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Risk computation for environmental restoration activities

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Abstract

Environmental restoration activities planned by the U.S. Department of Energy (DOE) and other agencies will require consideration of long-term environmental and public health risks. These restoration activities will require risk computations capabilities in support of baseline, remediation, and residual risk assessments. During the initial stages of problem characterization, risk screening approaches are useful; then, as more data become available, more detailed risk evaluations are appropriate. While a wide variety of models address specific site characteristics, transport media, and impact type, only a few models address the broad range of long-term public health issues encountered in environmental restoration activities. One such model, the Multimedia Environmental Pollutant Assessment System (MEPAS®) (© Battelle Memorial Institute, 1989, 1993), integrates radioactive and hazardous materials risk computations for major exposure routes via air, surface water, groundwater, and overland flow transport. By considering a broad range of potential environmental issues, models such as MEPAS can be used to help prioritize potential environmental problems. An illustrative application is described involving relative risk-based evaluation of the mixed waste in underground tanks. The results provide an indication of (1) the relative importance of each of the constituents from a public-health standpoint, and (2) the sensitivity of those rankings to important input parameters.

1. Introduction

Environmental and public health risks are being considered as part of environmental restoration activities planned by the U.S. Department of Energy (DOE) and other agencies. Remedial action activities covered under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) include consideration of environmental and health risks. The remedial action process starts with problem identification and leads to final cleanup activities. Risk is evaluated in each stage of this process. In the early stages, a baseline risk (i.e., which risks could occur) must be defined. During selection of a remedial action, candidate remedies are compared with the risk

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baseline in terms of residual long-term risks, short-term occupational and public health risks, and potential risks if the remedy fails. Reasonable future land uses are considered for the long-term risks.

Perhaps because the modeling integrates information from other risk assessment activities, risk assessment is sometimes (incorrectly) equated to risk computation. Risk computation is the step in risk assessment that combines information to provide a quantitative estimate of risk.

Actual and potential risks to the environment will need to be estimated for proposed environmental restoration activities. For cleanup efforts, these efforts will need to address public health and environmental risks for baseline, remediation, and post-remediation activities. The baseline and post-remediation impacts are evaluated as long-term chronic risks. The remediation impacts can involve both long-term chronic and short-term acute risks (accidental releases to public and work).

Risk evaluations are required at all stages of site cleanup. Computer models provide a consistent means of estimating risks using available information. A number of computer models are currently used to estimate risks related to environmental restoration activities at sites contaminated with hazardous wastes. This paper describes the role of one of these risk computation models, the Multimedia Environmental Pollutant Assessment System (MEPAS).

Figure 1 illustrates the ranges of risk computation applications involved in various stages of cleanup. Although the computational requirements for estimating levels of risk tend to be less at earlier stages, the uncertainty tends to be greater. As the stage of cleanup progresses, improved site characterization data should reduce the uncertainty in input parameters, and therefore, reduce

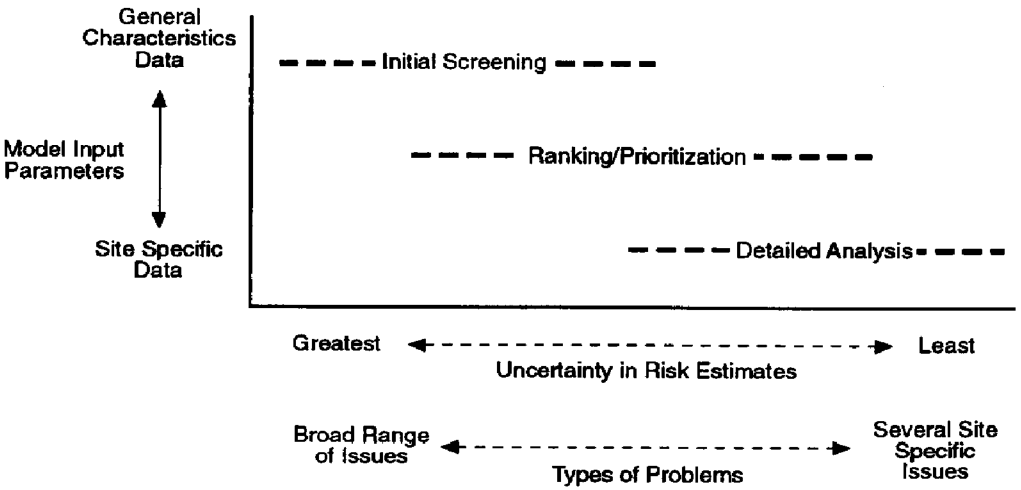

Fig. 1. Risk computation stages for environmental restoration.

the overall uncertainty in the estimated risk values. To provide this improvement, risk computation models need to be able to use available site data.

Initial screening efforts often involve qualitative assessment such as a questionnaire approach. Spread sheets, risk computation codes, and statistical programs on desktop computers are popular for intermediate efforts, which often involve ranking/prioritization of potential problems. The final detailed analysis efforts often require high-performance computers to simulate environmental transport and fate of the major problems at specific sites.

The requirements of a ranking application largely defines which models are appropriate. The selected model(s) must be able to address what is often a broad range of potential problems. Environmental releases can be to air, ground water, surface water, and soil. Effects of either, or both, radioactive materials and hazardous wastes may be involved. For hazardous wastes, carcinogenic and noncarcinogenic impacts may need to be included. For each of these, the major pathways for exposure will need to be defined and evaluated.

One approach to addressing a broad range of issues is to use a suite of different models. Although this approach has the advantage of allowing use of models specifically designed for various issues, this approach has several major drawbacks. Expanded resources may be required to run different models for different issues and differences in computed risks can be the result because of incompatibility between the different models.

When faced with the need for the risk-based prioritization of a large number of potential problems, the approach taken by the DOE was to develop a single "model" [1–3] for addressing a broad range of issues. The result was the MEPAS code; a collection of models based on standard computational methods for various environmental media that are integrated into a single system. The use of a single integrated system overcomes the problem of additional effort and inconsistencies because of fragmentation associated with using a suite of different models.

The MEPAS code was designed for the intermediate efforts shown in Fig. 1. By addressing a broad range of environmental problems with a uniform level of detail in a single system of models, MEPAS allows relative comparisons of risks across media, types of impacts, release sites, time, and space. MEPAS is not designed to replace detailed assessment tools but rather provide a means of directing detailed assessment efforts to allow focus on the most important potential problems.

2. MEPAS Overview

MEPAS was developed for the DOE by the Pacific Northwest Laboratory. MEPAS is based on standard physics-based risk estimation methods involving source-term, transport, exposure, and consequence models [2, 3]. These MEPAS models are configured to do site-specific assessments using readily available information. A design requirement was that detailed guidance be provided for estimating site-specific values for each and every input value.

These MEPAS models address a range of environmental problems using air, groundwater (vadose and saturated zones), surface water, overland, and exposure computations. The major components and their linkages are shown in Fig. 2. Whenever available and appropriate, U.S. Environmental Protection Agency (EPA) guidance and models are used to facilitate compatibility and acceptance.

Each of the major MEPAS models underwent a "reality" check as a model performance verification. By comparing model outputs with monitoring data and other modeled values, the ability of the models to reasonably simulate the fate and transport processes was demonstrated [4].

Although based on relatively standard transport and exposure computation approaches, the unique feature of MEPAS is that these approaches are integrated into a single system. Risk values are computed using a consistent approach for chemicals and radioactive carcinogens. Hazard quotients, based on reference doses, are computed for noncarcinogens. By using consistent approaches for potential problems [1, 3] along with detailed model application guidance [5–8], the effects of model and application differences on risk values are minimized. The use of a single system provides a consistent basis for evaluating health impacts for a large number of problems and sites.

MEPAS provides the standard means of using what is known about a site to estimate risk, or potential risk values. Following EPA guidance, the "best" of these means should be used for each situation. If exposure concentrations are known from monitoring, the risks can be computed directly. If intermediate environmental concentrations are the best information, then these data can be

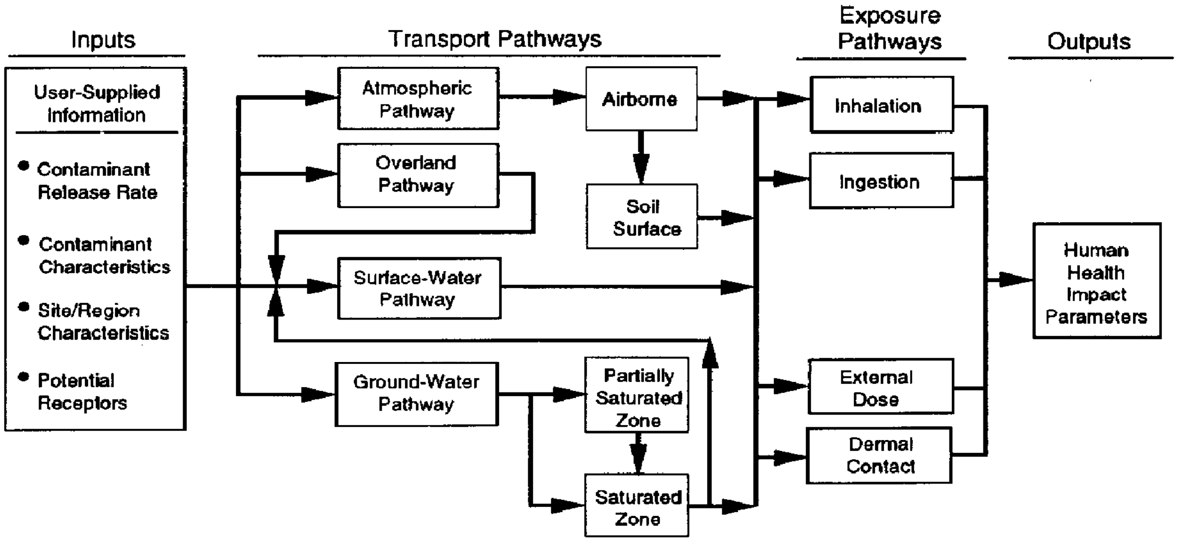

Fig. 2. MEPAS transport and exposure pathways.

used to estimate risks at other points in the environment. If the source information provides the best characterization, then risks can be estimated that result from emission and transport of materials. The user is given the flexibility of using the build-in models, their own models environmental computations, or monitoring data.

When ranking or comparing different sites using computed risks, it is essential to consider the inherent uncertainty in the computed risk values. Although single-value deterministic approach can rank problems in broad groups separated by many orders of magnitude in risk, a ranking of risks closer in magnitude requires consideration of the inherent uncertainty. For such applications, a MEPAS sensitivity module is available for analyzing the uncertainty in the risk values associated with the input parameters. This recently added module, which allows multi-variate sensitivity studies using latin-hypercube sampling, was not used in the single value sensitivity studies described later in this article.

No model is appropriate for all situations. Although MEPAS is designed to cover a range of problems, that does not automatically make it the best tool for all applications. MEPAS is of particular interest in programmatic risk computation, multiple-issue applications. MEPAS is a tool to assist in directing resources to the problems for which additional studies should be conducted. Depending on the specifics of the situation, these studies may involve activities such as more detailed fate and transport modeling, site characterization, environmental monitoring, uptake rates, and toxicity definition.

Implemented on a desktop computer as IBM PC-DOS compatible software, there have been three major releases of MEPAS. The first release, MEPAS 1.0, was used in the preliminary DOE Environmental Survey effort [2]. The second release added a user-friendly shell. The other major difference between these first two versions was the shift from a single measure of risk [7] to multiple measures of risk [9]. MEPAS 1.0 provided a single discounted population-based measure of risk whereby MEPAS 2.0 expanded the outputs to include additional population risks, maximum individual risks, environmental concentrations, and time of impact. Both these versions were designed for baseline risk computation applications.

The most recent release of the MEPAS software, Version 3.0, represents a major update with expanded functionality for remediation applications. The emission updates include a multimedia mass partitioning module, a revised set of models for volatilization, and remedy-specific release modules. Functionality is added to the emission and transport codes to allow direct evaluation of the potential risk reduction from various remedies. Flexibility is added to allow the user to incorporate specific regional guidance for risk computations. Exposure computations have been upgraded to conform with the most recent EPA guidance. These upgrades have all been incorporated in a new user-interface specifically designed for remediation applications.

MEPAS has been applied to the evaluation and comparison of risks from both active and inactive operations. These studies range from the comparison of many different sites to site-specific studies. These diverse applications illustrate the range of possible useful applications. Studies considering multiple sites are described by Whelan et al. [10]. A site-specific study conducted for the mixed waste in a set of underground tanks at Hanford [11, 12] is described below.

3. Mixed waste risk-based ranking

This study was an initial evaluation of the relative importance of constituents potentially stored in underground single-shell tanks (SSTs) at the U.S. Department of Energy's (DOE) Hanford Site located in south-central Washington State. Single-shell tanks contain chemical and radioactive mixed waste from past Hanford operations related to handling and processing nuclear materials.

This risk-based constituent analysis was undertaken several years ago to provide input to design the characterization plan for these underground single-shell storage tanks [11]. The high costs associated with analyzing samples combined with the wide range of materials potentially in these tanks made designing the characterization plan a difficult task. It was felt that risk-based information on the relative importance of these materials would be useful information to help in the design of a characterization plan.

3.1 Approach

This study considered predictions of potential human health impacts as the result of groundwater transport of radioactive and nonradioactive hazardous constituents. These predictions, which provided a means of ranking the relative importance of the constituents, were generated using a preliminary characterization of possible SST constituents, simplified estimates of constituent release rates and environmental transport, a hypothetical usage location, and a standard exposure scenario for Hanford.

The list of possible SST constituents includes those of concern in terms of potential health and regulatory considerations. From a base list of 68 radioactive constituents predicted by the Tracks Radioactive Constituents (TRAC) computer simulation of SST inventories, 40 were considered in this assessment. Also considered were 30 chemical constituents from the TRAC outputs supplemented with eight additional chemical constituents of regulatory concern that might, or are suspected to be, in the SSTs.

For constituents for which the inventory estimates were available and nontrivial (i.e., greater than zero), the tank-specific predictions by the TRAC computer program were used. For nonradioactive constituents not listed by TRAC, the rankings are based on the assumption that the mass of the constituent comprises a small, but nontrivial fraction of the wastes: an arbitrary inventory of 1% by weight was used.

At the Hanford site, the SSTs are located relatively close to each other, and groups of tanks are denoted as "tank farms." Based on similarities in geologic and hydrologic settings, the inventories for the 12 SST farms were combined and considered as six tank farm groups. Analysis of relative risk was based on the inventories and environmental settings of each of the six tank farm groups.

The constituent environmental movement was modeled using the MEPAS groundwater transport module using the transport and exposure scenario illustrated in Fig. 3. The wastes from the SSTs are assumed to be released from the storage tank into the unsaturated zone; the migration of these wastes was simulated through the unsaturated and saturated zones to a hypothetical usage location represented by a well 50 m downgradient from each tank farm group. This transport scenario accounted for the geologic conditions associated with each tank farm group. A standard Hanford exposure scenario based

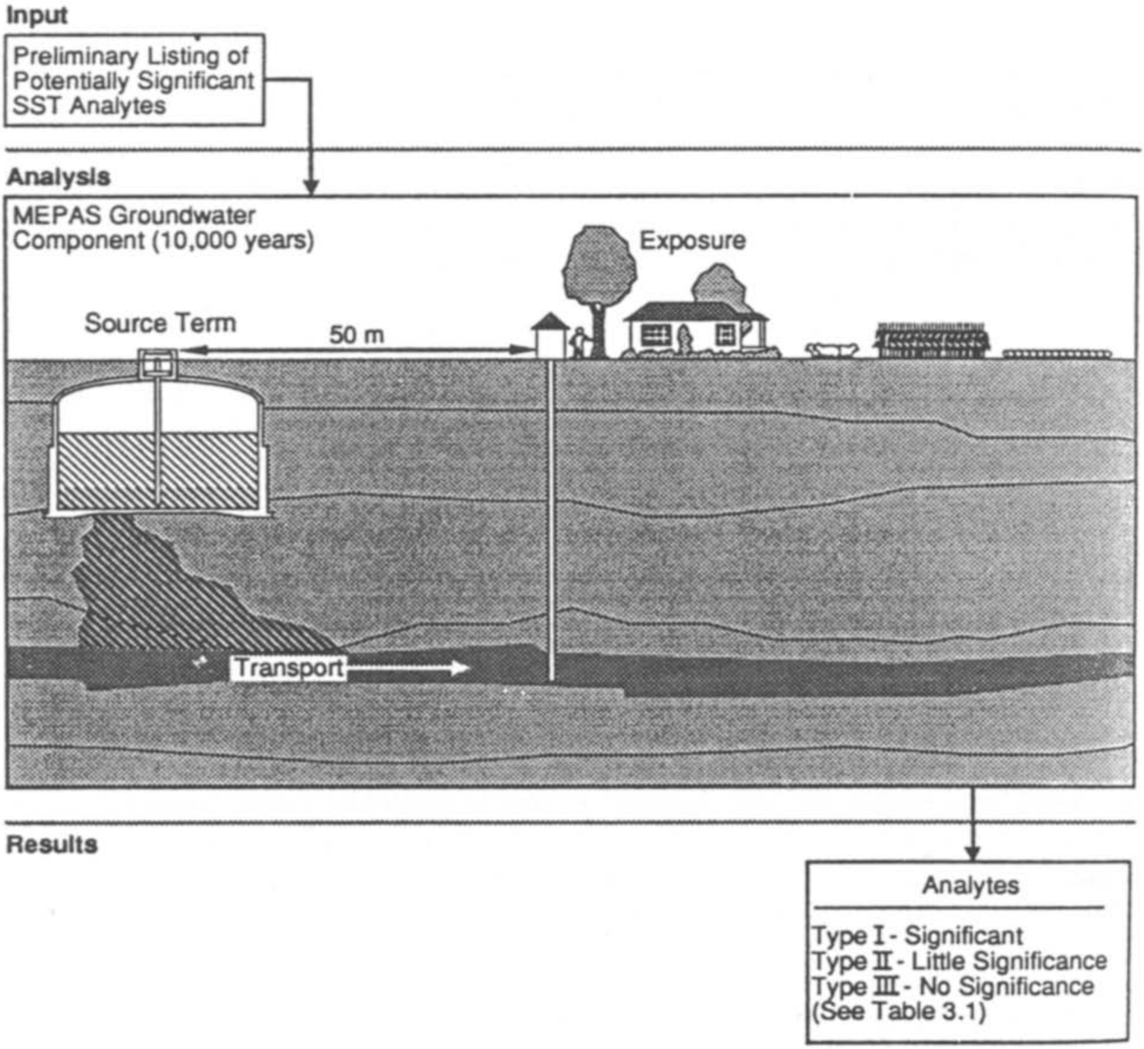

Fig. 3. The single-shell tank transport and exposure scenario.

on farm-related usage of the well water was used to evaluate potential impacts of SST constituents. These impacts at a hypothetical usage location for each tank farm group were computed out to 10,000 years in the future.

3.2 Risk-based rankings

The health impact rankings from the farm exposure scenario are considered for radioactive carcinogens, chemical carcinogens, and chemical noncarcinogens. The results show rankings with many orders of magnitude separation in relative importance of constituents from the perspective of relative health impacts. A large fraction of the constituents were predicted not to reach the well and thus were ranked as having no or very low potential for human health impact at this hypothetical receptor point. The rest of the constituents were ranked using the computed health impact indexes.

The results of radionuclide rankings from the first of the six tank farm groups, tank farm group A, are given in Table 1. Figure 4 is a plot of the relative rankings of radioactive constituents for the 10 cm/y recharge rate for this case. The radionuclide ranking index is computed as the product of an effective dose equivalent for an individual exposed for a 70-year lifetime in a farming scenario and a health effects conversion factor, expressed as risk per unit dose. The latter was the value derived by Buhl and Hansen [13] and from NAS [14]. The subsequent BEIR revision does not change the relative rankings but will slightly increase the importance of the ranking scale for radionuclides [9, 15].

The first three columns in Table 1 show the results of sensitivity studies that were conducted with a range of recharge rates that have been considered for other Hanford applications (0.5, 1.0, and 10.0 cm/y). The relative rankings for different recharge rates at the tank farms were nearly equivalent. However, the faster environmental transport times associated with increasing recharge rates did increase the magnitude of the health impact indexes and resulted in the appearance of several new constituents in the ranking.

In addition to the range of recharge rates, a transport sensitivity study considered the relationship between uncertainties in the distribution coefficients (K_d values) and rankings. In this effort, a set of enhanced transport runs was made for tank farm group A using the 10.0-cm/y recharge. The transport was enhanced by dividing the distribution coefficient (K_d) by a factor of 5. The last column in Table 1 shows that this change added a number of new constituents to the rankings. Some constituents had large changes in the ranking index value and others showed no change. These results show the importance of distribution coefficients.

Similar trends were seen for the other five tank farms. These sensitivity studies demonstrated that the rankings are influenced by changes in recharge rates and transport rates. The primary effect is mainly to add new constituents that are predicted to impact at a time near the end of the computational time period (10,000 years).

Although the results were similar for the different tank farm groups, there were some relatively large shifts in absolute as well as relative rankings

TABLE 1

Health ranking indices for radionuclides in Tank Farm A with computed generated inventories and varying recharge rates

Constituent	Recharge rate (cm/y)			
	0.5	1.0	10	10[a]
^{241}Am[b]	1.8×10^{-7}	2.1×10^{-6}	6.6×10^{-5}	6.6×10^{-5}
^{242m}Am[b]	8.6×10^{-5}	9.8×10^{-4}	3.8×10^{-3}	6.8×10^{-3}
^{14}C	4.7×10^{-4}	6.3×10^{-3}	5.7×10^{-2}	5.7×10^{-2}
^{242}Cm[b]	1.3×10^{-6}	1.5×10^{-6}	5.9×10^{-5}	5.9×10^{-5}
^{244}Cm[b]	6.9×10^{-10}	7.9×10^{-9}	3.0×10^{-8}	3.0×10^{-8}
^{245}Cm	–[c]	–[c]	–[c]	2.0×10^{-15}
^{129}I	1.5×10^{-4}	1.7×10^{-3}	6.6×10^{-3}	6.6×10^{-3}
^{93m}Nb	–[c]	–[c]	4.9×10^{-8}	1.2×10^{-2}
^{63}Ni	–[c]	–[c]	–[c]	9.7×10^{-12}
^{237}Np[b]	2.1×10^{-7}	2.4×10^{-6}	2.2×10^{-5}	1.4×10^{-1}
^{231}Pu	–[c]	–[c]	–[c]	3.8×10^{-5}
^{233}Pu	–[c]	–[c]	–[c]	1.0×10^{-5}
^{238}Pu[b]	1.2×10^{-5}	1.4×10^{-4}	6.4×10^{-4}	5.4×10^{-4}
^{239}Pu[b]	8.5×10^{-6}	9.9×10^{-5}	9.0×10^{-4}	9.0×10^{-4}
^{240}Pu[b]	3.9×10^{-5}	4.5×10^{-4}	1.7×10^{-3}	1.7×10^{-3}
^{241}Pu[b]	4.5×10^{-8}	5.3×10^{-7}	4.8×10^{-6}	4.8×10^{-6}
^{79}Se	–[c]	–[c]	–[c]	6.4×10^{-7}
^{99}Tc	2.0×10^{-3}	2.4×10^{-2}	9.1×10^{-2}	9.1×10^{-2}
^{233}U	1.8×10^{-7}	2.1×10^{-6}	1.9×10^{-5}	8.3×10^{-6}
^{234}U	3.1×10^{-6}	3.6×10^{-5}	1.4×10^{-4}	1.4×10^{-4}
^{235}U	1.1×10^{-4}	1.3×10^{-3}	5.0×10^{-3}	1.0×10^{-3}
^{238}U	2.4×10^{-3}	2.7×10^{-2}	1.0×10^{-1}	1.0×10^{-1}

[a] Sensitivity case with transport enhanced by dividing the distribution coefficient (K_d) for each constituent by a factor of 5.
[b] Risk is from decay products.
[c] Constituent did not reach well at hypothetical farm.

between tank farm groups. These shifts are the direct result of differences in inventories and local geologic settings.

The highest ranking radionuclides (i.e., those with the largest predicted level of impact) in the tank farm groups were carbon-14, technetium-99, uranium-238, uranium-235, and iodine-129. Uranium-234, uranium-233, thorium-229, and niobium-93m generally had lower levels of predicted impacts and thus lower rankings. An increase in the relative importance of neptunium-237, protactinium-231, protactinium-233, and selenium-79 was noted in the transport sensitivity test cases using enhanced transport rates.

For noncarcinogenic chemicals whose SST inventories were predicted by TRAC, cyanide ion, nitrite, nitrate, EDTA, fluoride, sodium, chromium VI, and sulfate tended to have the highest rankings. Beryllium ranked relatively high

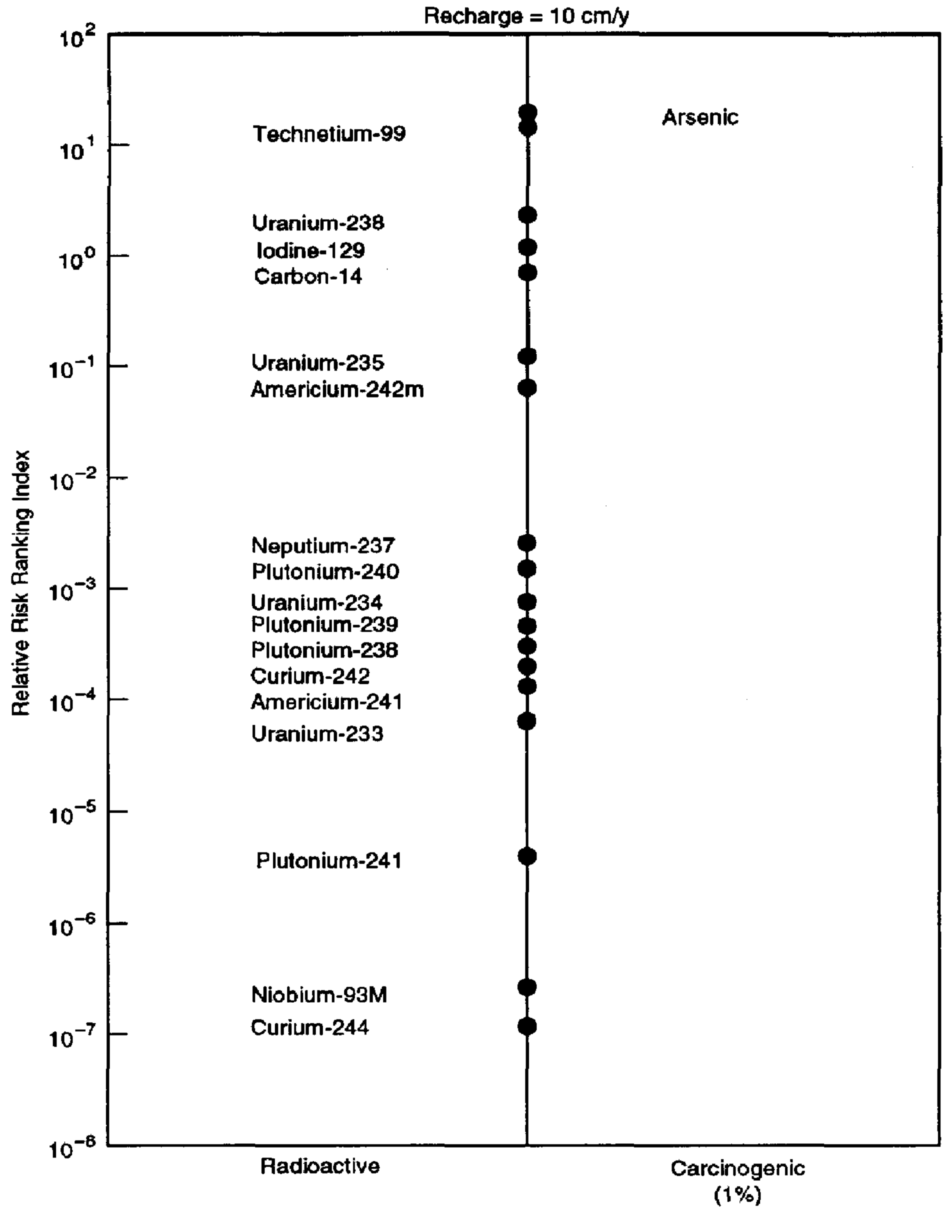

Fig. 4. Example of relative risk-based rankings of radioactive tank constituents.

in all tank farms in several of the Tank Farms. Zirconium, nickel, and iron ranked high for three of the Tank Farms. Silver and chloride ranked in the lower portion of the scale. The sensitivity study at Tank Farm A using enhanced transport rates resulted in the addition of zirconium to the rankings, a shift of iron from a low ranking to a high ranking, and some minor shifting of the ranking order of other constituents.

For noncarcinogenic chemicals without computer generated inventories, antimony, mercury, and vanadium consistently appeared in the rankings. Also ranking in this category of chemicals are sulfate for one Tank Farm, cadmium for two Tank Farms, and copper for one Tank Farm. The transport sensitivity study using enhanced transport resulted in additional appearances of copper and selenium in the rankings. For carcinogenic chemicals modeled with an assumed inventory, only arsenic appeared in any of the ranking results.

Many orders of magnitude differences are seen in the risk-based rankings for various constituents. These measures of relative importance proved to be one of valuable pieces of information used in designing characterization plans for these tanks. Specifically in the follow-up study, these risk ranking results were used to generate risk-based objectives and risk-based minimum detection goals for the characterization planning effort [12].

4. Conclusion

The above relative risk-based evaluation of the mixed waste constituents in underground tanks described illustrates how models such as MEPAS can be used to help prioritize various environmental remediation activities. This study particularly shows the value of risk-based considerations in the initial steps of a complex environmental restoration activity.

Public health and environmental risk computation integrates the information that is available. Risk information can be used from the very early stages of site evaluations to the subsequent detailed risk assessments. As more becomes known about the site, the uncertainty in the definition of risks generally decreases.

The various phases of environmental restoration efforts involve a broad range of risk issues. Risk computation models, such as MEPAS, which are designed to cover such a range of issues, can be a valuable tool for use in these efforts. By incorporating available site-specific data, decision makers can be provided with timely relative risk information covering a range of regulatory issues. Such information can be valuable both for comparing multiple sites and for comparing different aspects of one site.

Acknowledgments

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