared to those with surface activity. With a reasonable representation of the source terms, bulk and surface activity can be addressed separately and the resulting consequences evaluated on the consistent basis of potential doses to a member of the public.

Exposure models differ in the detail and depth of analysis, but all exposure models share the same basic conceptual elements. Many of these elements require the use of approximations or assumptions that limit the validity of the model for some applications. For the application of exposure models to residual radioactivity and release criteria, the identification of a dose limit is an important consideration. Without the identification of a dose limit, model results are difficult to evaluate and compare, which leads to results which are likely to be suggestive rather than conclusive. Another common element in exposure modeling is the definition of the source of radiation. Often this aspect of modeling is the most important and difficult component of the analysis. Models typically resort to some level of approximate analysis with respect to the source term that is subsequently propagated throughout the analysis. Assumptions invoked in defining the source term are typically the best indicator of the range of applications that an exposure model can be used and remain technically defensible. Having an established source term, models require the identification of exposure scenarios likely to occur as a result of the waste management practice under consideration. These scenarios are identified with the intent of encompassing potential exposures to the public and the environment in the future and are formulated with a conservative interpretation of possible events. With the establishment of the exposure scenario, the source is transported through environmental media to the point of human exposure by a modeled representation of the facility and site performance. At the point of human exposure, the concentrations of contamination are related to doses using the exposure scenarios identified. Model results alone rarely provide a definitive answer of the potential dose as compared to the prescribed dose limit because of the assumptions and approximations incorporated into the model. Consequently, interpretation of the results is necessary to support any decision resulting from the application of exposure modeling.

While exposure models all share the same basic conceptual elements, the variety of applications and different concerns addressed have resulted in a large number of models to consider in model selection. In spite of the extensive list of available models for performing exposure analysis, the existing models are of three basic types. These types can be regarded as generalized or generic models, simulation or research models, and compliance or site-specific models. Each model type has an important role in understanding the consequences of management decisions regarding radioactive materials. Generic models provide a general interpretation of potential exposures from a waste management practice and are useful in the support of rulemaking, such as the modeling used to support 10 CFR 61 [3]. Research models provide scientific estimates of the fate and behavior of radioactivity using best available scientific techniques and are useful for advancing the state-of-the-art in modeling potential exposures. Site-specific models provide conservative estimates of facility and site performance for demonstrating compliance with regulatory requirements for specific applications. This type of modeling is useful for demonstrating protection of public health and the environment when waste, facility and site characteristics are important considerations in determining the acceptability of the waste management practice. These site-specific factors frequently are critical to making decisions that are both appropriate and defensible.

Modeling potential exposure from a waste management practice provides forecasts of future consequences of the release of radioactive materials. In the evaluation of the consequences of the release of materials with residual levels of radioactivity, the potential uses of these materials following release is limitless. Once released, control is difficult to impossible to restore. Modeling can not and should not be expected to predict the future use of materials released for recycle. Since materials that are recycled will ultimately be disposed of as waste and waste may be salvaged for reuse, a conservative approach to exposure modeling that is defensible is to consider all materials with residual levels of radioactivity as wastes that are disposed of and salvaged in the future. By considering future salvage, exposure modeling needs to address the public adjacent to the disposal facility as well as an inadvertent intruder who comes in contact with the waste.

2.0 APPLICATION OF EXPOSURE MODELING TO BRC WASTE DISPOSAL

An approach to exposure modeling using generic models for BRC waste disposal has been prepared by EPA in support of the proposed 40 CFR 193 rulemaking process. The exposure model used to support the proposed rule evaluates doses in the context of risk to provide support to the selected dose limit for BRC waste disposal. In contrast to a generalized exposure model is a site-specific exposure model for a site with a defined waste stream. A site-specific model applied to the BRC disposal of uranium contaminated wastes from the Y-12 Plant in Oak Ridge illustrates the differences between generic and site-specific exposure models [4].

As a first step in defining a site-specific model, an annual dose limit of 4 mrem effective dose equivalent from all pathways was selected, which is consistent with the proposed BRC limit being considered by EPA. Since the wastes to be evaluated include only depleted uranium (0.02% U-235), modeling needs to focus on the likely pathways of exposure associated with long half-life materials where the predominant doses result from ingestion and inhalation of contaminated material. The disposal concept is to have a dedicated facility within the DOE Reservation in Oak Ridge which limits inadvertent intrusion into the waste until governmental control of the Oak Ridge Reservation is lost. Exposure modeling requires the evaluation of doses by considering concentrations of contamination; however, uranium is managed within the Y-12 Plant on the basis of activity. The management of uranium on an activity basis is important for uranium accountability requirements but necessitates the conversion of uranium activity to concentration by the use of the waste density. This conversion is not easily made since waste materials are likely to have a broad range of densities depending on the generating process. These site-specific issues and the unusual site characteristics of the Oak Ridge Reservation are not typically included in generic models. The use of generic exposure models for this application would necessitate extensive modifications to existing generic models. A more comprehensive technique for ensuring that important site-specific conditions are presented as part of the exposure model is to utilize site and facility data to define the scope and detail of the exposure model. By focusing on the known data and associated issues, site-specific analysis can become an extremely useful tool in waste management for examining alternatives and developing management practices that are acceptable to regulatory requirements and protective of public health and the environment.

Site-specific exposure modeling is typically founded on the data that are available to examine potential exposures; however, numerous assumptions are typically required to provide a complete picture of the waste management practice. Assumptions are chosen to be conservative but not all assumptions are well supported and can only be regarded as best estimates. For the application to Y-12, these assumptions are described for offsite and intruder exposure scenarios, site performance, waste form and the disposal facility. The details of the assumptions are shown in Table 1. While many assumptions are invoked the use of data is maximized. Important site-specific data are incorporated into the transport calculations that are determined from site characterization investigations of the proposed disposal site. The combination of the assumptions and data are used to define the limiting concentration of uranium in a dumpster unit that contains uranium contaminated materials and meets the prescribed dose limit. The resulting dumpster loadings and activity limits are presented in Table 2.

3.0 DISCUSSION

The preceding exposure modeling methodology illustrates the differences in detail and approach between site-specific and generic modeling. The most striking difference is the focused orientation of the site-specific analysis in contrast to the comprehensive analyses common to generic models. Emphasis is placed in site-specific modeling on those factors that are significant to the protection of public health and the environment to guide acceptable management decisions. In humid environments, where the dominant pathway for the transport of contamination is by surface water and groundwater, examination of the potential for atmospheric exposure is tangential to selecting acceptable management practices. Similarly, the consideration of decay and direct exposure from the wastes is not a major consideration for uranium contaminated wastes. Uranium contaminated wastes provide an excellent example of the usefulness of site-specific analyses because uranium is a ubiquitous element that needs to be addressed as a contaminant in the context of the increment over natural background. Additionally, the activity of uranium contaminated materials can vary widely depending on the isotopic composition of the uranium source material. Failing to consider the specific differences between the various forms of uranium can lead to widely varying results. The unique features of uranium need to be considered separately along with the unique institutional and site characteristics associated with uranium contaminated materials that could be considered for management as BRC wastes.

Exposure modeling for site-specific applications can be anticipated to yield results that are representative of the materials to be considered for release with residual levels of radioactivity. Results from site-specific analyses can be expected to yield results that differ from generalized models whenever material properties or site characteristics are unusual. Since one or the other of these conditions is commonly encountered, generic modeling results can be misleading unless the results are subjected to careful interpretation. Likewise, results from site-specific modeling need to be carefully considered against results from generic models to ensure site-specific models incorporate the significant pathways of exposure. Research models have an important role in determining the appropriateness and correctness of the simplified model components typically invoked in generic or site-specific models. Consequently, each type of exposure model has an important role in providing protection to public health and safety, and no one type of model should be ignored or excluded when considering an approach to modeling a specific disposal system.

4.0 CONCLUSIONS

Exposure modeling provides a basis for the application of sound and reasoned principles in radiation protection to the release of materials with residual levels of radioactivity. Exposure modeling supports criteria for the release of materials that are technically defensible and consistent while having the flexibility of examining specific or unique applications. As a result, exposure modeling supports rulemaking, the determination of compliance with existing rules and the improved understanding of the consequences of the release of materials with residual levels of radioactivity. By the use of exposure models, criteria can be established that define overall performance objectives with specific exemption levels defined by generic exposure models. Exceptions from specific exemption levels for unique materials or sites can be accommodated by the application of site-specific exposure modeling.

5.0 REFERENCES

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Table 1
Assumptions Applied to BRC Disposal of Depleted Uranium

Offsite Exposure Scenario
- Contaminated groundwater consumption
- Point of consumption at facility boundary
- Exposure occurs at highest concentration

Intruder Exposure Scenario
- Intrusion occurs 50 years after facility closure
- Foodstuffs consumed that are grown in contaminated soil
- Contaminated groundwater consumption
- Contaminated milk and meat are consumed
- External exposure and inhalation

Site Performance
- Dilution of leachate occurs in unsaturated zone by infiltrating precipitation
- Consumption of contaminated water occurs at the top of the saturated zone without aquifer dilution
- 50% of site surface area is dedicated to disposal
- Dilution of leachate determined by application of FEMWASTE code

Waste Form and Disposal Facility
- 50% of waste is soluble
- Release of soluble portion occurs uniformly over a 10-year period
- 50% of the leachate generated is collected by the leachate collection system
- Waste is diluted by a factor of 4 within the disposal unit by uncontaminated materials
- Waste resembles soil at the time of intrusion
- Waste and uncontaminated soil are uniformly mixed across the disposal site area upon intrusion
- Average concentrations in disposal units are the concentrations in each and every dumpster disposed of at the disposal facility
- FEMWASTE assumptions that include:
    - Leachate concentrations controlled by solubility limits
    - Kd determined by lowest experimental equilibrium value

Table 2
BRC Limits for Depleted Uranium Calculated by Exposure Modeling

Dumpster Size (Cubic Yards)	Activity (uCi)	Mass (g)
6	200	400
10	300	700
12	400	900