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Author(s): J. R. Cochran, B. M. Crowe, F. Di Sanza

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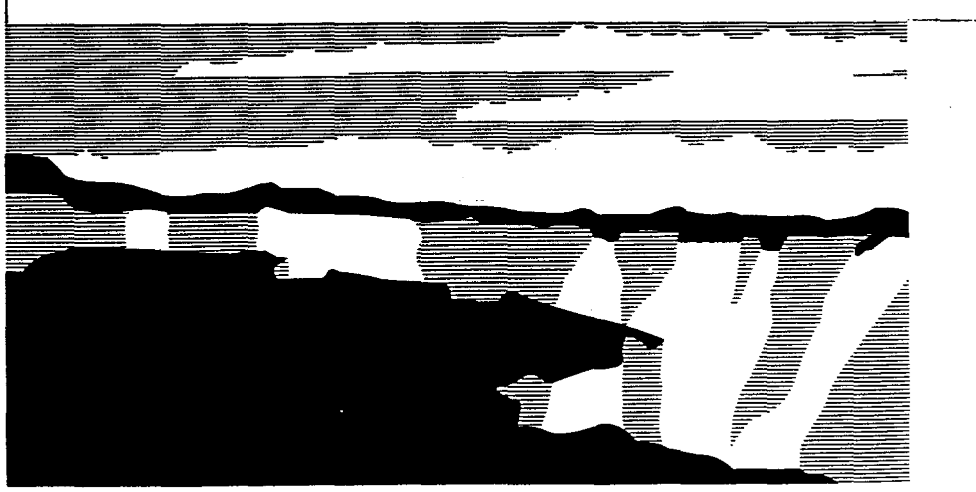

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Intermediate Depth Burial of Classified Transuranic Wastes in Arid Alluvium

John R. Cochran
Environmental Risk and Decision Analysis Department
Sandia National Laboratories

Bruce M. Crowe
Geologic Integration Group
Los Alamos National Laboratory

Frank Di Sanza
Division Director, Waste Management Division
Nevada Operation Office
U.S. Department of Energy

ABSTRACT

Intermediate depth disposal operations were conducted by the United States (U.S.) Department of Energy (DOE) at the DOE's Nevada Test Site (NTS) from 1984 through 1989. These operations emplaced high-specific activity low-level wastes (LLW) and limited quantities of classified transuranic (TRU) wastes in 37 m (120-ft) deep, Greater Confinement Disposal (GCD) boreholes.

The GCD boreholes are 3 m (10 ft) in diameter and founded in a thick sequence of arid alluvium. The bottom 15 m (50 ft) of each borehole was used for waste emplacement and the upper 21 m (70 ft) was backfilled with native alluvium. The bottom of each GCD borehole is almost 200 m (650 ft) above the water table.

The GCD boreholes are located in one of the most arid portions of the U.S., with an average precipitation of 13 cm (5 inches) per year. The limited precipitation, coupled with generally warm temperatures and low humidities results in a hydrologic system dominated by evapotranspiration.

The U.S. Environmental Protection Agency's (EPA's) 40 CFR 191 defines the requirements for protection of human health from disposed TRU wastes. This EPA standard sets a number of requirements, including probabilistic limits on the cumulative releases of radionuclides to the accessible environment for 10,000 years. The DOE Nevada Operations Office (DOE/NV) has contracted with Sandia National Laboratories (Sandia) to conduct a performance assessment (PA) to determine if the TRU wastes emplaced in the GCD boreholes complies with the EPA's 40 CFR 191 requirements.

This paper describes DOE's actions undertaken to evaluate whether the TRU wastes in the GCD boreholes will, or will not, endanger human health. Based on preliminary modeling, the TRU

wastes in the GCD boreholes meet the EPA's requirements, and are, therefore, protective of human health.

INTRODUCTION

In 1984, the DOE demonstrated the feasibility of using GCD boreholes for disposal of high-specific activity LLW at the DOE's NTS. After that demonstration, eight additional GCD boreholes were used for emplacement of difficult radioactive wastes, including TRU wastes which are classified for national security reasons. This paper describes DOE's actions undertaken to determine whether or not the TRU wastes in the GCD boreholes will endanger human health. These actions are described under the topics of: site setting; disposal history; performance objectives; treatment of uncertainty; PA model; and preliminary modeling results.

SITE SETTING

The GCD boreholes are located at the Area 5 Radioactive Waste Management Site (RWMS) in the southeastern part of the NTS (1). The following section describes the "undisturbed" conditions at the Area 5 RWMS, where the average precipitation is 13 cm per year (5 inches per year). Based on 30 years of record keeping, 23 cm (9 inches) of precipitation was received in the wettest year and 2.9 cm (1.1 inches) was received in the driest year.

The Area 5 RWMS is founded in the thick, arid alluvium of the Frenchman Flat topographic basin. Based on measurements from a number of characterization wells, groundwater is approximately 235 m (775 ft) below the land surface (2). The limited precipitation, coupled with generally warm temperatures and low humidities, results in a hydrologic system dominated by evapotranspiration. The movement of water within this 235 m (775 ft) thick unsaturated zone can be subdivided into two zones, the near surface zone and the deeper zone.

The near surface zone is the hydrologically "active" region of the unsaturated alluvium. In the near surface, precipitation is pulled downward by gravity and is either aided or resisted by the capillary tension of the soil (depending on the moisture content and textural properties of the soil). The forces acting to remove the moisture include evaporation and plant root uptake. Based on a number of field studies, the balance of these forces is such that only the upper 1 m (3 ft) is hydrologically active, and aerially distributed infiltration never infiltrates deeper than 1 m (3, 4). The *average* volumetric moisture contents in the near surface zone are very low, ranging from 1% to 3%.

Under current climatic conditions, water soluble constituents, such as chloride, are carried downward by infiltrating moisture, only to be deposited at 1 m (3 ft) depth, as the infiltrating moisture is removed by evaporation and plant uptake. This process (a) moves water soluble constituents to the lower boundary of the near surface zone, and (b) provides a marker of the depth of infiltration. The bottom of this zone can be thought of as a "no-flux" liquid phase boundary based on the net effect of this transient cycling.

A number of plants have adapted to the arid climate of the desert southwest. These plants are able to rapidly capture infiltrating moisture and then hold that moisture through long dry periods. In addition to capturing soil moisture, plant roots also absorb minerals and heavy metals, carrying those minerals and metals to the plants above ground biomass. A plant uptake model which reflects rooting depths, biomass turnover and the ability of plants to uptake radionuclides has been drafted (5). This plant model presents modeling factors for both the current plant community and for the plant community that could exist if a wetter and cooler climate returns to the Area 5 RWMS.

In addition to plants, rodents, invertebrates, and reptiles burrow into the deserts soils to seek refuge from: temperature fluctuations; the dry, desiccating environment; and predators. Burrows can also function as routes taken in foraging activities and as storage areas for surplus food. All of these activities have the potential to transport contaminated soil from the subsurface to the surface. A draft model has been proposed to address the effect of bioturbation on the movement of TRU radionuclides from the GCD boreholes (6). Bioturbation and plant uptake occur primarily in the near surface vadose zone, although both process can move limited amounts of radionuclides from the deeper vadose zone.

The deeper vadose zone is hydrologically inactive. The volumetric water content in the deeper zone is approximately 8% to 13% (2). These low-volumetric water contents impede the flow of liquid by significantly reducing the hydraulic conductivity. Between a depth of 1 to 35 m (1 to 115 ft), the alluvium shows decreasingly negative matric potential with depth (for example, (-) 10 bars at 50 m depth and (-) 75 bars at 5 m depth), indicating a steady and *very slow upward flux of pore water,* i.e., there is no groundwater recharge.

A static zone where the hydraulic gradient is negligible exists between approximately 40 to 90 m (120 to 300 ft) and from 90 to 235 m (300 to 775 ft) very slow gravity drainage is still occurring. Detailed discussions of the deep vadose zone are presented in Shott, et al. (4).

Because infiltrating moisture is recycled in the near surface, moisture movement in the deeper vadose zone is controlled by long-term climatic and geologic processes. The rates of moisture movement in the deep vadose zone are far too slow to be measured. However, studies of the concentrations of natural environmental tracers allows quantification of the movement of water in the deep vadose zone.

Tyler, et al. (3) used concentrations of stable chlorine, chlorine 36, deuterium and oxygen 18, as well as carbon 14 dating (a) to estimate the rates of movement of soil water and (b) to reconstruct the water infiltration history at the Area 5 RWMS. As a simplification, the climate was much wetter and cooler 120,000 years ago and the water table received aerially distributed recharge. Subsequently, recharge significantly decreased, or ceased. Then, from 50,000 to 20,000 years ago, the climate was wetter and cooler, resulting in recharge to the water table under surface water drainage features. Aerially-distributed precipitation has not reached the water table in the past 120,000 years. A more xeric environment now exists, and the drying of the land surface is pulling moisture from depth, resulting in the *very slow upward flux of pore water* evidenced by the soil matric potentials.

To assess the potential impact of climate change, Sandia examined past global, regional, and site-specific empirical records of proxies of past climatic conditions (7). The records of the isotopic oxygen composition of marine sediments (8), and thick ice deposits (9) provide global scale evidence of past climatic conditions. Studies of the isotopic composition of calcite deposits in Nevada's Devils Hole spring (10, 11) provide a 500,000 year record of past climate conditions in the southwestern U.S., and finally, studies of paleo vegetation from pack rat middens (e.g., (12)) allow the reconstruction of past climatic conditions at the NTS.

There is very good agreement between the global ice core records, the regional Devils Hole record, and the local pack rat midden records (e.g., Figure 16 of reference (7)). All of the records showed a cyclic pattern of climate change in which the climate varies between relatively persistent glacial climates (cooler, wetter periods) separated by interglacial climates (warmer, drier periods) of relatively short duration. At the Area 5 RWMS, cooler and wetter equates to 3 to 5 C cooler, with an average precipitation of 25 to 30 cm (10 to 12 inches).

The cyclic nature of past climatic conditions is solidly supported by a large number of studies of many different physical phenomena. However, the low resolution of some of the proxy records and the natural variability in the length of the climatic cycles does not allow a accurate estimation of the time when the climate will return to the more dominant, cooler, and wetter conditions.

The accumulation of anthropogenically-derived carbon dioxide (a greenhouse gas) may alter near-term climatic conditions. The effects of anthropogenic climate change were assess for the near-by Yucca Mountain facility using an expert elicitation and it was concluded that anthropogenic climate change will have a negligible impact at the NTS (13).

For the PA, it is assumed that the past climatic conditions can be used to estimate future conditions and responses. Based on this assumption, it was concluded that (a) it is not possible to rule out a return to cooler and wetter conditions over the next 10,000 years, and (b) there is significant uncertainty in the timing of the return to those conditions.

The GCD boreholes are co-located with the LLW trenches in the Area 5 RWMS. Subsidence of those trenches is expected, and will, at a minimum, alter the movement of water in the near surface. Sandia is currently analyzing the movement of water in the vadose zone, given subsidence, precipitation, and assuming a return to cooler and wetter climatic conditions. Some combination of conditions might lead to groundwater recharge -- if so, the PA model will be modified to included the effect of those conditions on overall performance.

DISPOSAL HISTORY

In 1981, the DOE's Defense LLW Management Program asked DOE/NV to demonstrate the feasibility of using GCD boreholes for disposal of high-specific activity LLW (i.e., waste packages containing large amounts of tritium). This disposal method consists of boreholes approximately 3 m (10 ft) in diameter and 37 m (120 ft) deep. The bottom 15 m (50 ft) is used for waste disposal and the upper 21 m (70 ft) is backfilled with native alluvium. The GCD concept was so named because it provides greater confinement than shallow land burial (14).

The first borehole, the GCD Test (GCDT) borehole, was constructed in 1983 (15). GCDT was augured, instrumented, loaded with wastes, and monitored in order to test the GCD disposal concept. The tests consisted of burying 500,000 curies of heat-producing cesium and strontium with 700,000 curies of tritium and measuring the releases of tritium, and other factors.

These tests were judged to be successful (16, 17) and twelve more boreholes were augured and used to dispose of additional radioactive wastes including TRU waste. Boreholes 1, 2, and 3 contain TRU wastes from nuclear weapons accidents and borehole 4 contains waste materials from nuclear weapons production or disassembly. In total, about 38,000 kg (40 tons) of TRU wastes, containing less than 6 kg (13 pounds) of plutonium 239 were buried in the 4 boreholes. All of the TRU wastes emplaced in the GCD boreholes are classified for national security reasons and therefore, do not meet the waste acceptance criteria for the proposed Waste Isolation Pilot Plant (WIPP).

PERFORMANCE OBJECTIVES

At the time of emplacement, DOE-titled TRU waste was governed by Chapter II of former DOE Order 5820.2. That DOE Order defined two options for disposal of TRU wastes that could not be certified for disposal in WIPP; (1) storage or (2) "*...disposed by greater confinement...*" (DOE 5820.2 II 3. C. (3), emphasis added).

In addition to requiring disposal by greater confinement, Chapter II of DOE Order 5820.2 also required that TRU waste disposal systems must meet the EPA's requirements for disposal of TRU wastes which (in this case) is the 1985 version of 40 CFR 191 (18). DOE/NV contracted with Sandia to conduct a technical analysis or PA to determine if the TRU wastes emplaced in the GCD boreholes meet the requirements set forth in the EPA's 40 CFR 191. 40 CFR 191 includes four sets of requirements: Containment; Assurance; Groundwater Protection; and Individual Protection.

Containment Requirement (40 CFR 191.13) The disposal system shall provide the **reasonable expectation**, based on a PA, that the cumulative releases of radionuclides **to the accessible environment** for 10,000 years after disposal from all significant processes and events shall:

(a) have a likelihood of less than one chance in 10 of having an EPA Sum greater than

one, and
(b) have a likelihood of less than one in 1,000 of exceeding an EPA Sum of 10.

The EPA sum is the ratio of the calculated, commutative releases (the calculated, total curies that move through the controlled area boundary in 10,000 years) divided by the number of curies set by the release limit. The release limit is taken from a table in the back of 40 CFR 191.

Assurance Requirement (40 CFR 191.14) The Assurance Requirements state that the DOE must: maintain active institutional controls; monitor the disposal system; and undertake other actions related to closure. The purpose of the Assurance Requirements is to provide confidence and defense in depth that the Containment Requirement will be met. Demonstrating compliance with the Assurance Requirements is not addressed in this paper.

Individual Protection Requirement (40 CFR 191.15) The disposal system shall provide a reasonable expectation that, for 1,000 years after disposal, **undisturbed performance** of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public **in the accessible environment** to exceed 25 millirems to the whole body or 75 millirems to any critical organ.

Groundwater Protection Requirement (40 CFR 191.16) - Disposal systems shall be designed to provide a reasonable expectation that, for 1,000 years after disposal**, undisturbed performance** of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of **a special source of ground water** to exceed standards defined in the regulation.

The EPA defines several terms used in 40 CFR 191:

- *Accessible environment* is defined as the atmosphere and the lands surface and all of the lithosphere that is beyond the controlled area;
- *Controlled area* is defined as (1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and **extends horizontally no more than five kilometers in any direction** from the outer boundary of the original location of the radioactive wastes in a disposal system; and (2) the subsurface underlying such a surface location; and
- *Undisturbed performance* is defined as: the predicted behavior of a disposal system, including consideration of the uncertainties in the predicted behavior, **if the disposal system is not disrupted by human intrusion** or the occurrence of unlikely natural events.

In this paper we present preliminary results relative to the probabilistic Containment Requirements and the dosed-based Individual Protection Requirements of the Standard.

TREATMENT OF UNCERTAINTY

The processes and events that could affect the movement of radionuclides over the next 10,000 years are uncertain. Therefore, a general framework for incorporating uncertainty into the PA for the TRU wastes in the GCD boreholes has been developed (19). Fundamental to this methodology is the philosophy that PA models are not a prediction of how the system will respond. Rather, they provide simulations of a range of plausible outcomes given a state of knowledge. These simulations provide information for decision-making and are consistent with the EPA's requirement of a "reasonable expectation" of future performance.

Three principles of this framework are: (1) if more than one possible interpretation of the system can be justified, consider each interpretation and focus resources on those interpretations that may compromise the disposal system; (2) parameter uncertainty is addressed by including the unbiased range of possible parameter values; and (3) proceed in an iterative fashion.

PERFORMANCE ASSESSMENT MODEL

Based on the geology, biology, climate, and undisturbed hydrology of the Area 5 RWMS, the processes which are modeled include: diffusion of gaseous radionuclides; upward liquid-phase advection; dispersion and diffusion of solutes in the pore water; plant uptake; bioturbation; adsorption; precipitation; and radioactive decay and production. The effects of climate change are included by assuming that the past climatic conditions and the responses to those conditions can be used to estimate future conditions and responses. Inadvertent human intrusion is addressed in the PA, but is not discussed in this paper.

The PA uses a number of simplifying assumptions to facilitate numerical modeling of the disposal system's performance. Within the overall system, each simplifying assumption is made to either match or overestimate the expected performance. For example, a number of years, or centuries will be required for the waste contains to decompose in the arid soil of Frenchman Flat. Rather than attempt to model this decomposition, the model assumes that the waste containers do not exist, and that the waste is immediately available for transport in the alluvial pore water. Thus, the modeled release of radionuclides to the pore water overestimates the actual performance (which involves the breakdown of containers before release to the pore water can occur).

For the undisturbed conditions, radionuclide movement is modeled as one-dimensional upward via advection, diffusion, dispersion, plant uptake, and bioturbation. Steady-state movement through homogeneous and isotropic alluvium is assumed. Conceptual model uncertainty is addressed using alternative conceptual models. Monte Carlo analysis and probability density functions are used to capture parameter uncertainty and variability. The conceptually simple transport processes are modeled using an EXCEL (TM) spreadsheet and code written in Visual Basic (TM). This model calculates the movement and cumulative releases of 19 different radionuclides over a 10,000-year regulatory period, along with the associated EPA Sum and resultant Complementary Commutative Distribution Function (CCDF) as described in 40 CFR 191 and it's A, and B Appendices.

For the dose assessment, the member of the public (MOP) is assumed to live in a house near all four boreholes. Drinking water is taken from the aquifer that is in the accessible environment (i.e., 5 km from the disposal site). The MOP has a garden which is also near the boreholes. Leafy vegetables, root vegetables, fruits, grains, and hay are grown in the garden. The hay and some of the grain are used to feed chickens and cows that produce poultry, eggs, beef, and milk that the MOP consumes.

Contamination of the garden soil occurs as radionuclides are transported in the wind from the ground surface above the boreholes to the nearby garden. As a simplifying and conservative assumption, all radionuclides released to the ground surface over 1,000 years accumulate and are transported to the garden.

PRELIMINARY MODELING RESULTS

The full PA model is near completion. For the natural system, all processes have been included in the model except for bioturbation. The effects of subsidence of the LLW trenches on the movement of water in the vadose zone is being investigated. If subsidence alters the vadose zone processes, the PA model will be modified to reflect the "altered system." The effects of both bioturbation and subsidence are anticipated to be included in the full PA in FY 1999.

To demonstrate compliance with the EPA's Containment Requirements, the modeled EPA Sums are plotted against their complementary cumulative probabilities. Recall that the EPA's Containment Requirements state that the cumulative releases of radionuclides to the accessible environment for 10,000 years shall:

(a) have a likelihood of less than one chance in 10 of having an EPA Sum greater than one, and

(b) have a likelihood of less than one in 1,000 of exceeding an EPA Sum of 10.

The EPA Sums from the TRU wastes buried in the GCD boreholes do not exceed the EPA's probabilistic standards, as presented in Figure 1.

Figure 1 also presents an example of the distribution of possible doses to a MOP in the accessible environment. All doses are less than 0.03 mrem per year and the mean dose is about 0.0005 mrem per year. Both the mean and the highest doses are far below the regulatory standard of 25 mrem per year. Base on these preliminary results, GCD facility may meet the EPA's standards for disposal of TRU wastes and would therefore be protective of human health.

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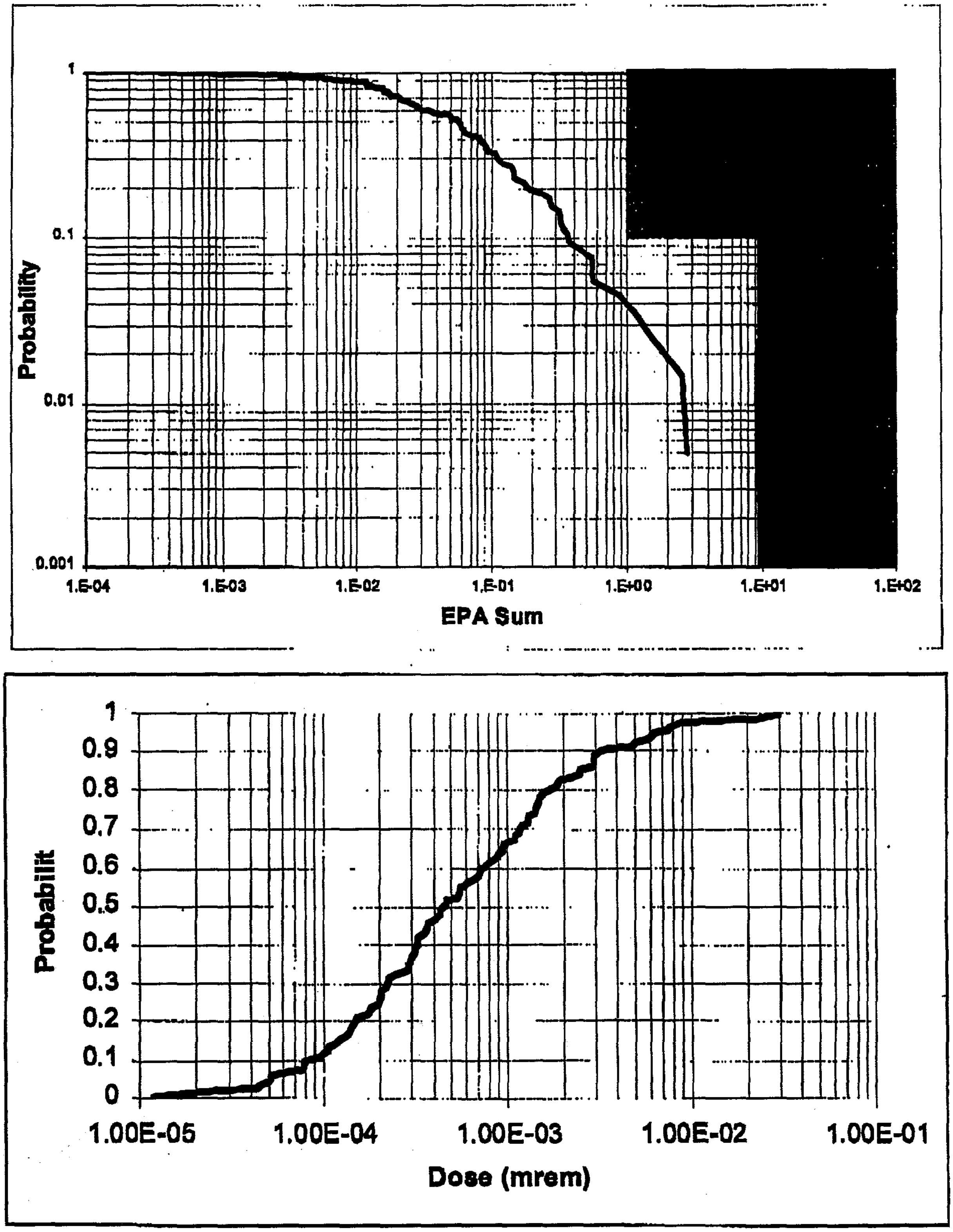

Figure 1 - Example of Performance - Complementary Cumulative Distributions of both the EPA Sums and Doses to a Member of Public