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PATHWAYS ANALYSES AND THEIR ROLE IN THE DECISION MAKING PROCESS FOR SELECTION OF LOW-LEVEL WASTE DISPOSAL SITES*

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PATHWAYS ANALYSES AND THEIR ROLE IN THE DECISION MAKING PROCESS FOR SELECTION OF LOW-LEVEL WASTE DISPOSAL SITES

by
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ABSTRACT

Pathways analyses have been extensively used to evaluate the suitability of proposed sites for disposal of low-level radioactive waste. The analyses rely on conservative scenarios to describe potential human exposure to the waste. Conceptual and numerical models are used to simulate the long-term transport of contamination to man and additional conservatism generally is built into the analysis when assumptions concerning future events have to be made or when uncertainties concerning site or waste characteristics exist. This conservatism is useful in ascertaining whether the site provides an adequate buffer to persons outside the site boundary. In reaching conclusions concerning site capacity and site acceptability, however, considerations must be given to the uncertainties involved in the analysis. Analytical methods to quantitatively assess the sensitivity of the results to data uncertainties may prove useful in the decision making process for site suitability.

INTRODUCTION

Both the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC) have issued regulations [DOE Orders 5480.1A and 5820, and 10 CFR 61, respectively (DOE, 1981, DOE, 1983, NRC, 1982)] for land disposal of radioactive wastes. Of particular interest for this paper are the site suitability requirements and performance objectives for disposal of low-level waste (LLW). They are essentially the same for both agencies and provide a logical basis for ascertaining the suitability of a potential LLW disposal site. New disposal sites are to be selected in compliance with applicable federal, state, and local laws, and regulations. Additional site selection criteria should address, as appropriate, the following:

(1) Size, including disposal and administrative areas, and buffer zones;

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(2) Hydrogeologic characteristics which permit disposal completely above or completely below the transition zone (the zone between the unsaturated and saturated zones) and reliable prediction and control of radionuclide migration;

(3) Potential impacts of natural hazards such as floods, erosion, tornadoes, earthquakes, and volcanoes on site performance; and

(4) Impacts on current and projected population distributions and displaced families or businesses; land use, resource development plans and nearby public facilities (i.e., parks, schools, and streets); accessibility to transportation routes, and utilities; and the location of waste generators.

Consequently, characterization of the geologic, hydrologic and geographic systems of a potential host site is necessary for analysis of the site suitability. Additionally, a buffer zone must be established within the site boundary, beyond which unrestricted public activity is allowed. The buffer zone, identified using predictions of radionuclide migration, is a three-dimensional zone outside which doses to man and radionuclide concentrations will not exceed regulatory limits. Therefore, for verification of the acceptability of a potential site, it is necessary to perform a dose-to-man pathways analysis for waste likely to emanate from the disposal facility. Pathways of greatest potential for producing high doses to man are examined in the greatest detail. Since site acceptability requires a system analysis of both wastes and site characteristics, the results can also be utilized to specify the allowable volume, radionuclide concentrations and composition of the waste that can be buried and to determine what operational controls must be maintained.

APPROACH TO PATHWAYS ANALYSES

The principal thrust of a pathways analysis is the study of the exposure pathways to man for waste disposed of at proposed sites. Pathways of most concern for land disposal sites are (1) inadvertent intrusion into the waste and its subsequent intake by inhalation and ingestion and (2) groundwater and surface water transport of leachate from the waste and subsequent use of the contaminated water for irrigation and drinking. As illustrated in Fig. 1, wind and water erosion are also processes of transit that can result in environmental exposures. The intruder pathway may occur after site closure and involve either direct contact (e.g. someone searching for artifacts) or indirect contact with the waste (e.g., agricultural activities). In general, intruder-exposure pathways depend on and limit the maximum concentration of the radionuclides in the buried waste and tend to be more individual restrictive and not site specific. Conversely, groundwater migration of leachate from the waste (Fig. 1) depends on site-specific parameters and tends to limit the total radionuclide quantity disposed of.

Two time periods are generally considered in the analyses: (1) an institutional control period (e.g., 100 years) following site closure and (2) a performance period (post institutional period) extending to

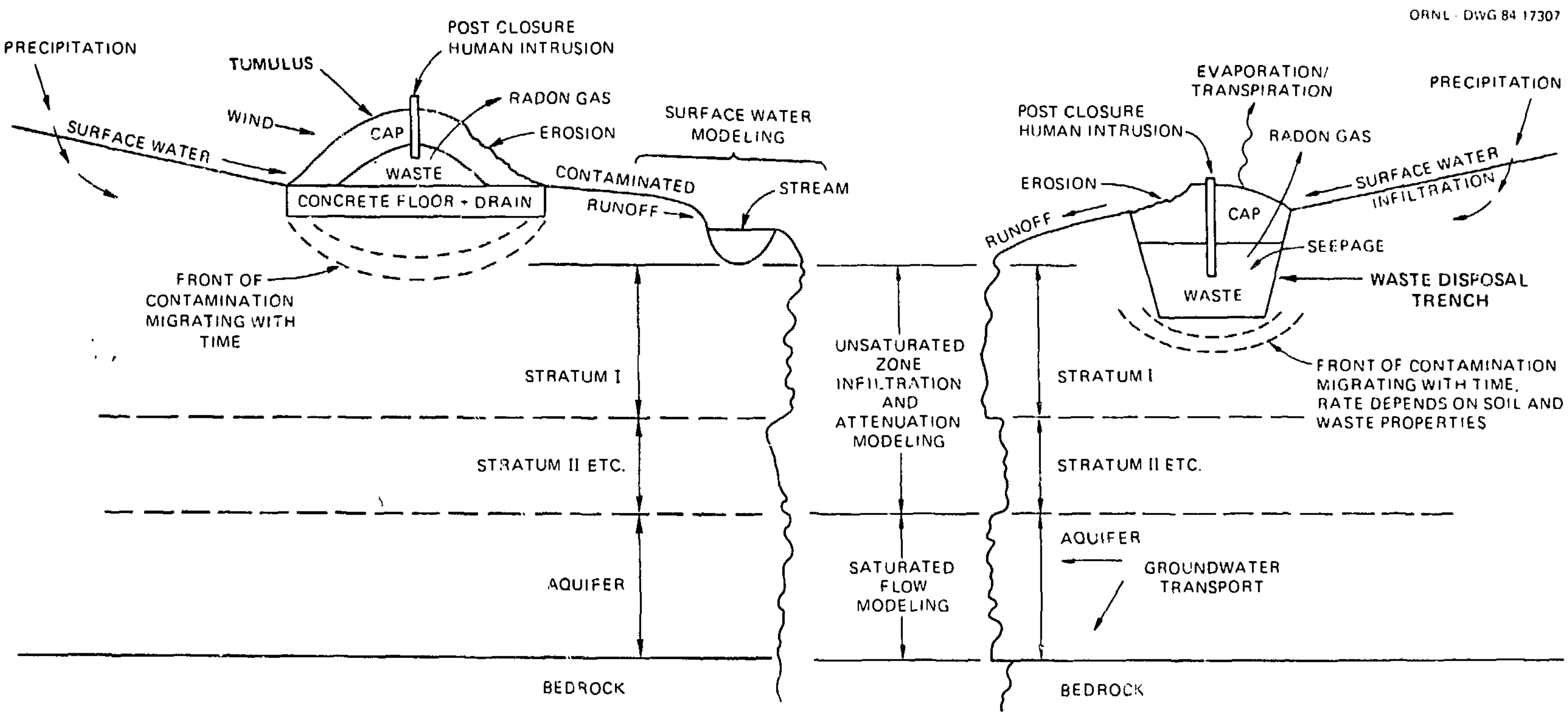

Fig. 1. Schematic of exposure pathways for shallow-land burial and tumulus-type disposal of low-level radioactive waste.

at least 500 years after site closure. Since scientific analysis cannot forecast events for such intervals, scenarios of future development are constructed to provide a basis for the analyses. During institutional controls, it is generally assumed that inadvertent intrusion can be prevented and that if public exposure occurs, it will result from off-site migration of contamination. The site is also assumed to be properly operated and maintained and to have an appropriate remedial action program so that generation of leachate would be minimal and migration of contamination into the soil would not be significant. After institutional controls, inadvertent intruders may enter the site. The analyses usually consider that an inadvertent intruder lives on the site and consumes food produced from farming activities. External and internal doses to an inadvertent intruder could result from (1) direct exposure to contaminated soils and materials, (2) inhalation of contaminated dust particles suspended in air by various activities, (3) ingestion of food crops grown in contaminated soil, and (4) ingestion of contaminated groundwater or surface water. When maintenance of the site ceases, rapid degradation of the disposal units is assumed. This would result in infiltration of water into the disposal units and saturation of a portion of the waste. Following such an event, leachate would be generated and could migrate out of the trenches into the soil. Based on site and waste characterization data, scenarios describing one or several modes of wetting events and/or generation of leachate can be formulated. The scenarios are not intended to be inclusive of all possible events but are expected to provide a conservative yet realistic representation of future events.

The site and waste characterization studies also provide data to construct conceptual models that are expected to represent the site under future conditions. The conceptual models are used to qualitatively estimate the migration of contamination and, in conjunction with appropriate numerical codes, to provide predictions of concentration of radionuclides as function of space and time. Doses to man can then be estimated using methodologies such as the one described in Adams and Rogers (1978) or Killough and McKay (1976).

Consequently, performance of a pathways analysis must include a detailed characterization of the geohydrology of the site, a detailed characterization of the waste, the development of scenarios describing future events, the development of conceptual models based on the site characterization studies, modeling of the site performance and an analysis of the dose to man receivable from the transport of contamination.

UNCERTAINTIES

The selection of and consideration given to each pathway and the calculation of the resultant dose are affected by site-specific factors and characteristics of the waste. These are fixed quantities that must be determined as accurately as possible to provide realistic input to the calculations. The comprehensive field investigations of the geology and geohydrology of the sites and the characterization of the waste provide the framework and some of the site-specific information needed for the pathways analyses. In the course of performing the analysis, however, major uncertainties concerning site-specific parameters are pointed out and assumptions concerning future events have to be made. Since the regulations require calculations of doses to man at points of maximum probable exposure, the pathways analyses generally rely on conservative approaches; that is, when site-specific information or data concerning future events are unknown or uncertain, the values of the corresponding basic parameters are chosen to maximize intake or exposure to man. These conservative approaches are useful in the decision making process for site selection since, if they result in doses to man and sizes of buffer zones that are acceptable when calculated for an extreme worst case, they determine the suitability and the acceptability of the proposed site. This conservatism, however, which sometimes leads to an overestimation of the doses to man by orders of magnitude, may be undesirable if results concerning site capacity are sought. A widely used methodology to remedy this problem consists of duplicating the numerical calculations of the analyses using different values of the uncertain parameters. This method of variation of the parameters over predetermined ranges, however, is not applicable to parameters for which uncertainties result from field heterogeneities or discontinuities. Common examples can be found in studies of contaminant migration in subsurface media that include preferential flow paths or buried channels of high hydraulic conductivity. In such media, flow and contaminant transport are controlled by the high hydraulic conductivity of the discrete permeable features, which may be several orders of magnitude greater than the mean value of the hydraulic conductivities measured at random locations in the fields. The results of analyses performed using mean values of conductivity data in such media would, therefore, be of dubious value for performance assessments and of no significance in treating the uncertainties inherent to the heterogeneity of the fields. As mentioned earlier, conservatism is built into the analyses when assumptions concerning future events have to be made or when uncertainties concerning site or waste characteristics exist. In order to reduce this conservatism, the analyses should, therefore, be coupled with in-depth quantitative analyses of (1) the probability of scenarios describing future events to occur and (2) the uncertainties involved in the analyses. The results of the pathways analyses could then be interpreted in a less restrictive manner for determining site capacity and site performance.

The uncertainties present in pathways analyses are broken down into three categories. Systematic errors arising from approximation in the conceptual modeling of the problem, modeling uncertainties arising from approximations in the mathematical description of the problem physics or engineering, and data uncertainties arising from statistical or distributional behavior of the modeling data and parameters. Uncertainties of the first two kinds are most difficult to estimate and propagate and limited theoretical help is available to avoid the use of engineering judgement. The data uncertainty area, however, can be dealt with in a systematic and quantitative way with established methods. These latter procedures are usually broken down into two steps. The first step is a sensitivity analysis to determine the important modeling parameters in a pathways problem and the second is an uncertainty assessment and propagation exercise to determine the overall pathways uncertainties arising from the most important parameter uncertainties. Several established methodologies are available for performing these studies, the two chief ones being statistical experimental designs and adjoint sensitivity theory. The statistical approach is based on the generation of systematic perturbations in the model data base and analyzing the statistical changes in model results. Adjoint theory utilizes efficient computational methods for determining model sensitivities (i.e. derivatives of results with respect to model parameters) and then approximating the functional behavior of the results through power series or interpolation schemes to estimate model uncertainties (see Weisbin et al., 1978, or Cacuci et al., 1980 for example). Both methodologies are appropriate for large-scale uncertainty analysis problems with some additional problem-dependent modifications. The methodologies have already been successfully applied to similar problems in the high-level waste isolation research program.

CONCLUSION

Pathways analyses provide useful tools for evaluating the suitability of proposed sites for hosting low-level waste disposal facilities. The analyses require comprehensive investigation of the sites. The results are useful in interpreting worst case performance of the sites for determining site acceptability and in developing design criteria for site development. However, the analyses remain conservative in nature. They require the development of scenarios incorporating conservative assumptions of future development, waste characteristics and site characteristics. The interpretation of the results for determining site capacity and site performance is complicated by the uncertainties inherent to the analysis of the geohydrologic system of the site, the geochemical behavior of the waste, and the forecasting of events hundreds of years in the future. The use of presently available analytical methods to quantitatively assess the probability of future events to occur and the sensitivity of the results to data uncertainty may prove useful in relaxing some of the conservatism built into the analyses. Future investigations should include the development and the application of such methods to pathways analyses and licensing practices.

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