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Analysis of Health Impact Inputs to the U.S. Department of Energy's Risk Information System

J. G. Droppo, Jr.
J. W. Buck
D. L. Strenge
M. R. Siegel

August 1990

Prepared for Office of
Environment, Safety, and Health
U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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ANALYSIS OF HEALTH IMPACT INPUTS TO THE U.S. DEPARTMENT OF ENERGY'S RISK INFORMATION SYSTEM

J. G. Droppo, Jr.
J. W. Buck
D. L. Strenge
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Pacific Northwest Laboratory
Richland, Washington 99352

PREFACE

The U.S. Department of Energy (DOE) is in the process of completing a survey of environmental problems, referred to as the Environmental Survey, at their facilities across the country. The DOE Risk Information System (RIS) is being used to prioritize these environmental problems identified in the Environmental Survey's findings.

The RIS is a two-step process for prioritizing DOE's environmental problems. The first step is to use quantitative and qualitative methods to define scores for criteria related to human health and environmental issues. In the second step, these scores are used as a basis for an expert panel to prioritize these environmental problems.

This report contains a discussion of site-specific public health risk parameters and the rationale for their inclusion in the RIS. These parameters are based on computed potential impacts obtained with the Multimedia Environmental Pollutant Assessment System (MEPAS). MEPAS is a computer-based methodology for evaluating the potential exposures resulting from multimedia environmental transport of hazardous materials. MEPAS was developed by the Pacific Northwest Laboratory[a] for DOE's Office of Environment, Safety, and Health for application to the Environmental Survey.

This report has three related objectives: 1) document the role of MEPAS in the RIS framework, 2) report the results of the analysis of alternative risk parameters that led to the current RIS risk parameters, and 3) describe analysis of uncertainties in the risk-related parameters.

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SUMMARY

The U.S. Department of Energy (DOE) is in the process of completing a survey of environmental problems at its facilities. The survey effort is referred to as the Environmental Survey, or Survey, and consists of a structured program of site visits, sampling and analysis, and prioritization of environmental problems. An environmental problem was defined in terms of a potential hazard to human health or the environment. The Survey results will be contained in an Environmental Survey Summary Report.

This report contains the results of an analysis of the health impact parameters in terms of their use in the Risk Information System (RIS). The RIS is being used to conduct the Survey's prioritization effort.

The environmental problems identified in the Survey's findings at 36 DOE facilities are being prioritized. The RIS generates and uses a series of scores that are indicators of public health and environmental risks. The Multimedia Environmental Pollutant Assessment System (MEPAS), which is a multimedia environmental transport and exposure assessment model, is used to compute health impact parameters on a site-specific basis. These health impact parameters are used to define public health risk scores. A system based on Environmental Protection Agency's Hazard Ranking System (40 CFR 300) is used to characterize environmental impacts. A RIS expert panel translates these parameters for each ranking unit into an overall prioritization of environmental problems.

As an intermediate step in conducting the Survey, DOE prepared a Preliminary Summary Report for 16 DOE facilities directly involved in defense production activities (DOE 1988). In addition to providing valuable preliminary information on the environmental problems at these sites, this application provided a starting point for studying options for inputs to the RIS.

In the Preliminary Summary Report, the prioritization was mainly based on a single risk parameter related to human health impacts. This MEPAS output parameter, the Hazard Potential Index (HPI), is a time-weighted measure of population risk. The HPI represents only one of many possible measures of different aspects of health impacts. Examples of other measures

include impact for an individual, impact without time weighting, and time of significant exposure. The analysis in this report uses the preliminary prioritization as a starting point to study the implications of the use of HPI and/or other parameters in the prioritization process.

The comparison of the rankings of environmental problems using HPI and other health impact parameters demonstrates the complexity of using these parameters as ranking criteria. Some parameters appear to be highly correlated, and little information is gained by using more than one of these parameters. However, in some cases the parameters provide enough sufficiently different information that the inclusion of both is desirable. The results show that the time weighting factor used to progressively discount future impacts is important when generating a ranking parameter. For example, the time-weighted HPI value, as compared to the non-weighted HPI, greatly increases the relative importance of current impacts.

Analysis shows that important information regarding impacts may be lost if a single parameter is used to rank the impacts of environmental problems. Instead, a series of parameters are required to characterize each environmental problem.

The design of the RIS reflects the results of this analysis. RIS considers multiple aspects of potential health impacts including population, and individual exposures as well as time of impacts. For average population risks, in addition to the time-discounted single contaminant score based on the HPI, scores are generated for each ranking unit based on an undiscounted HPI, multiple contaminant HPI, and undiscounted multiple contaminant HPI. For maximum individual risks, two scores are used based on actual and hypothetical receptor impacts. A health effect category defines the type of effects associated with the risk, and the time of arrival gives information on the immediacy of impacts.

The uncertainty in the ranking parameters is characterized in RIS in two ways. First, a baseline variability score is derived based on the sensitivity of the HPI to variations in the input parameters. Second, a score is provided that reflects the data quality category for input parameters.

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1.0 INTRODUCTION

The U.S. Department of Energy (DOE) is in the process of completing a survey of environmental problems at 36 DOE sites. The DOE Environmental Survey, hereafter referred to as the Survey, involves identifying, inspecting, sampling, and reporting activities aimed at characterizating DOE's environmental problems. The environmental problems identified in the Survey findings are being prioritized relative to their potential for affecting public health and the environment. These Survey results will be presented in a final Environmental Survey Summary Report, hereafter referred to as the final Summary Report.

As part the Survey effort, computer simulations were made to estimate the risks posed to human populations as a result of the identified environmental problems. The Multimedia Environmental Pollutant Assessment System (MEPAS) was developed for the purpose of providing a single consistent tool for conducting these simulations.

The overall system being used by the Survey to prioritize the findings is referred to as the Risk Information System (RIS). The RIS incorporates both human health and environmental concerns. MEPAS is the component of the RIS for computing health impact parameters that are used to characterize human health risks. The proposed revised Hazard Ranking System (HRS) developed by the U.S. Environmental Protection Agency (EPA) (40 CFR 300) is used to characterize environmental impacts. This chapter describes the scope of the Survey, the preliminary prioritization effort, and the objectives of this report.

1.1 ENVIRONMENTAL SURVEY

The Environmental Survey, being conducted by the DOE's Office of Environment, Safety, and Health, consists of identifying and prioritizing, on an agency-wide basis, the DOE sites that potentially pose risks to public health and the environment. The results of the Survey will provide DOE management with baseline information on each environmental problem; this

information can be used to develop uniform, comprehensive, long-range plans for reducing potential public health and environmental risks posed by the identified problems.

In the Survey efforts, an environmental problem is defined as either of the following (DOE 1988):

1. the existence of pollutants or hazardous material in the air, surface water, groundwater, or soil that results from DOE operations and that poses or may pose a hazard to human health or the environment

2. the existence of conditions at a DOE site that poses or may pose a hazard to human health or the environment.

In general, environmental problems result when the amount of a hazardous material exceeds federal, state, or local regulations for release of, contamination by, or exposure to that particular material or when operating conditions violate regulations or requirements. Conditions that meet regulatory or other requirements, where such do exist, are generally considered not to constitute a potential hazard and are not identified as an environmental problem in the Survey. Environmental problems may also result when a nonregulated material is present at a concentration that results in sufficient potential hazard to the local human population or environment.

Figure 1.1 shows the progression of efforts associated with the Survey and how this report fits in that progression; only major Survey efforts and product categories are shown. The first major Survey activity included a review of all existing environmental information concerning the 36 DOE sites, followed by site visits of 1 to 3 weeks by DOE Survey Teams. During the site visits, team members reviewed additional documents pertaining to current and past site operations and environmental status, inspected facilities and operations, interviewed personnel, and observed environmental sampling and monitoring. Following the site visits, preliminary reports containing the initial Survey findings (i.e., known and potential environmental problems) were prepared for each site.

On completion of the initial site visit, limited sampling and analyses were conducted to confirm the existence of contamination and to provide additional information concerning the nature of environmental problems. In

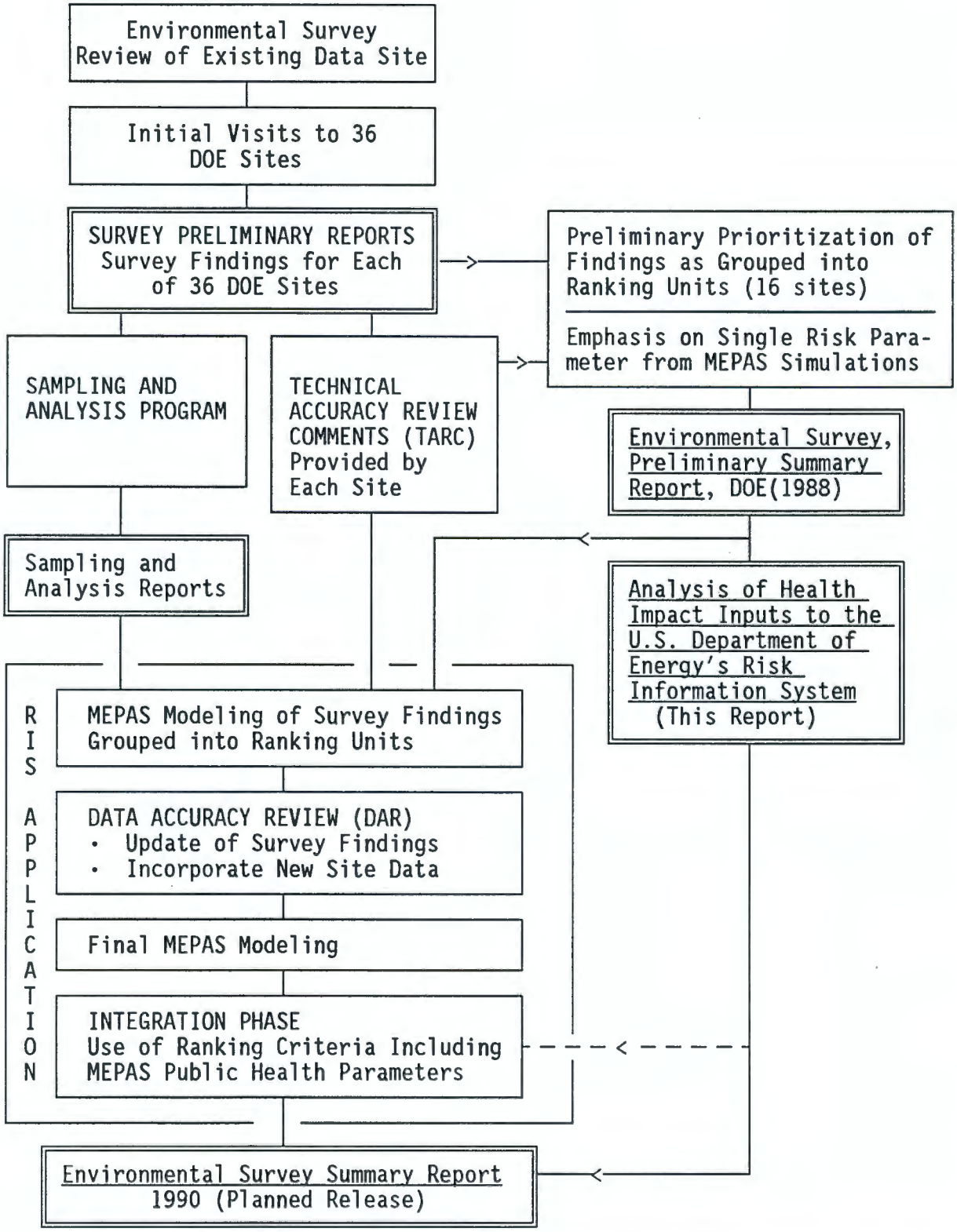

FIGURE 1.1. Relationship of this Report with Major Environmental Survey Efforts and Reports. (Survey efforts are enclosed with a single line and survey report products with a double line.)

addition, DOE management at each of the sites reviewed the preliminary report for each site and provided comments, referred to as Technical Accuracy Review Comments (TARC).

As an intermediate step (shown on the right side of Figure 1.1), the Survey prepared a preliminary assessment for a subset of the DOE sites. The preliminary assessment considered environmental problems based on the findings reported in the Survey's preliminary reports for each of DOE's 16 defense production (DP) sites. That effort provided a test of the prioritization system and a preliminary definition and prioritization of environmental problems for the DP sites. The prioritization of these environmental problems in the Preliminary Summary Report (DOE 1988) relied mainly on outputs from MEPAS. Additional detail on the preliminary assessment effort is given below as background for the analysis of health impact parameters.

The activities associated with the application of the RIS are shown as enclosed in a box in the lower portion of Figure 1.1. The Survey initially used MEPAS to model the environmental problems for the 36 sites. The environmental problems at DOE sites identified in the Survey findings were grouped into ranking units. The ranking units were based on existing or suspected contamination or situations that could result in future risks.

The Survey Teams revisited the sites in 1989 to identify and obtain more up-to-date data and to update the preliminary findings. As a result of these revisits, referred to as the Data Accuracy Review (DAR), a number of earlier findings were modified and others were closed (i.e., the identified problem had been corrected). In addition, a significant amount of new information concerning the findings was provided to and evaluated by the Survey.

The updated findings for the 36 sites were remodeled as appropriate using MEPAS. These modeling efforts incorporate revised information from the original sites visits, as updated by the sampling and analysis program, the TARC, and the DAR.

The MEPAS outputs were used in the RIS judgmental or integration phase where the relative significance of each criterion was considered and an overall ranking of the environmental problems was developed. Approximately 400 ranking units, covering the 36 sites, were ranked using the RIS.

This overall ranking generated in the RIS application will form the basis of the final Summary Report (Figure 1.1).

1.2 PRELIMINARY PRIORITIZATION EFFORT

As part of the evaluation of the preliminary prioritization effort, the interrelationships of risk and risk-related input parameters were analyzed. The preliminary prioritization of DOE's Survey findings at 16 DP sites (DOE 1988) encompassed a variety of environmental problems and issues for facilities located across the United States. Within these 16 DOE DP sites (listed in Table 1.1), 208 ranking units encompassing hundreds of different environmental problems were identified by the DOE Survey Teams. A total of 393 different constituents were identified for the Survey; this included radionuclides, carcinogenic chemicals, and noncarcinogenic chemicals. These environmental problems in the analysis for the Preliminary Summary Report encompassed over 500 different transport and exposure scenarios.

The environmental problems and contaminants described in the Preliminary Summary Report varied greatly across the sites. Some of the common environmental problems included those associated with active and inactive landfills, sediment and evaporation ponds, above ground and underground storage tanks, contaminated soils from spills and leaks, injection wells, stack and vent releases (planned and unplanned), tank farms, leach pits, and drum storage areas.

In the Preliminary Summary Report, the largest MEPAS Hazard Potential Index or HPI value for a constituent at each ranking unit was used to generate a score for that environmental problem. Recognizing the lack of precision inherent in the HPI, these scores for ranking units were reported in groups from 0 to 10. These groups were then divided into five levels whose significance is explained in Table 1.2.

The modeling application experience in this preliminary ranking effort resulted in a number of changes and enhancements in MEPAS (Droppo et al. 1989c). New release, transport, and exposure components were added, and existing components were improved. Also, in addition to this output, MEPAS

TABLE 1.1. Name and Location of DOE Defense Production Sites Included in the Preliminary Summary Report

Site Name	Location
Feed Materials Production Center	Fernald, Ohio
Hanford Site	Richland, Washington
Idaho National Engineering Laboratory	Idaho Falls, Idaho
Kansas City Plant	Kansas City, Missouri
Lawrence Livermore National Laboratory	Livermore, California
Los Alamos National Laboratory	Los Alamos, New Mexico
Mound Facility	Miamisburg, Ohio
Nevada Test Site	Nye County, Nevada
Pantex Facility	Amarillo, Texas
Pinellas Plant	Largo, Florida
Portsmouth Uranium Enrichment Complex	Piketon, Ohio
Rocky Flats Plant	Golden, Colorado
Sandia National Laboratory	Albuquerque, New Mexico
Sandia National Laboratory, Livermore	Livermore, California
Savannah River Plant	Aiken, South Carolina
Y-12 Plant	Oak Ridge, Tennessee

provides (or was modified to provide) a series of intermediate and final output products to give a more detailed definition of various aspects of potential risk. The completion of this preliminary effort provided a DOE-specific database for the analysis of MEPAS risk-related output parameters.

1.3 SCOPE AND ORGANIZATION OF THIS REPORT

The objectives of this report are to document the role of MEPAS in the RIS and discuss the human health impact parameters used in RIS. The role of MEPAS is described in Sections 2.0 and 3.0. Section 2.0 contains an overview of the RIS with the rationale for its development. Section 3.0 contains an overview of MEPAS as the methodology used to compute health impact parameters. In Section 4.0, a variety of health impact parameters computed by MEPAS are evaluated for inclusion in the prioritization process. Finally, in Section 5.0, application uncertainty issues are discussed.

TABLE 1.2. DOE Scoring of Hazard Significance of HPI Groups[a]

Level	Group[b]	Potential Hazard Significance[c]
I	10 9 8	These groups include the environmental problems of most concern in terms of the potential hazard to the public. The scores are based on the sizes of the potential receptor populations and the toxicity and concentration of the contaminants.
II	7 6	These groups include environmental problems that represent a secondary level of concern in terms of potential hazard to the public. The scores for these groups are generally driven by large receptor populations with moderate concentrations and/or toxicity of contaminants. However, a few problems in these groups include small receptor populations with high toxicity or concentrations.
III	5 4	These groups include environmental problems that present a tertiary level of concern in terms of potential hazard to the public. Scores for these groups are generally a result of small receptor populations, low doses, or low-toxicity contaminants.
IV	3 2 1	These groups include environmental problems that are characterized as generally reaching receptors at levels well below those used in regulatory decisions.
V	0	This group includes environmental problems that are not projected to reach receptors.

(a) Table was taken from DOE (1988).
(b) An HPI group is defined in terms of a HPI range. The "0" group represents ranking units with a HPI less than or equal to zero. Ten point ranges are used for all other groups in impacts: Group "1" occurs for ranking units with HPIs greater than zero and less or equal to 10, Group "2" occurs for ranking units with HPIs greater than 10 and less or equal to 20, etc. Each ten points in HPI corresponds to an order of magnitude change in computed impacts.
(c) Significance is based on the size of the potential receptor population most frequently encountered.

2.0 RISK INFORMATION SYSTEM

The DOE's RIS is a methodology for organizing information on various aspects of public health and environmental risks potentially posed by environmental problems at DOE sites and for prioritizing those problems based on these potential risks. The RIS ranking methodology, developed for application to the problems identified in Survey findings, evolved based on internal and external reviewers' comments on the ranking methodology used in the Preliminary Summary Report.

In addition to being the ranking methodology for the environmental problems that will be presented in the final Summary Report, the RIS is designed as a possible prototype of the method by which risk to public health and environment can be integrated into DOE clean-up plans. The DOE currently anticipates conducting external and internal reviews of the final Summary Report and the methodology underlying the RIS. These technical reviews of the RIS, including the underlying risk-based modeling (MEPAS), are planned to be undertaken by the National Academy of Sciences and DOE laboratories. The DOE also plans to have a formal public review of the RIS (and MEPAS) methodologies.

2.1 OVERVIEW OF THE RIS

As illustrated in Figure 2.1, the RIS consists of two distinct sequential phases. First, the mechanistic phase provides quantitative and qualitative information related to public health risk and risk to the environment. Second, the judgmental phase[a], during which the information gathered or generated during the mechanistic phase is integrated to establish a ranking of the various environmental problems.

In the mechanistic phase, information describing various aspects of the risk potentially posed by each of the problems is compiled. Public health criteria (expressed in terms of scores) are based on risk outputs from simulations using the MEPAS methodology. The use of this pathway-based

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(a) Also referred to as the "integration phase."

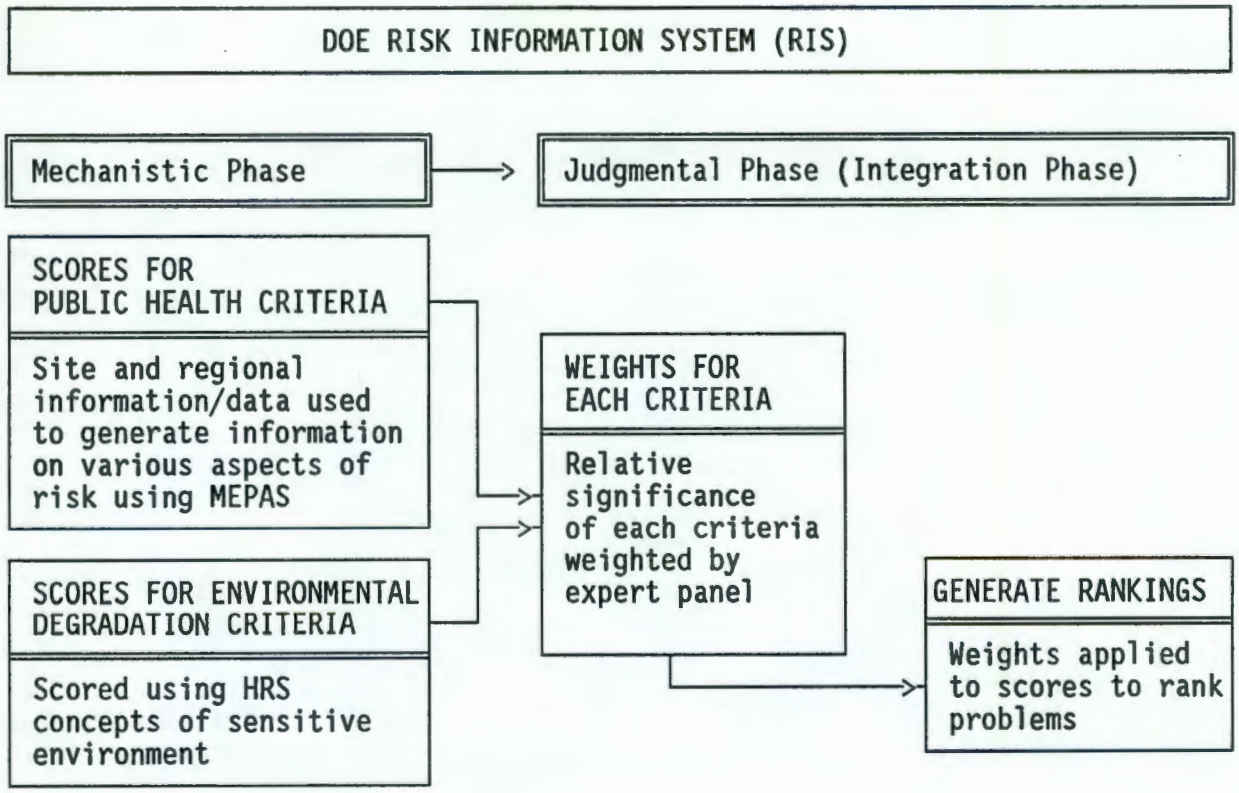

FIGURE 2.1. Elements of DOE's Risk Information System

computational approach for generating public health criteria inputs allows DOE to take advantage of the monitoring and exposure data available at most major DOE sites. Environmental degradation criteria are generated using a qualitative approach based on the sensitive environment concept within the proposed revised HRS developed by the EPA (40 CFR 300). This qualitative approach allows scores for the environmental degradation criteria to be developed based on the limited information available.

Data and assumptions used in the mechanistic phase are reviewed with each DOE site. The information derived from MEPAS and from environmental degradation scoring describes various aspects of risks to public health and the environment. The output from this mechanistic phase is not a single score, but rather a set of scores describing various aspects of the risks posed by each ranking unit.

These scores from the mechanistic phase will be integrated into a ranking during the judgmental phase by a panel of DOE environmental officials. This panel will evaluate the various aspects of risk (e.g., risk to individuals, risks to population) and assign weights to develop an integrated ranking. The results will be agency-wide, integrated, risk-based rankings and rationale for weights for the factors used in the ranking.

In the RIS, the data analysis activity of the mechanistic phase was designed to be separate from the prioritization activity in the integration phase. This separation helps prevent policy decisions from obscuring the analyses that take place in the mechanistic phase. For example, in the mechanistic phase, several human health criteria will be developed including maximally exposed individual risk and general population risk. The generation of risk criteria is independent of the subjective and policy decisions in the integration phase where these risk criteria may be used to derive the final rankings.

2.2 MECHANISTIC PHASE

The RIS defines environmental problems at each site in terms of potential human health and environmental risks from ranking units. In the mechanistic phase, each of these ranking units is characterized based on 13 ranking criteria - 10 public health risks and 3 environmental risks. These criteria include both quantitative and qualitative information for potential human health and environmental risks.

2.2.1 Public Health Risk Scores

In the mechanistic phase, 10 risk and related parameters contained in the MEPAS output are compiled for each ranking unit. This is in contrast to the approach used in the Preliminary Summary Report, where the HPI, a MEPAS output parameter (Whelan et al. 1987), served as the primary ranking parameter.

Both population and individual impact scores are used in the RIS. These scores are based on potential impacts computed using MEPAS for a time period from the present out to 100 lifetimes (7000 years) in the future.

The RIS includes measures of potential population impacts with and without time weighting. These HPIs use the risk computed for a single contaminant as being representative of the problem. These HPIs are supplemented with HPI parameters based on total risk from multiple contaminants to provide a fuller characterization. Thus, the four population impact parameters used in RIS are

- Single Contaminant Population Risk - Discounted A composite population risk score that referred to as the HPI in this report is computed for each constituent. This index is based on the time-weighted total population risk resulting from exposure to a particular contaminant. The time weighting involves an exponential discounting of the magnitude of future impacts. The constituent with the largest HPI value is used to define the HPI score for each ranking unit.

- Single Contaminant Population Risk - Undiscounted Identical to the HPI except the health impacts to future generations are not discounted. This index is referred to as the undiscounted HPI in this report. The lack of discounting makes the time period length more important for the undiscounted HPI than for the HPI.

- Multiple Contaminant Population Risk - Discounted A composite score referred to as the combined contaminant HPI that is similar to the HPI except the time-weighted population risks for all constituents are added before converting the risk to an HPI score.

- Multiple Contaminant Population Risk - Undiscounted Same as combined contaminant HPI except the impacts to future generations are not discounted.

The three measures of potential individual impact from MEPAS revolve around the question of locations of current and future receptors. These measures of individual impact are

- Maximum Individual Risk to Modeled Receptor - An estimate of the highest potential individual risk projected to the receptors modeled based on current receptor locations. As unweighted risk, this information provides an indication of the potential current risk to an individual.

- Hypothetical Maximum Individual Risk at Site Boundary - An estimate of the potential risk posed by contamination concentrations computed at the site boundaries. This value represents a worst-case future risk presuming access restrictions are maintained for onsite activities. This component represents DOE's current radiation management approach.

In addition to the above information from MEPAS outputs, three factors will provide additional important risk information. Addressing the type, the time, and the uncertainty of impacts, these factors are

- Health Effect Category - A parameter that indicates the health effect category [carcinogen (both radionuclide and chemical), or noncarcinogen] that contributes the greatest fraction of risk to the constituent of interest.

- Time of Arrival - The time at which an individual risk at a receptor reaches a designated level of risk for that material. For carcinogens, a designated risk level of 10^{-7}, representing one-tenth of the commonly used 10^{-6} action risk level is used. For noncarcinogens, the level is one-tenth of the reference dose. If the designated risk level is not exceeded, time of arrival defaults to the time that the maximum individual risk occurs.

- Qualitative Uncertainty - An assessment of the uncertainty associated with the modeling of public health risks. The assessment is based on a combination of the base-case variability for a well-characterized site reported in a sensitivity study (Doctor et al. 1990) and Survey information on uncertainty related to the sources of input data.

Finally, a measure of potential future impact for a person at the worst possible location is provided as an indicator for the loss of institutional control:

- Loss of Institutional Control - The significance of potential contamination assuming future loss of institutional control over the site. This parameter describes the fraction of the initial risk from ingestion of contaminants which remains within site soils one hundred years from the present, the time when institutional control is assumed to be relinquished.

For input to the RIS judgmental phase, these parameters are converted to scores representing specific levels of impact. With the exception of Hypothetical Maximum Individual Risk and the Loss of Institutional Control, the basis for the choosing of all the public health parameters included in the RIS analysis is presented in Section 4.0 of this report. The basis for choosing the qualitative uncertainty factors is discussed in Section 5.0.

2.2.2 Environmental Degradation Scores

For environmental degradation, the RIS focuses on potential harm to "sensitive environments," as identified by EPA in the proposed revised HRS (40 CFR 300). The RIS relies on the judgment of Survey Teams -- experts with direct knowledge of the sites -- to evaluate the three environmental degradation criteria: 1) the type of sensitive environment affected, 2) the likelihood that contaminants will reach that environment, 3) and the time of contaminant arrival. In this subjective process, experts make broad but important distinctions based on all available information. The method does not include any measure of severity or possible consequences of potential exposure at sensitive environments because of a lack of sufficient scientific information to categorize these consequences.

2.3 JUDGMENTAL PHASE

In the judgmental phase, the scores from each criteria from the mechanistic phase are used as a basis for ranking the environmental problems. An expert panel defines weights for the different criteria reflecting public health and environmental risks. A revised Analytical Hierarchy Process (AHP) is used in the RIS to derive these weights. The application of AHP in the RIS judgmental phase is based on an adaption of EPA's Risk Based Decision Making (RBDM) project (EPA 1989a).

Priority setting, either formal or informal, has always been a component of most decision-making processes. Generally, decision makers have been forced to use available information to set priorities in an informal manner. This sort of system worked well when only a small number of sites was involved. However, as the number of sites increases, the decision maker is not able to make such evaluations with the same level of confidence. With a large number of sites, the decision maker will be unable to make consistent comparisons among sites because of the extent of the information that must be integrated and the range of criteria that must be weighted for each site.

The judgmental phase of the RIS is intended to address this problem. The expertise of the panel is incorporated directly into the prioritizing process. Furthermore, the method of assigning weights to the ranking

criteria formalizes the decision makers' informal ranking process, allowing the consistent application of experience in ranking release sites.

The design of the RIS judgmental phase explicitly acknowledges that human judgment is an integral element of any ranking system. For instance, the panel may decide that a large immediate risk to a relatively small population should be ranked higher than a smaller risk to a much larger population. The use of expert judgments provides a logical, experience-based method to make such decisions. The RIS, however, makes these underlying judgments clear both to those making and those reviewing the rankings. The RIS presents information from all factors and requires the panel to explicitly decide on the relative weights for each factor, thus formalizing the decision makers' informal ranking system and facilitating a consistent approach to the ranking of numerous sites. The RIS, however, does not impose consistency; it only ensures that the decision makers are aware of any inconsistencies, thereby allowing them to either adjust the weights or justify the apparent inconsistency.

3.0 MULTIMEDIA ENVIRONMENTAL POLLUTANT ASSESSMENT SYSTEM

All the public health scores used in the RIS are derived from, or relate to, MEPAS output parameters. Hence, to understand these public health scores used in RIS, a knowledge is needed of the process used to compute these output parameters.

This section provides a brief description of the MEPAS methodology. The objective of this section is to present the reader with sufficient detail to understand the overall process by which health impact parameters are computed using MEPAS. More detailed descriptions of the MEPAS formulations are given in Droppo et al. (1989c), and Whelan et al. (1987). The detailed guidance used in applying MEPAS in the Survey is given in Droppo et al. (1989a, 1989b).

3.1 BACKGROUND

MEPAS, which is an enhanced version of the Remedial Action Priority System (RAPS) (Whelan et al. 1987), is a multimedia environmental assessment system that starts with contaminant releases and simulates the movement of contaminants though major transport pathways to human exposure routes. MEPAS provides estimates of human health impacts though airborne, waterborne, and direct exposure routes. Model outputs include environmental concentrations, health impact parameters, and related parameters.

MEPAS is based on mathematical algorithms that simulate contaminant release to the environment and transport through environmental media to receptor locations. Using the computed environmental concentrations at the receptor locations, exposures and resultant health impacts are computed. The mathematical algorithms in MEPAS are based on standard approaches for modeling releases, transport and dispersion, and health impacts in atmospheric, groundwater, surface water, and overland transport media. Inhalation, ingestion, direct contact, and direct exposure pathways are included in the health impact component. The interaction and coupling between the transport pathways and the exposure assessment component of MEPAS are illustrated in Figure 3.1.

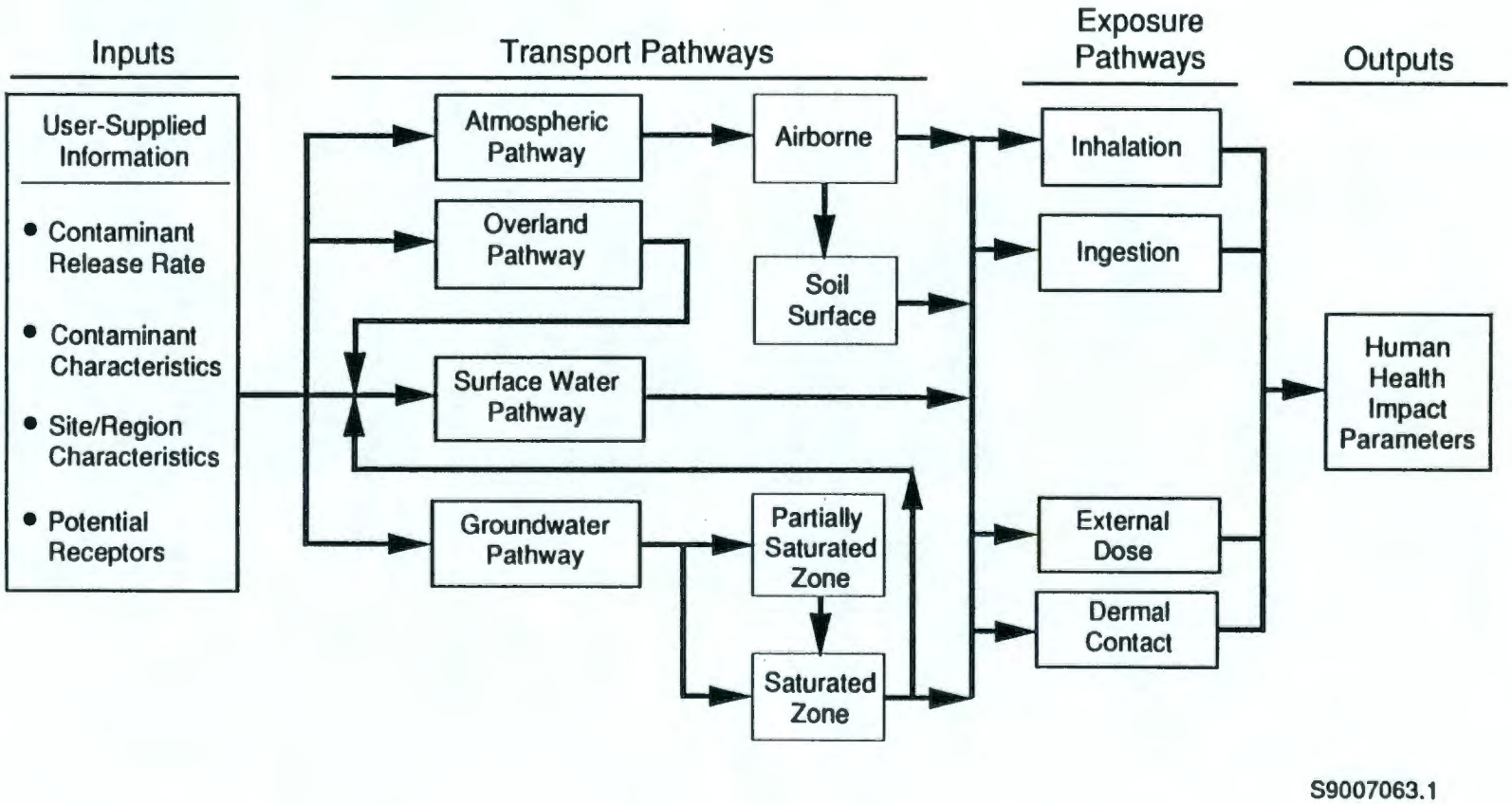

FIGURE 3.1. Schematic Diagram Illustrating the Interactions Between the Various Contaminant Transporting Media and How Contaminants Affect Humans Through Their Environment

To reduce the number of required inputs and standardize the values used for certain non-site-specific parameters, a MEPAS constituent database was developed (Strenge and Peterson 1989). This MEPAS database contains toxicity data, transfer factors, chemical and physical constants, and other relevant constituent data.

For additional information on MEPAS components, refer to Droppo et al. (1989c), Whelan et al. (1986), and Whelan et al. (1987), and for implementation information refer to Buck et al. (1989) and Droppo et al. (1989a, 1989b, 1989c).

3.2 HUMAN HEALTH IMPACTS

The human health impacts are computed by MEPAS and expressed in terms of risk factors. For applications of MEPAS, environmental problems are expressed in terms of ranking units. The overall operation, referred to as a facility, may have any number of ranking units. Each ranking unit may have multiple releases to one, or more, transport media. Each release has an associated transport and exposure scenario for computation of potential human health impacts.

3.2.1 Constituents and Associated Potential Impacts

MEPAS considers three types of constituent impacts: radioactive carcinogenic, chemical carcinogenic, and noncarcinogenic constituents. In MEPAS, a risk factor is one of the factors used in computing the potential impacts (Whelan et al. 1987). A risk factor characterizes the pertinent constituent toxicity properties for each pathway, population group, and exposure time.

The computation of risk factors uses regulatory levels based on protection of public health from harmful exposures to a constituent. Carcinogenic risk factors are based on increased cancer incidences. Noncarcinogenic risk factors are based on acceptable daily intakes for the chemicals of concern based on EPA guidance.

The risk factor for carcinogenic effects from radionuclides is calculated assuming low-level exposure over the lifetime of an individual and is

equal to the product of the computed individual lifetime dose and the health effects conversion factor. The dose factors are based on dosimetry of ICRP (1979 - 1982). The health effects conversion factor, expressed as risk per unit dose, was the value derived by Buhl and Hansen (1984) from NAS (1980).

Chemical carcinogenic risk factors are defined for ingestion and inhalation exposure routes estimated from cancer potency factors (primarily developed by the EPA). These cancer potency factors relate the daily intake per unit body mass averaged over an individual's lifetime to the risk of developing cancer.

For noncarcinogenic impacts, EPA (1989b) defines the chronic reference dose (RfD) as an estimate "of an exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime." The EPA includes in their definition the fact that the uncertainties of the RfD span perhaps an order of magnitude or greater. The MEPAS risk factors for noncarcinogenic impacts, which are based on the RfD levels as established by the EPA for intake via inhalation and ingestion, are the ratio of the estimated dose divided by the RfD.

Although normally one type of impact is associated with a constituent, a constituent can have different types of impacts. A few constituents are carcinogenic for one exposure route and noncarcinogenic for another exposure route. Constituents also may be of concern both as a result of their radioactive and chemical properties.

Risk factors are computed using information in the MEPAS constituent database. Strenge and Peterson (1989) document the source of each data value. The toxicity data are based on EPA values whenever possible with other references and estimation methods used only to supplement EPA data.

3.2.2 Environmental Releases

Each of the four primary transport pathways considered by MEPAS (groundwater, surface water, overland, and atmospheric) has several associated environmental release types. Detailed information on these release types may be found in Droppo et al. (1989a). For the groundwater, surface water, and

overland pathways, the release types are precipitation-driven release rate, known contaminant release rate, or known water concentration at the receptor.

The atmospheric transport pathway in MEPAS has three major release types: 1) stack/vent releases, 2) suspension of contaminated soil, and 3) gaseous releases through volatilization. The stack/vent is treated as a point source and the latter two releases as area sources. Stack/vent releases are either modeled with known emission rates or environmental air concentrations. Suspension and volatilization have three different release types: 1) known emission rate, 2) emission rate internally computed by MEPAS based on release and site characteristics, and 3) known environmental air concentrations. For both point and area sources, the known environmental air concentrations are used to back-calculate an emission rate.

3.2.3 Transport and Exposure Scenarios

The transport scenarios designate how the contaminant may move through the environment. Table 3.1 shows the transport scenarios currently included in MEPAS. Multiple layers may be defined in the partially saturated zone (vadose zone). Direct leaching to a saturated zone is also possible. The outputs of the waterborne transport component include a time series of contaminant fluxes or concentrations in each of the modeled media along with separate listings of initial contaminant arrival time, time of peak concentration, and peak concentration value for each constituent. The outputs of the airborne component include long-term average air concentration and deposition patterns as a function of distance and direction from the ranking unit.

The exposure scenarios designate the exposure routes and receptors for computing health impact parameters. Exposure scenarios evaluated by MEPAS are listed in Table 3.2. In these scenarios, populations at the receptors can be exposed to contamination via inhalation, ingestion, direct contact, and external exposure. The exposure analysis is based on 70-year increments. Airborne exposures are computed only for the first 70-year period. For the waterborne transport component of MEPAS, the exposure analysis is conducted

TABLE 3.1. MEPAS Transport Pathways and Transport Scenarios

Gaseous or particulate emissions to air from ranking units that have uncontaminated surface soil or nonsoil-type releases:

Ranking unit → Air/Surface soil[a]
Ranking unit → Air → Surface soil → Air/Surface soil[a][b]
Ranking unit → Air → Surface soil[a][b] → Groundwater
Ranking unit → Air → Surface soil[a][b] → Groundwater → Surface water
Ranking unit → Air → Surface soil[a][b] → Overland → Surface water
Air as a source[c]

Gaseous or particulate contaminants in the surface soil with emissions from 1) landfills, to the atmospheric or overland environments, or 2) nonlandfill, to the groundwater environment (SS = surface soil):

Surface soil → Air/Surface soil[d]
Surface soil → Groundwater[d]
Surface soil → Groundwater → Surface water[d]
Surface soil → Overland → Surface water[d]

Releases to groundwater from ranking units, including landfills (GW = groundwater):

Ranking unit → Groundwater
Ranking unit → Groundwater → Surface water
Groundwater as a source[c]

Starts with releases to surface water (SW = surface water):

Ranking unit → Surface water
Surface water as a source[c]
Surface water as a source → Air[a]
Surface water as a source → Air → Surface soil[a]

A direct exposure to contaminants at receptor (DE = direct exposure):

Direct soil ingestion at receptor
Measured food concentrations at receptor
Measured radiation doses at receptor

(a) This transport scenario currently involves a two-step modeling process. Eventually, this two-step process will be internally handled by the model.
(b) The second surface soil location is the result of atmospheric deposition of materials transported from the first surface soil location.
(c) The source is characterized by measured environmental concentrations that take precedence over any modeling effort and that are used in the exposure and health effects assessment.
(d) Measured contaminant concentrations are available to compute emissions (gaseous and particulate) from contaminated surface soils.

TABLE 3.2. MEPAS Exposure Pathways and Exposure Scenarios

Exposure to contaminated air:

Air/Surface soil → Inhalation, External exposure[a], and/or Soil ingestion

Air/Surface soil → Crops → Ingestion
Air/Surface soil → Crops → Animals → Ingestion

Exposure to contaminated groundwater:

Groundwater → Ingestion
Groundwater → Bathing → Ingestion/Inhalation
Groundwater → Irrigation → Crops → Animals → Ingestion
Groundwater → Animals → Ingestion

Exposure to contaminated surface water:

Surface water → Ingestion
Surface water → Fish/Shellfish → Ingestion
Surface water → Irrigation → Crops → Ingestion
Surface water → Irrigation → Crops → Animals → Ingestion
Surface water → Animals → Ingestion
Surface water → Bathing → Ingestion
Surface water → Recreation → External exposure[a]
Surface water → Recreation → Ingestion

Direct exposure to contaminants:

Direct ingestion of surface soil
Measured food concentrations
Measured radiation doses[a]

(a) For radionuclides only.

for one transport pathway, one receptor, and one 70-year period at a time. The required 70-year average concentrations are computed from the time series generated by the waterborne transport component.

3.2.4 Hazard Potential Index (HPI)

The HPI is an index that reflects long-term average population impacts and contains an option for discounting impacts that do not occur in the next 70 years. In the RIS version of MEPAS, HPI values are reported with and without a time-discount factor. The time-discount factor is an exponential factor with a half-life of 70 years (assumed to be one human lifetime). Table 3.3 shows how this factor varies with 70-year time periods. The discounting factor only applies to waterborne exposures as waterborne exposures are computed out to 7000 years while airborne exposures occur in the first 70-year period. HPIs with a time discounting were reported in the Preliminary Summary Report (DOE 1988).

The HPI is computed using a multistep process. First, a preliminary Hazard Index (PI) is computed for each constituent. The PI is equal to the product of the risk factor, the population, and the time factor summed for each exposure pathway, receptor, time step, and transport pathway. This PI is based on total human population exposure from a single constituent. The PI is converted into the final HPI value by multiplying the base-10 logarithm of the PI by 10.0.

The HPI is scaled such that exposures to a single person will correspond to a given constituent's reference level of protection (10^{-6} for carcinogens and RfD for noncarcinogens) will give the same magnitude of HPI. Thus the HPI scales for carcinogens and noncarcinogens use the reference level of protection as a common point for comparison. This formulation is not meant to imply any equivalence of effects for these two classes of materials.

The HPI ranges from -250 to greater than 100 with the range of interest from 0 to 100. An HPI computed for the exposure of a single person at a risk level of 10^{-6} has a value of 0. Higher HPIs indicate greater impacts. HPIs less than 0 are generated for low-level exposures down to an arbitrary small value of -250. HPIs are computed for each constituent identified for a ranking unit, and the ranking unit scores are based on the constituent with the greatest computed total potential health impacts.

TABLE 3.3. HPI Discount Factor as a Function of Time

70-year Time Period	Start Time year	Fractional Discount Factor
1	0	1.00
2	70	0.50
3	140	0.25
4	210	0.125
5	280	0.063
6	350	0.031
7	420	0.016
8	490	0.0078
9	560	0.0039
10	630	0.0020
15	980	6.1×10^{-5}
20	1330	1.9×10^{-6}
30	2030	1.9×10^{-9}
40	2730	1.8×10^{-12}
50	3430	1.8×10^{-15}
70	4830	1.7×10^{-21}
100	6931	1.6×10^{-30}

3.2.5 The Maximum Individual Index (MII)

In addition to the HPI, a Maximum Individual Index (MII) is computed from MEPAS outputs of maximum individual impacts for the modeled receptors. The maximum individual risk is equal to the maximum risk to an individual from all of the pathways identified for the constituent. The total exposure for a constituent is computed as the sum of the highest individual intake rates for each exposure pathway over all time periods. This maximum exposure may be greater than that which would occur to any one individual in the population. The same time weighting that is used for the HPI is also applied to the MII.

Mathematically, the MII is the sum of the risk factors. The risk factor is based on the maximum average daily intake from inhalation and ingestion (Dh_{ij}, Dg_{ij}) for all usage locations and time periods (Whelan et al. 1987). As with the HPI, the MII can be computed with and without time-discount factors.

$$MII_i = \sum_{j_n = 1}^{\text{exposure pathway}} RF_{ij} \text{ (maximum)}$$

where MII is the maximum individual index for constituent i, j_n is the numbered exposure pathways, and RF_{ij} is the maximum risk factor for constituent i and exposure pathway j for all usage locations and time periods based on daily average individual intake rates.

The MII used in the analysis in this report is a version of a maximum exposed individual parameter. The maximum exposed individual parameter is an index parameter representing the maximum risk that occurs in the affected population. The MII is based on the sum of maximum individual impacts that may be affecting different individuals. Although it is a conservative assumption to sum risks over pathways for individuals, the distinction is normally unimportant for screening applications because the highest risk value generally defines the magnitude of the summed risk.

The MII selected for this analysis represents only one method of using MEPAS outputs to define maximum exposed individual impact. For the RIS, the maximum individual impact is characterized by two parameters, one based on the highest impact to any current receptor and the other the maximum impact to a hypothetical individual at the site boundary.

4.0 HEALTH IMPACT PARAMETER ANALYSIS

An analysis was conducted to study the implications of the use of various measures of public health risk in the RIS. This analysis was based on the ranking units that were considered in the Preliminary Summary Report effort described in Section 1.2. These ranking units for the 16 DOE DP sites provide a set of cases for considering issues related to using various measures of public health risk.

The transport and exposure computations for these ranking units were rerun using the final Summary Report version of MEPAS. Following the efforts for the Preliminary Summary Report (DOE 1988), MEPAS was updated for the final Summary Report to incorporate refinements from ongoing efforts (Droppo et al. 1989a). This more recent version provides additional output parameters for characterizing different aspects of health impacts. A set of health impact parameters was thus generated for each constituent considered at each ranking unit. This version of MEPAS also incorporates a number of corrections and updates in the code and associated databases. As a result, a one-to-one correspondence will not necessarily occur between rankings in this report and rankings in the Preliminary Summary Report (DOE 1988), although only minor differences are expected for most cases.

As described in Section 3.0, MEPAS is a computer-based methodology that can be used to compute various human health impact parameters. In the preliminary ranking effort, a single MEPAS output parameter (HPI) was used as a measure of public health risk. In the final Summary Report effort, the RIS will use several measures of public health risk including aspects such as individual and population impacts, time of impacts, and type of impacts.

The results of the analysis of the various health impact parameters are discussed below in terms of comparisons between the HPI and alternative parameters to describe human health impacts. The range of concerns addressed in this analysis arose mainly as the result of experience and comments related to the preliminary ranking effort. For the sake of discussion, these concerns are stated in terms of a series of issues related to use of the HPI

alone (as was done in the preliminary ranking). The discussion of each issue includes background, analysis results, and conclusions.

4.1 MAXIMUM EXPOSED INDIVIDUAL

An issue being considered is whether to include a health impact parameter that reflects maximum individual exposure in addition to the HPI, which is based on population exposures. This issue was evaluated by comparing rankings of problems based on the HPI with those based on individual health impact parameters.

4.1.1 Discussion

If a population-impact-based parameter alone is used, the resulting ranking may not adequately characterize risk for those individuals with the highest computed exposure. Certain individuals within a population will either have lifestyles or locations that qualify them as maximally exposed individuals (e.g., avid fisherman for a situation where consumption of contaminated fish is the primary exposure pathway). Furthermore, the population ranking parameter may yield the same value for a case with low exposures in a highly populated area as a case with high exposures in a sparsely populated area. In an extreme case, an area with significant individual exposures could score lower than a more populated site that has minimal individual exposures. In contrast, for two environmental problems with identical maximum individual impacts, one centered in an urban area and another in a rural area, the population risk parameters for these two problems will reflect differences in the size of the affected populations whereas the individual risk parameters will not.

4.1.2 Analysis

The MII, which reflects risk to an individual with the highest exposures, was used to represent the individual impact parameter. The HPI, which reflects the average risk to a population, was used to represent the population risk parameter. To eliminate the effect of time discounting in comparing of MIIs and HPIs, the MII included the same time-discounting factor as the HPI. The influence of the time-discounting factor is considered

separately in Section 4.4. Furthermore, because the HPI is expressed as a logarithm of risk, the MII was converted to a similar scale.

Figure 4.1 shows the relationship between Log(MII) and the HPI for all 421 constituent pathways modeled for the 16 DP sites. The populations for the HPIs in Figure 4.1 range from 10 to 3,000,000 people. The correlation coefficient between HPI and MII is +0.94 indicating, as would be expected, that the HPI and MII are highly correlated.

The high correlation coefficient calculated for HPI and MII does not mean these two parameters are redundant. In fact, the scatter of the individual points in Figure 4.1 shows that a range of up to five in the Log(MII) occurs for any given HPI. This range corresponds to a five order-of-magnitude variation in the maximum individual risk for a given HPI value. Although the scatter appears to decrease with increasing HPI, this decrease could be the result of fewer data points used to compute the larger HPI values.

A line corresponding to regulatory decision levels for exposures of individuals is plotted on Figure 4.1. For this discussion, if a data point is above that line, that constituent is said to be "of regulatory concern for individual exposures." This line crosses the HPI population-based values at an HPI of about 40 points with a scatter of 15 points. Additional regulatory decision levels for exposure of populations are discussed by Travis et al. (1987).

Figures 4.2 and 4.3 are graphs of the HPI versus the MII for waterborne and atmospheric constituent pathway cases, respectively. There are 312 constituent pathways for the waterborne cases and 109 for the atmospheric cases. The data points for the waterborne (Figure 4.2) and atmospheric (Figure 4.3) constituent pathways show the same overall trend as the composite of all pathways (Figure 4.1). The correlation coefficient between HPI and Log(MII) for the waterborne cases (Figure 4.2) is +0.91; for the atmospheric cases, +0.93 (Figure 4.3).

Using Figures 4.1, 4.2, and 4.3 to indicate the correspondence between population and individual impacts provides a relationship that is consistent with the interpretation of HPIs used in the preliminary rankings (see

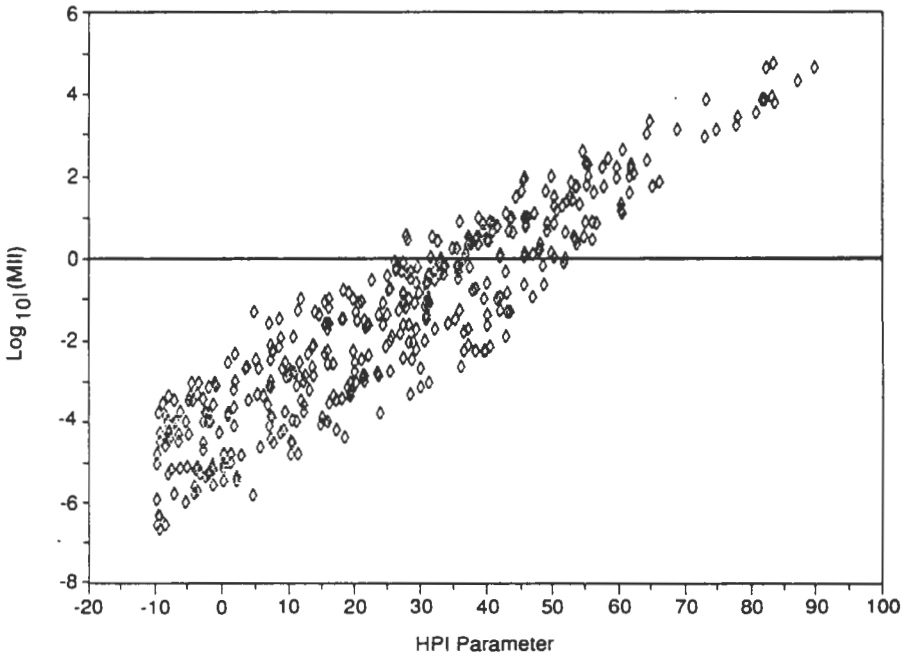

FIGURE 4.1. Log_{10} (MII) as a Function of HPI for All Constituent Pathways

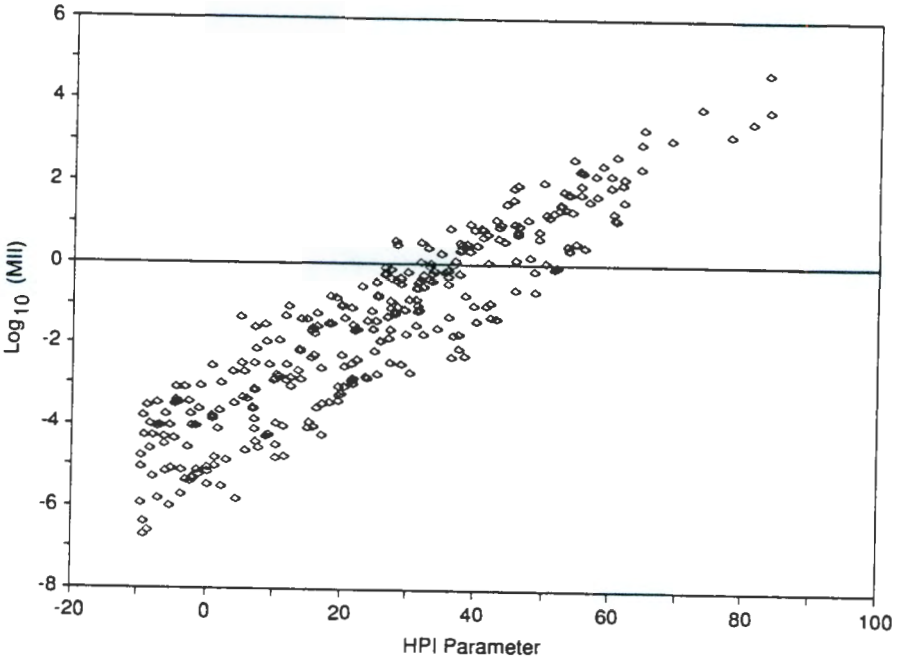

FIGURE 4.2. Log_{10} (MII) as a Function of HPI for Waterborne Constituent Pathways

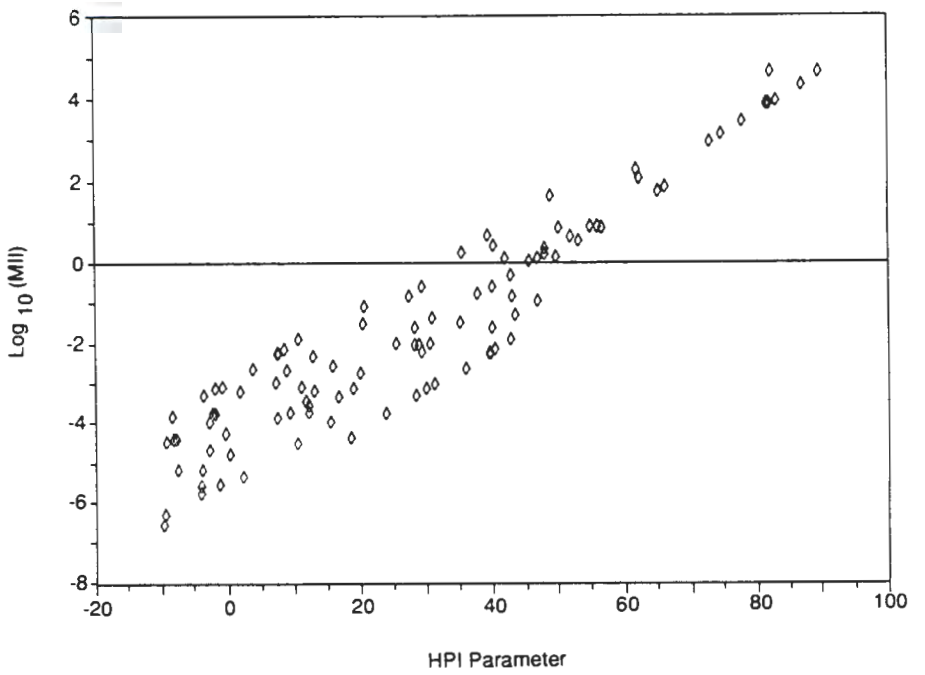

FIGURE 4.3. Log_{10} (MII) as a Function of HPI for Airborne Constituent Pathways

Table 1.2). HPI values for constituents in Groups 8, 9, and 10 (i.e., 70 < HPI ≤ 100) correspond to high MII values well above the level of regulatory concern at Log(MII) of 0; constituents ranked as Groups 6 and 7 (i.e., 50 < HPI ≤ 70) predominantly have an MII above the level of regulatory concern on Figures 4.1, 4.2, and 4.3. Groups 4 and 5 (i.e., 30 < HPI ≤ 50) have MIIs on the order of 1.0 and are borderline as being categorized of regulatory concern. The majority of constituents with an MII under 1.0 are assigned to groups denoting a low level of concern because of potential health impacts.

Although these graphs show a consistency with the HPI definitions in Table 1.2, the position of specific environmental problems (represented as data points) on this plot varies widely.

For illustrative purposes, a combination index "MIX" (short for mixture) is defined that attempts to represent both individual and population health impacts in a single parameter. This index was developed to investigate how these two regulatory approaches interact in various transport pathways. The MIX index is equal to the population risk (HPI) for cases where individual

exposures either exceed or are within an order of magnitude of a regulatory exposure limit. For lower exposures, the index is equal to the maximum individual exposure (MII).

To compare HPI and MIX parameters, the constituent pathways in the Preliminary Summary Report were ranked using the numerical values of both the HPI and MIX - the highest value had the number one ranking, the second highest the second ranking, etc. Each constituent pathway was thus assigned both an HPI ranking number and an MIX ranking number. These rankings are shown in Figure 4.4 where a low ranking number indicates a high HPI and a high ranking number indicates a low HPI. The correlation coefficient between HPI and MIX for all pathways (groundwater, overland, surface water, and atmospheric) in Figure 4.4 is +0.95.

The high correlation for the HPI and Log(MII) is due in part to the fact that MIX values are equal to HPI values for those cases that represent the worst human health impacts and have the highest ranking (i.e., approximately the first 100 cases). After the 100th-ranked constituent pathway, scatter begins to appear in the correlation between the two rankings. This is equivalent to the transition zone between using HPIs and MIIs to define the MIX parameter value (approximately the next 30 points). This scatter represents the difference between using the population-based HPI and using the population/individual MII combination parameters for ranking. After the 450th-ranked constituent the agreement between the HPI ranking parameter value and the MIX ranking value again becomes very close. This region of the plot represents cases with large populations and relatively low contaminant exposures where the MIX is nearly equal to the HPI.

The waterborne constituent pathways include both groundwater and surface water cases. Figure 4.5 is a graph of the HPI ranking versus MIX ranking for the groundwater constituent pathways. This plot shows a one-to-one correlation between the HPI and MIX rankings for the first 95 constituent pathways, which reflects the fact that the MIX parameter is defined by the HPI for these constituents. The MII is greater than 10% of the regulatory level of concern for these 95 constituent pathways. These 95 constituent pathways

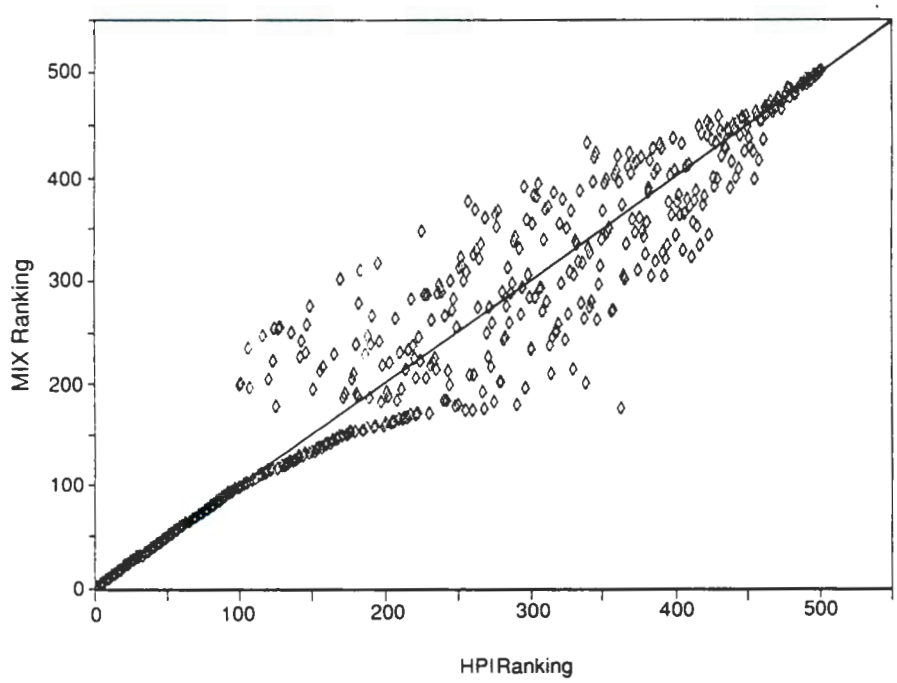

FIGURE 4.4. Comparison of Rankings Between the HPI and MIX Parameters for All Constituent Pathways

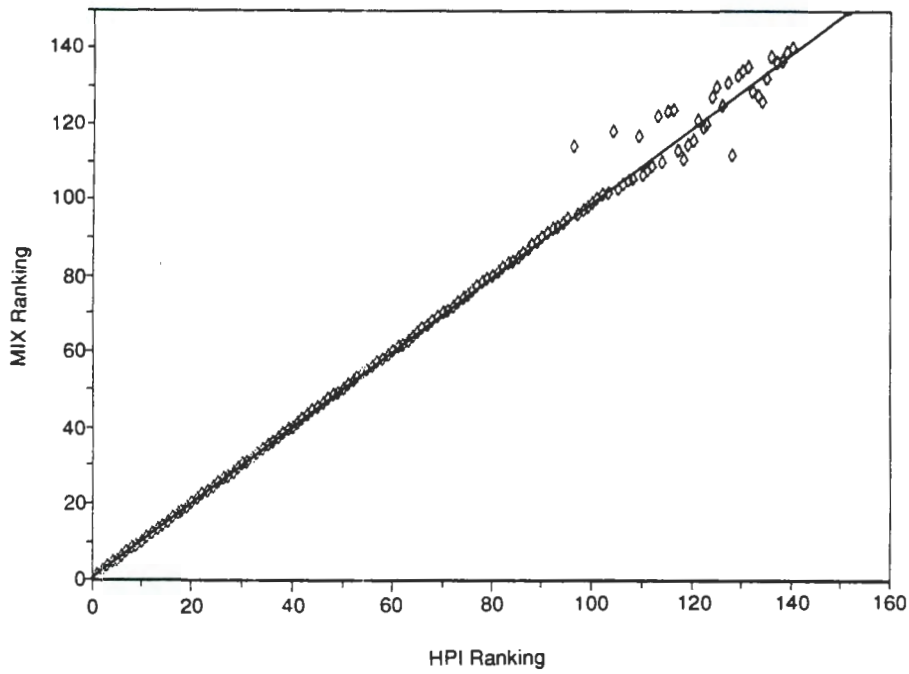

FIGURE 4.5. Comparison of Rankings Between the HPI and MIX Parameters for Groundwater Constituent Pathways

represent approximately 70% of the groundwater cases. A similar relationship occurred for the surface water cases.

Figure 4.6 is a graph of the HPI ranking versus MIX ranking for only the airborne constituent pathways. As noted for the groundwater pathway, there is a one-to-one correlation between the MIX ranking and the HPI ranking until near the 30th-ranked constituent. This plot indicates that only 30% of the constituents associated with the airborne pathways have MIIs greater than 10% of the regulatory level where the MIX is defined by the HPI. More scatter in the ranking occurs after this transition point than in the waterborne case in Figure 4.5. From the definition of MIX, the greater scatter for airborne than groundwater indicates that the airborne constituent pathways have a greater fraction of cases where the MIXs are defined by MIIs.

4.1.3 Conclusions

The analysis results show that maximum individual exposure information should be included in the RIS health impact ranking parameters. Rankings of constituent pathways based on the MII and HPI have similar overall trends, especially for the constituent pathways with larger computed human health impacts. The average results are equivalent, even when the data points are sorted by transport pathway. However, the scatter in the MII and HPI comparisons is large enough that rankings based on each of these individual parameters can be expected to show considerable variation on a problem-to-problem basis.

The analysis using the MIX parameter shows how the individual and population risk considerations interact. The MIX parameter resulted in a one-to-one correlation between MIX rankings and HPI rankings for about 25% of the constituent pathways. Thus, 25% of the constituent pathways in this data set have MIXs defined by MIIs. Nearly 70% of the ranked groundwater constituents had MIXs defined by MIIs, though only 30% of the airborne constituents had MIIs of this magnitude. This means that most of the groundwater pathways with high HPIs (greater than 40) are probably also above regulatory limits. In the case of the airborne constituent pathways, most of the cases with high HPIs tend to have a mixture of MIIs above and below the presumed regulatory

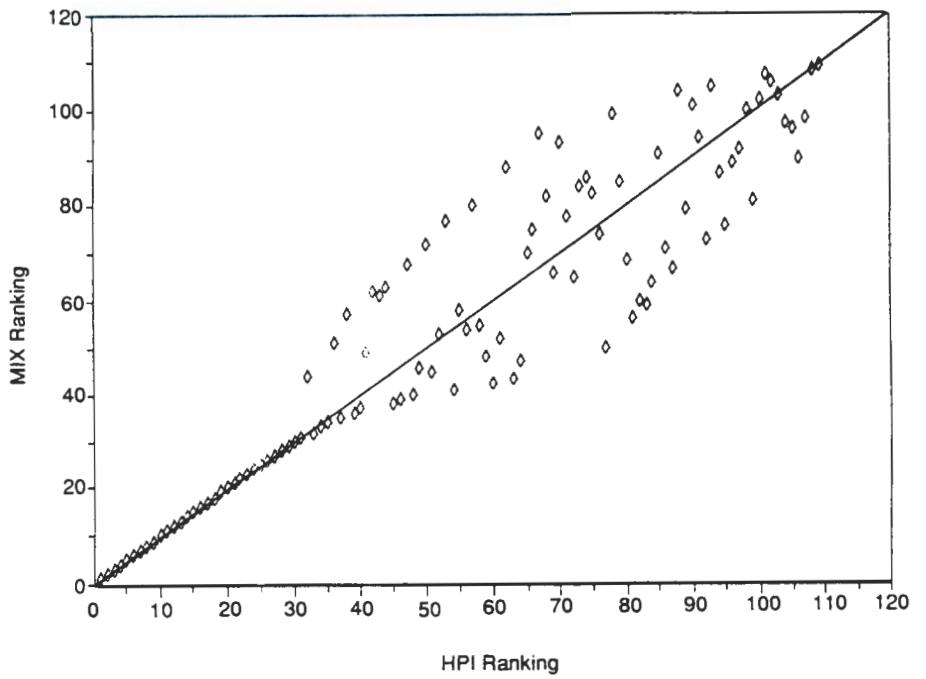

FIGURE 4.6. Comparison of Rankings Between the HPI and MIX Parameters for Airborne Constituent Pathways

limits. The combined information generated by using both the HPI and the MII appears to affect the airborne rankings more than the waterborne rankings.

The HPI and MII are thus related but are different measures of potential impacts. Based on external review guidance to provide whenever possible actual statistics on different aspects of risk, a combination parameter such as MIX was not adopted in the RIS. Separate parameters were used to characterize the population and individual impacts. Individual impacts are incorporated in the RIS by use of two parameters to characterize maximum individual impacts to a modeled receptor and hypothetical maximum individual impacts defined at the facility boundary. The former provides an indication of current maximum individual impact, and the latter provides an indication of the maximum possible individual impact.

4.2 TYPE OF CONSTITUENT IMPACT

An issue being considered is whether to use the HPI as a single ranking index to compare constituents with different types of health impacts. The

principal concern is comparisons of carcinogenic and noncarcinogenic impacts. A secondary concern is the variation of effects within each constituent type (e.g., radioactive and chemical carcinogens). Analysis of the DOE ranking units in the Preliminary Summary Report provided information on the distribution of HPIs in the different constituent categories.

4.2.1 Discussion

The issue of comparing impacts from different types of constituents arises because carcinogens and noncarcinogens cause different types of health effects. Carcinogens are of concern because they cause cancer. Radioactive carcinogenic constituent risk parameters are based on cancer fatalities (NAS 1980, 1990). Human health risk parameters for chemical carcinogenic constituents are based on cancer incidences or fatalities depending on the database used by the EPA in determining the dose response function for each constituent. Effects of noncarcinogenic constituents are general measures of human health impacts, with emphasis on health impacts that may be considered life threatening.

In MEPAS, the effects of carcinogenic chemicals are based on cancer potency factors and dose. The risk resulting from exposures to carcinogenic chemicals are then compared to a risk limit set in EPA guidance. A standard level of protection of public health is about one cancer per million people (EPA 1989b) or a 10^{-6} risk limit. An initial review of the recently proposed revisions of toxicity assessment for radioactive materials (NAS 1990) suggests that these revisions would increase the estimate of the number of fatal cancers per unit exposure. This change, which involves less than an order of magnitude, will result in a relative increase in importance of radioactive carcinogens compared to chemical carcinogens. This shift is not expected to significantly affect overall comparisons of problems with differences in computed risk spanning many orders of magnitude.

The potential for health effects from a noncarcinogenic chemical is based on a comparison of the actual dose with the acceptable exposure limit, RfD (EPA 1989b). Noncarcinogenic health effects are assumed to only occur above this RfD. The RfD is thus a threshold limit for exposure above which health effects may occur. It represents a standard level of protection for

noncarcinogens. The question of how to include threshold information for noncarcinogens in the RIS is addressed separately in Section 4.3.

As part of the concern over comparison of different effects, the question arises of how the HPI relates to the number of effects. The HPI is defined in terms of a ratio of the exposure for a constituent compared to a regulatory level of protection for public health for that constituent. For carcinogens this HPI definition makes the HPI proportional to the logarithm of the number of effects. For exposures to noncarcinogens that exceed the RfD, the number of health effects are expected to increase with larger HPI values. However, for noncarcinogens, the HPI is not expected to be necessarily proportional to the logarithm of the number of effects. For exposures less than the Rfd, the HPI is a level of concern index representing only how close the predicted exposures are to a maximum acceptable exposure represented by the RfD.

4.2.2 Analysis

To analyze the issue of type of constituent impact, the constituent types were defined for each HPI based on the largest contributor to impact at each ranking unit. Figure 4.7 shows the distribution of carcinogens and noncarcinogens for these ranking units. The percentage of the constituents in each HPI group (with each group 10 HPI points wide) for carcinogens is generally greater than for noncarcinogens. Figure 4.7 shows HPIs for all constituents modeled for the ranking units (as opposed to the highest scoring constituent), and therefore does not show the relative percentage of those ranking units with the highest HPIs for carcinogens and noncarcinogens. Inspection of data points for the individual ranking units summarized in this plot revealed that when a ranking unit contained a mixture of carcinogens and noncarcinogens, the carcinogenic risk tended to be larger than the noncarcinogenic risk.

The analysis showed that the issue of comparing carcinogens and noncarcinogens applies to ranking units with low HPI scores. The issue of whether or not to include threshold information is particularly applicable for these lower HPI values (see discussion in Section 4.3).

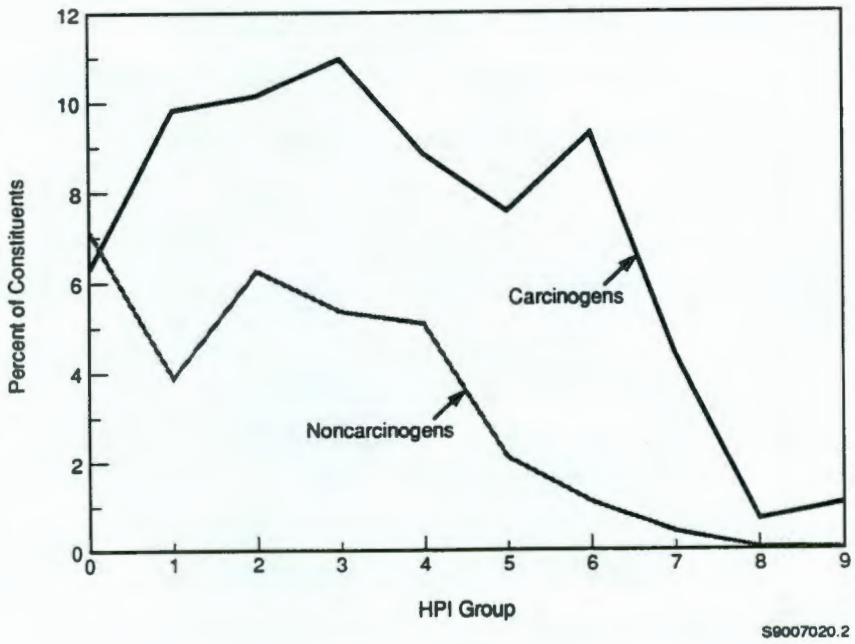

FIGURE 4.7. Percentage of Carcinogen and Noncarcinogen Constituent Types by HPI Groups for All Constituent Pathways

4.2.3 Conclusions

The discussion and analysis clearly indicate the care that must be taken in using the HPI as a single ranking index to compare different types of health impacts. Although the HPI formulation results in a convenient continuous index for all cases where contamination reaches the receptors, additional information on type of impact (carcinogenic or noncarcinogenic) is needed to interpret HPI values in terms of expected effects.

The comparison of HPI values based on different types of health impacts is addressed in the RIS by providing a health effect category. This category defines the type of effect (radionuclide carcinogen, chemical carcinogen, or noncarcinogen) represented by the constituent with the largest component impact in the HPI for a ranking unit. The carcinogenic types are divided into chemical and radiological because historically these two types have been treated independently.

4.3 THRESHOLD LIMIT FOR NONCARCINOGENIC CONSTITUENTS

How the threshold limit for noncarcinogenic constituents should be incorporated into the ranking process is also an issue of concern. This issue was addressed by comparing rankings generated using different threshold assumptions.

4.3.1 Discussion

In risk assessment analyses, effects from noncarcinogenic chemicals are based on a comparison of the actual dose with the acceptable limit, RfD (EPA 1989b). According to EPA's definition, noncarcinogenic effects only occur above a threshold limit that is equal to the RfD.

For the HPI parameter, a linear model is used to represent noncarcinogenic constituents such that for all exposures the HPI is based on fractional values of the RfD at the receptor. The HPI formulation is an expedient method for generating a continuous ranking for all cases where contamination reaches the receptors.

The concern arises because if no threshold is used for noncarcinogens, it is possible for comparisons to be made of no-effect noncarcinogenic exposures with expected-effect carcinogenic exposures. Because the HPI considers the exposed population, it is also possible that no-effect exposures for large populations may be ranked higher than expected-effect exposures for smaller populations.

Because the RfD is, by definition, a safe intake rate, the RfD is a logical parameter to use as a threshold value to separate exposures. In the current screening of a large number of sites, large uncertainties exist in the computed magnitudes of exposures (see Section 5.0). As a result of this uncertainty, the use of a threshold value may not be as appropriate as in more detailed individual site investigation where the uncertainties may be less.

4.3.2 Analysis

To analyze use of a threshold limit, the Log(MII) is plotted versus the HPI for noncarcinogenic constituent pathways in Figure 4.8. This graph can be compared to Figure 4.1, which includes evaluation of all constituents.

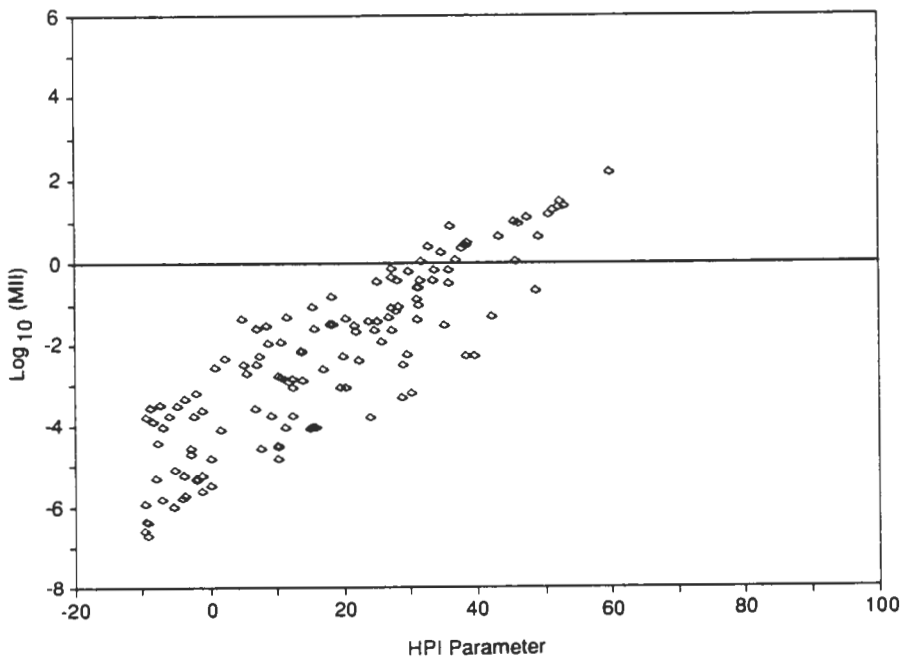

FIGURE 4.8. Log_{10} (MII) as a Function of HPI for Noncarcinogenic Constituent Pathways

The noncarcinogenic constituent pathways account for 31% (131 out of 427) of all the constituent pathways analyzed that had HPIs greater than -10.0. The horizontal line at Log(MII) equal to 0.0 corresponds to exposure at the RfD value for the noncarcinogenic constituents.

The use of a cutoff limit below which the noncarcinogens are not included in the rankings was considered in this analysis. If only noncarcinogenic constituents with their intake rates greater than or equal to the RfD (threshold limit model) were used for ranking, only 15% of these constituents would be ranked. In Figure 4.8, all noncarcinogens have been ranked and their scores reported. Figure 4.9 shows the percentage of noncarcinogenic constituents that would be ranked based on different cutoff levels referred to the threshold limit. The cutoff values plotted on the logarithmic x-axis correspond to the minimum MII values for constituents that are considered in the ranking. A cutoff equal to the RfD has a value of

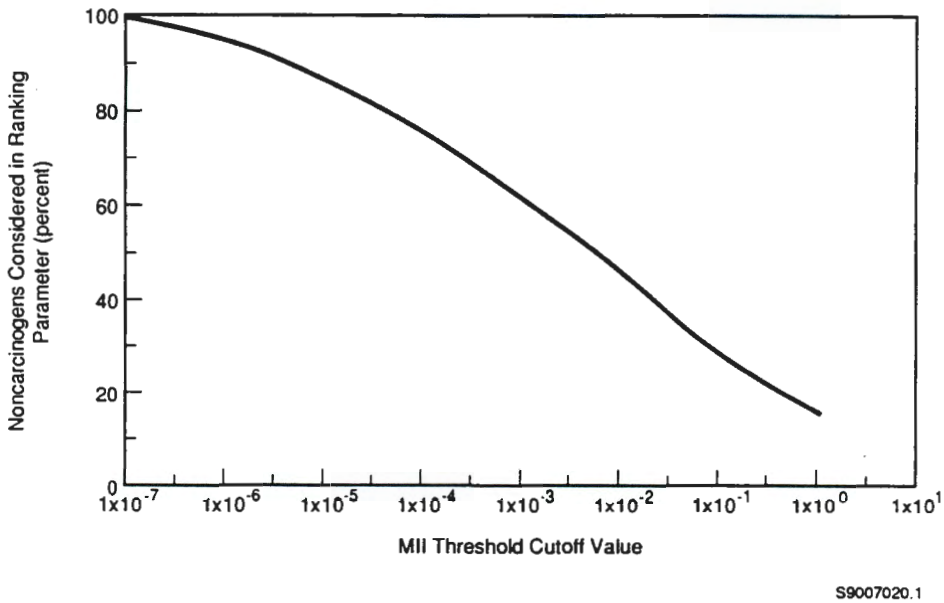

FIGURE 4.9. Percentage of Noncarcinogenic Constituent Pathways Ranked as a Function of MII Threshold Cutoff Value

1 (1×10^0). Although expressed as powers of ten, the MII data plotted in Figure 4.9 are not risk values but rather the ratios of the exposures to the RFD for each constituent.

The relationship shown by the points plotted in Figure 4.9 can be used to estimate the percentage of noncarcinogenic constituents that could be included for different selections of MII cutoff values. Including all noncarcinogens in this data set is equivalent to having a MII cutoff limit of 10^{-7}. When the MII cutoff is set equal to the reference dose (1×10^0), all but the highest 20% of MII values are eliminated. If an MII cutoff of 0.1 (1×10^{-1}) is used then the highest 30% of the MII values are used.

4.3.3 Conclusions

This issue of a threshold limit for noncarcinogens is addressed in the RIS by providing additional information to interpret the HPI (as opposed to computing the HPI with a threshold level for noncarcinogens). A health effect category from MEPAS is supplied to provide a definition of the type of effect (radionuclide, chemical carcinogen, and noncarcinogen) associated with a particular constituent generating the HPI score. In addition, the maximum

individual risk input parameters for the RIS define how close the computed maximum individual risk is to a regulatory level of concern for each type of constituent.

For noncarcinogenic constituent exposures below the Rfd, the HPI provides useful ranking information on the proximity of the exposures to effects levels. However, the analysis shows that information on the maximum individual exposure needs to be included in the ranking process. Although the magnitudes of these HPIs generally correspond to a relatively low level of concern, considerable scatter occurs in the relationship between the Log(MII) and HPI. Ranking units with HPIs indicating impacts of secondary concern have exposures both greater than and less than the RfD (Figure 4.8). The maximum individual exposure provides additional information for case-by-case interpretation of the HPI.

The results show that the rankings obtained are consistent with the definitions of HPI groups used in the preliminary rankings (see Table 1.2). No noncarcinogenic constituents ranked as Group I, and only a few that ranked as Groups II and III were above or near the RfD value. All noncarcinogenic constituents well below the Rfd were assigned to appropriate groups representing a low level of concern for potential health impacts.

4.4 TIME OF IMPACT

The issue of whether to include the time of impact in the set of health impact parameters in the RIS was studied by comparing rankings based on time-discounted and undiscounted risks.

4.4.1 Discussion

The time at which impacts occur can be an important aspect of the potential health impacts for an environmental problem. The time of impact provides information that can be used to assign different weights to predicted impacts based on when they occur. Normally, a major impact that will occur tomorrow is of more concern than an equal impact that will occur 7000 years from now.

For each constituent, MEPAS provides information on the time of first arrival, time of arrival of peak concentrations, and duration of exposure at the receptor location. MEPAS also provides detailed tables of environmental constituent concentrations as a function of time at the receptor. These parameters describe the distribution of contaminant arrival at a receptor.

The HPI includes a factor for progressively discounting future impacts as a function of when they occur. MEPAS computes the HPI for consecutive average 70-year time periods for a total of 100 time periods (i.e., 7000 years). Seventy years is assumed to represent a typical lifetime of an individual. A time weighting factor reduces the magnitude of the health impact exponentially with a half life of 70 years for every 70-year time interval beyond the first 70-year period. Table 3.3 lists the time weighting factors for selected times during the 100 70-year lifetime periods used to compute the HPI. The weighting factors in Table 3.3 are approximately equivalent to a 1% annual discount rate.

Time of travel is mainly of concern for cases involving movement of contaminants through groundwater because exposure times often extend, or occur, beyond the first 70 years. Other waterborne and airborne pathways generally have considerably faster movement of constituents in the environment. For example, the HPI for airborne releases is evaluated only for the first 70 years based on the assumption that these immediate impacts will always be the greatest in this pathway.

The choice of whether or not to use discounting for future health impacts is mainly a policy issue. The argument in favor of using a time weighting factor is that the more immediate environmental problems should be ranked higher than ones that may occur in the future. The opposing argument is that major future problems may receive low or insignificant rankings compared to less important near-term problems. A related argument against discounting future impacts is that now is the best time to remedy certain long-term impacts.

Related to the time-of-impact issue is the assumption that existing conditions will remain the same into the future. No allowance is made for future population, land-use, or climate changes. This assumption of static

conditions when evaluating future impacts is often referred to as a "snapshot" approach. Morris and Meinhold (1988), in their discussion of time considerations for MEPAS, point out that not only are populations, rivers, lakes, and land formations subject to change, but advances in medical science might also make exposures to carcinogens or other toxic materials unimportant. Morris and Meinhold (1988) suggest that major changes in rankings can result from reasonable changes in the environmental conditions. However, they also acknowledge that predicting such changes would be virtually impossible. Furthermore, including potential changes will tend to greatly increase the uncertainty in the resultant rankings. Morris and Meinhold (1988) conclude that the assumption of static conditions does provide a well-defined situation for a comparative analysis and the resultant rankings do reflect the relative hazard presented by different waste sites. They also note that the time discounting factor reduces the importance of long-term effects, which are much more uncertain compared to near-term effects.

4.4.2 Analysis

Although complete resolution of the time-of-impact issue is beyond the scope of this report, the following comparisons of undiscounted and discounted ranking parameters will provide information for evaluating effects of time discounting. HPIs with time discounting, HPIs without time discounting and Time Of Arrival (TOA) of contaminant at the exposure location were computed for each the ranking units considered in the Preliminary Summary Report. The TOA is the time at which an MII computed for a constituent in a drinking water pathway first exceeds a value of 0.10. Thus the TOA indicates the time at which significant concentrations first reach the receptor.

For the purposes of this analysis, the cases with a TOA less than or equal to 70 years have been separated from cases with TOA values greater than 70 years. The former represents cases with near-term impacts and the latter represents cases with impacts in the distant future. The near-term impacts reflect relatively short groundwater travel times normally resulting from some combination of small distribution coefficients (K_ds) for constituents, high groundwater velocities, and/or short travel distances.

Figure 4.10 is a plot of discounted HPI versus undiscounted HPI for cases with impacts starting during the first 70 years. The high correlation reflects the small effect of the discounting factor for impacts starting in the first 70 years (but perhaps extending out over several lifetimes). Cases falling on the one-to-one line represent cases in which all the significant impacts occurred in the first 70 years. Cases above the line are cases in which the HPI has significant contributions from impacts occurring after the first 70-year time step.

Figure 4.11 is a plot of discounted HPI versus undiscounted HPI for cases with impacts starting in the distant future (i.e. after the first 70-year time period). The effect of discounting on the ranking parameter for future impacts is obvious. The scatter from the one-to-one line indicates that the HPI scores are reduced between 0 to 60 points by the time discounting.

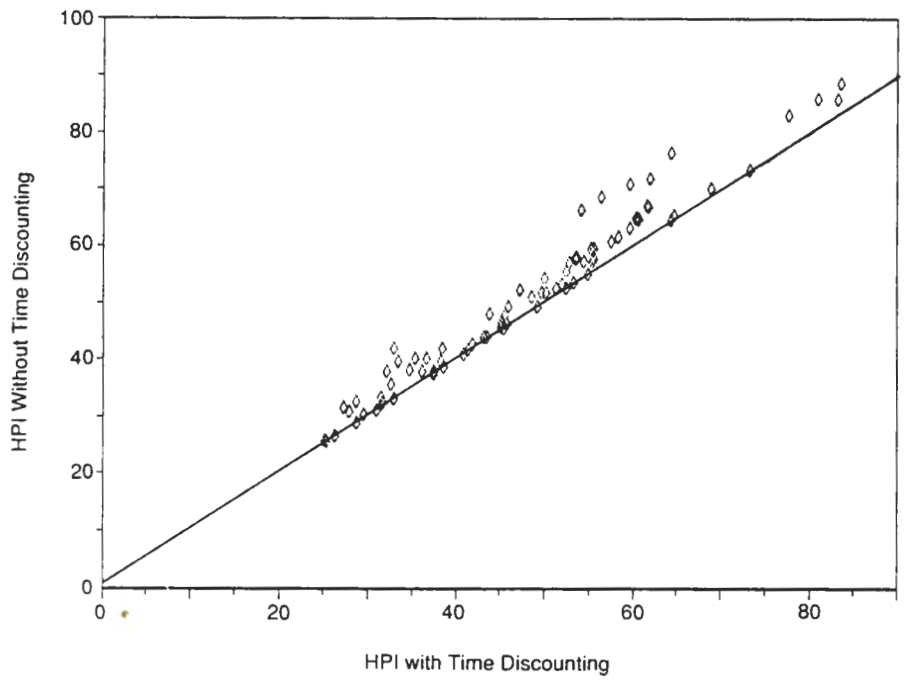

FIGURE 4.10. Undiscounted HPIs as a Function of Discounted HPIs for Waterborne Constituent Pathways with Impacts Starting in the First 70 Years

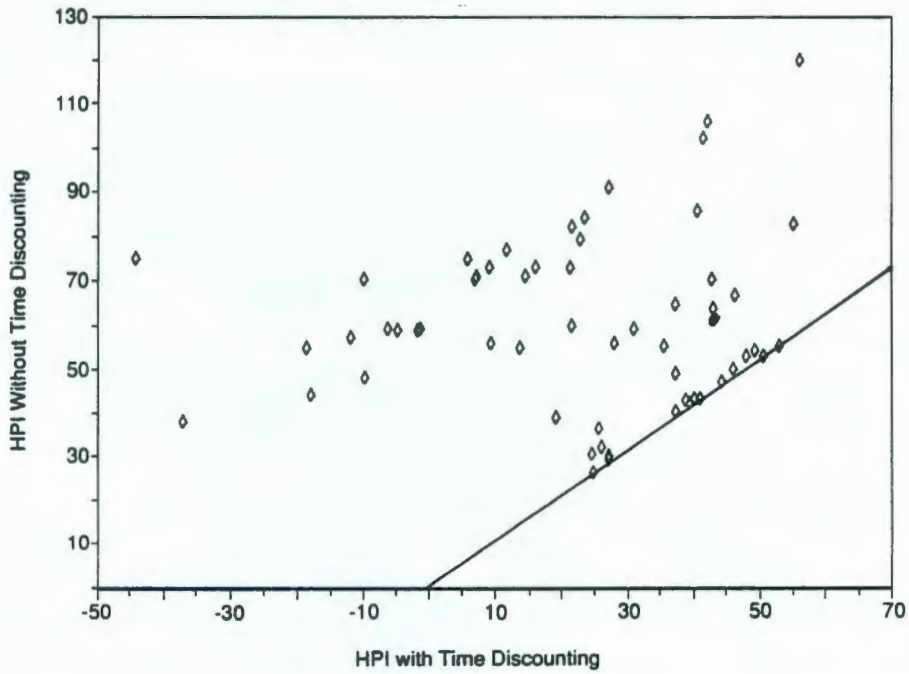

FIGURE 4.11. Undiscounted HPIs as a Function of Discounted HPIs for Waterborne Constituent Pathways with Impacts Starting after the First 70 Years

4.4.3 Conclusions

This analysis shows that the time-discount factor does significantly reduce the magnitude of the ranking parameter for future impacts (Figures 4.10 and 4.11). The ranking parameter without the time discounting factor provides valuable additional information for interpreting the ranking parameter with the time-discount factor.

The effect of time of impact is incorporated two ways in the RIS. For near-term impacts (those predicted to occur in the first 70 years), the time of arrival is used as a measure of the immediacy of the problem. A RIS parameter is provided that designates the arrival time in one of five time period groups covering the first 70 years. For impacts of concern beyond the first 70 years, the time when impacts are predicted to occur is accounted for in the HPI by the time discounting factor.

4.5 PEAK VERSUS INTEGRATED EXPOSURES

Also considered is whether the ranking should be based on exposures calculated from peak or average concentrations. This issue was addressed by comparing ranking parameters based on peak concentration with the HPI, which is based on integrated exposures.

4.5.1 Discussion

Transport scenarios involving the groundwater pathway often have impacts extending far into the future. HPIs are based on the sum of time series of 70-year-average contaminant impacts at the receptor for the next 7000 years. A time discounting factor is used to discount future impacts (see Section 4.4). These concentrations may take hundreds or even thousands of years to arrive at a receptor because of slow groundwater flow rates or attenuation in the soil. Thus for groundwater transport, the water concentrations may first arrive at the receptor far in the future. In addition to arriving in the future, the arrival distribution may also be spread over hundreds or even thousands of years depending on source characteristics, groundwater flow, and attenuation. Thus, the distribution of effects for contaminants in the groundwater pathway at a particular site may be spread over quite different periods of time.

4.5.2 Analysis

The distribution of environmental concentrations at the receptor influences the determination of human health impacts over time. An approach other than using average concentrations is to base the ranking parameter on the peak concentrations. The approach for analyzing peak versus integrated exposures was to examine the relationship between ranking with HPIs and a new parameter, Npeak, which is based on normalized peak concentrations. Npeak for a constituent pathway is defined as the peak water concentration at the receptor divided by the water concentration corresponding to a regulatory level for that constituent. The objective is to see how similar or dissimilar the ranking results are based on these two parameters.

Npeak differs from the HPI in two ways. First, Npeak is based on a single peak exposure rather than an exposure integrated over time. Second, Npeak does not include a time discounting factor. Npeak differs from the undiscounted HPI only in the concentration used to characterize the exposure.

To evaluate the relationship between Npeak and an equivalent HPI parameter, Npeak was plotted as a function of undiscounted HPI (Figure 4.12). The results indicate a relationship exists between this HPI and Npeak parameters, although considerable scatter occurs in the relative rankings indicated by the two parameters.

4.5.3 Conclusions

The comparison between rankings generated with integrated concentrations and rankings based on peak concentrations shows that although a relationship exists between the HPI and Npeak parameters, they provide rankings with

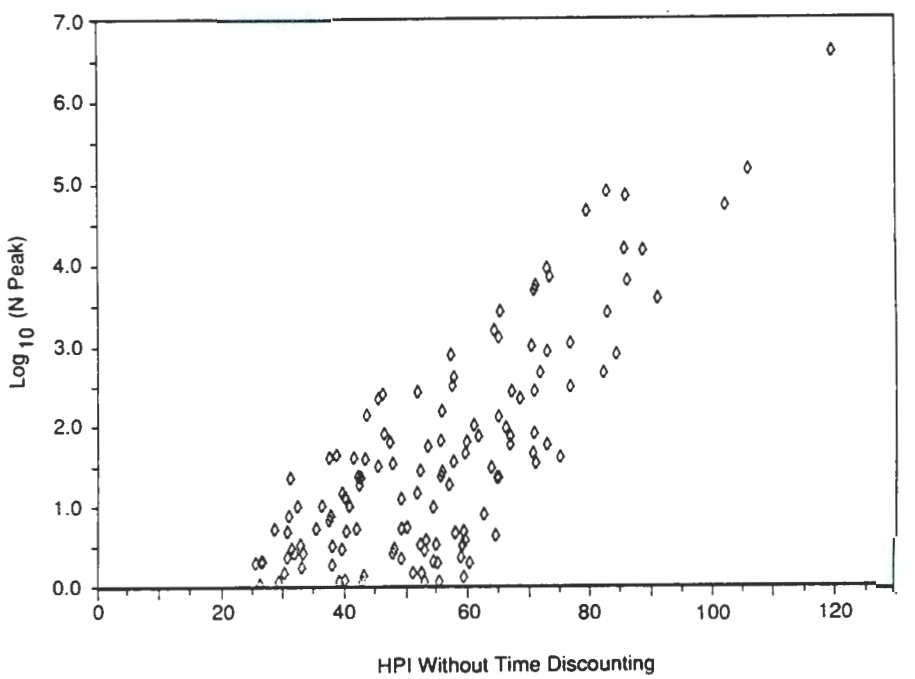

FIGURE 4.12. Log_{10} of Normalized Peak Water Concentration as a Function of HPI Without Time Discounting

significant differences. The scatter may represent differences in the distribution of how impacts are predicted to occur and not necessarily differences in total impacts.

Although the RIS does not directly incorporate a peak exposure parameter, selected information is provided in the RIS on the time distribution of impacts. The RIS provides a time of arrival to define when near-term (i.e., first 70 years) impacts start. The RIS uses maximum 70-year values to define maximum individual impacts to modeled and hypothetical receptors.

4.6 SINGLE VERSUS MULTIPLE CONSTITUENTS

An issue being considered is whether to characterize impacts of a ranking unit based on the constituent with maximum impact, as is done with the HPI, or on the sum of impacts by multiple constituents. This issue is addressed by comparing rankings generated using both assumptions.

4.6.1 Discussion

The use of the constituent with the greatest impact to represent the impacts of a site allows the analysis to focus on the worst constituent at a site. Furthermore, there is no credit or penalty to the ranking based on the number of constituents modeled. Of course, the more constituents that are known and modeled, the greater the probability that a constituent with a large impact is included. The use of the constituent with the greatest computed impact also avoids the issue of adding impacts across different constituent types. Because different types of constituents cause different health effects (see Section 4.2), simple addition of level-of-concern indexes may be inappropriate.

To understand the difference between the two methods tested for ranking environmental problems, one must understand how the last step of the HPI is calculated. The HPI is based on a logarithmic scale; an HPI is defined for each constituent pathway at a ranking unit. The equation for an HPI is

$$HPI = 10 * LOG(PI)$$

where PI is the Preliminary Hazard Index of concern for each transport and exposure pathway for a particular constituent. The PI can be thought of as equivalent to the number of health effects for an exposed population.

Because the HPI is based on a logarithmic scale, the sum of impacts from multiple constituents must be much larger than the maximum impact from a single constituent (i.e., the basis of the HPI) for the multiple constituent HPI to be significantly different than the single constituent HPI. For example, consider a ranking unit with PIs for constituents A and B of 1.0×10^2 and 5.0×10^2, respectively. The individual HPI would be 20.0 for constituent A and 27.0 for constituent B. Because the ranking units are ranked by the constituent with the largest HPI value, the HPI for the ranking unit in this example would be 27. Basing the ranking on the sum of PIs for these two constituents, the resulting HPI for the ranking unit is 27.8. Even if these two constituents, A and B, each had equal impacts that gave HPIs of 27.0, the HPI based on the sum of PIs for these constituents would be 30.0 showing that the magnitudes of HPIs are relatively insensitive to whether impacts are based on one or multiple constituents. The argument for the use of total constituent impacts is mainly that this approach provides a more comprehensive characterization of impacts. In the extreme case, use of a single constituent could result in a site with multiple constituents being ranked lower in importance than a site with a single constituent, even though the total risk from the multiple constituents is greater than that of the single constituent.

4.6.2 Analysis

In the preliminary rankings, the HPI score for a ranking unit was based on an HPI computed from the constituent with the maximum human health impact. As part of the HPI computation, the individual impacts were computed for all constituents of concern in each ranking unit. In this analysis alternative HPI values were computed based on the sum of impacts for multiple constituents, rather than the highest impact from a single constituent.

Figure 4.13 shows the comparison between the two ranking approaches: one based on the highest impact for a constituent and the other based on the sum of impacts for all constituents. There are only small differences

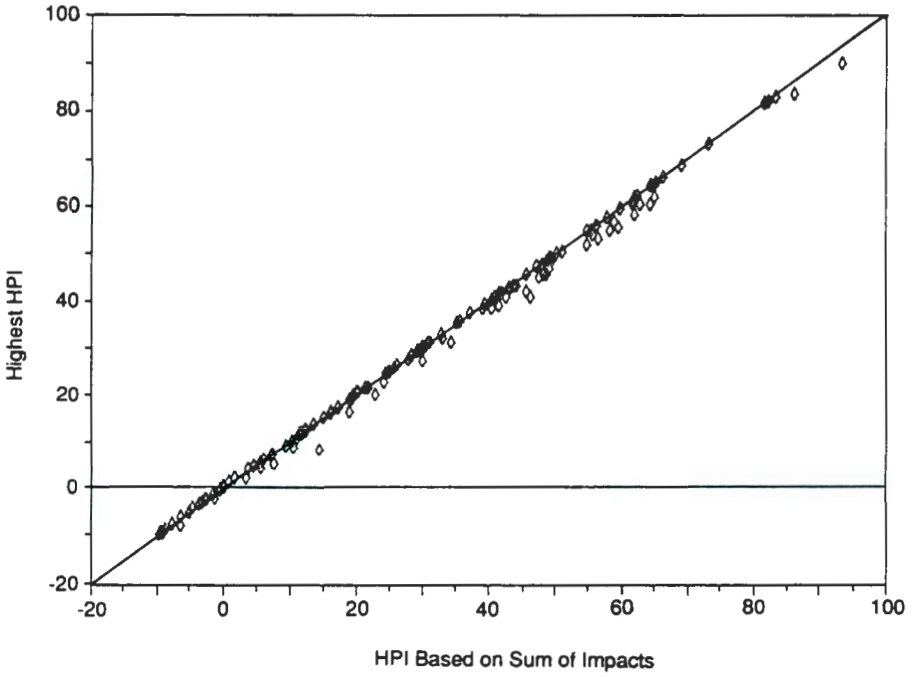

FIGURE 4.13. Highest Scoring HPI as a Function of HPIs Based on Sum of Impacts

between these two rankings. The largest difference between these two rankings is less than 5 HPI points, which is within the overall uncertainty of HPIs as discussed in Chapter 5.0.

4.6.3 Conclusions

There is little difference between basing the HPI on the constituent with the maximum impact and basing the HPI on the sum of impacts for all constituents. The logarithmic nature of the HPI requires large changes in the impacts to change the HPI significantly.

The RIS uses rankings based on both the maximum single constituent as well as the sum of modeled constituents. Although there is little difference between the rankings based on single and multiple constituent impacts, the inclusion of HPIs computed by both approaches will provide information on the multiplicity of defined contaminants at a site.

5.0 UNCERTAINTY IN HEALTH IMPACT PARAMETERS

Uncertainties associated with the exposure assessment process include input parameter uncertainty, model uncertainty, scenario uncertainty and risk factor uncertainty (EPA 1988). The EPA notes that estimating uncertainty from all the above sources quantitatively is difficult for applications of models (such as MEPAS).

Input parameter uncertainty for MEPAS describes how well the input parameters are known. This uncertainty includes error in actual measurements of the parameters and error resulting from inadequacies in the characterization data used for the input parameters. Also recognized by EPA (1988) are uncertainties related to computing human health impact. The uncertainty in computing health impact parameters together with the measurement errors represent baseline variability for the input parameters.

Model uncertainty is a measure of how well a model describes the physical processes being represented in an application. Aspects of model limitations are discussed in the mathematical formulations documents for MEPAS (Droppo et al. 1989a; Whelan et al. 1987). To supplement these MEPAS formulations, a discussion of mass budgets uncertainty is given in Appendix A. For the preliminary rankings, the Survey documented sources of model application limitations (DOE 1988). The final Summary Report will also discuss model application limitations.

In applications of models such as MEPAS, a common assumption is that conditions remain static. This assumption means that future populations, land use, and climate, for example, do not change in the future. In addition, medical science, upon which the parameters used to estimate human health impact are based, is also assumed not to change. These assumptions result in exposure scenario and risk factor uncertainty.

Uncertainties in input parameters and models may have different impacts for different problems. Morris and Meinhold (1988) point out that uncertainty in inputs may result in a conservative characterization of a problem. For such instances, high impacts computed for poorly characterized sites may be the direct result of uncertainty in input parameters. Because problems

with larger input uncertainties will tend to be ranked higher rather than lower as the result of the use of conservative assumptions for those cases, the process will tend not to exclude potential problems as a result of the uncertainty in the computed risk parameters.

5.1 EVALUATION OF UNCERTAINTY FOR THE ENVIRONMENTAL SURVEY

Uncertainties in the health impact parameters generated by MEPAS can arise from data, model, and application uncertainties. Data uncertainties occur for application-specific data (i.e., input parameters) and for fixed-value data (i.e., constants) associated with the computer code or its associated databases. A sensitivity analysis for the MEPAS application to the Environmental Survey (Doctor et al. 1990) was conducted to determine the minimal variability in HPI values associated with the various transport and exposure components of the MEPAS methodology. The variability in user-defined input parameters was chosen to be the smallest expected for each parameter at an ideal well-characterized site. The sensitivity analyses were performed for a set of environmental pathways and exposure scenarios representative of those associated with the DOE ranking units described in the Preliminary Summary Report (DOE 1988).

The sensitivity study did not address uncertainties in constants used in the model. The uncertainty of constants in the model can vary depending on the nature of the constants. For example, most of the physical and chemical parameters treated as constants have accepted fixed values, and uncertainty for those parameters is therefore small. However, many of the toxicological parameters that were also treated as constants are known to have large uncertainties associated with them. This uncertainty in the toxicological parameters is known to be a major source of uncertainty in computed health impacts (EPA 1988). An initial analysis of the uncertainty from toxicological parameters was conducted and is reported in Appendix B. This analysis was developed for assessing uncertainties associated with these parameters based on the source and quality of information.

The uncertainty for MEPAS application to the Environmental Survey was evaluated with respect to application-specific data. The baseline HPI

uncertainty for a well-characterized site is discussed. The way that uncertainty was accounted for in the Survey is described in the section on data quality categories.

5.1.1 Baseline HPI Uncertainty

One of the inputs to the RIS is a baseline HPI variability for a well-characterized site representing the major transport and exposure scenarios identified by the Survey. A sensitivity analysis (Doctor et al. 1990) provided estimates of the baseline variability for a representative set of the transport pathways and exposure routes used in the Survey (DOE 1988).

The baseline HPI variability for four categories of constituents and the groundwater and overland flow pathways from Doctor et al. (1990) is given in Table 5.1. The four categories, based on combinations of constituent half-lives and constituent distribution coefficient (K_d), in Tables 5.1 though 5.4 are 1) radionuclides with short half-lives (<140 years) and low K_d (<1.0 mL/g)[a]; 2) radionuclides with short half-lives and high K_d, represented by ^{90}Sr and ^{90}Y; 3) either organic or, inorganic constituents, or radionuclides with long half-lives and low K_d, represented by perchloroethylene (PCE) and toluene; and 4) either organic or inorganic constituents, or radionuclides with long half-lives and high K_d, represented by As, PCE, and Hg.

The HPI ranges for the waterborne transport in Figure 5.1 are given for known flux cases (known flux) and precipitation-driven (precip) "ranking unit to groundwater to surface water" (RU -> GW -> SW) pathways and for precipitation driven "ranking unit to overland to surface water" (RU -> OL -> SW). The baseline variability of the atmospheric pathways from Doctor et al. (1990) is given in Table 5.2. HPI ranges are given for a point (stack) release both with downwash (DW) and without downwash (NDW) for "ranking unit to airborne exposure" (RU -> AIR). HPI ranges are given for area particulate (resusp) and gaseous (volatil) releases.

(a) In the application of these results to the implementation of RIS, the criteria for application of the "low K_d" results were expanded to include K_d less than or equal to 3 mL/g.

TABLE 5.1. Base HPI Ranges for Waterborne Transport Scenarios and Constituent Types for the MEPAS Methodology[a]

Transport scenario linkage	Radioactive constituent with a short half-life		Radioactive, organic, or inorganic constituent	
	low K_d	high K_d	low K_d	high K_d
RU->GW->SW precip	2	28	3	28
RU->GW->SW known flux	4	32	2	18
RU->OL->SW precip	22	30	29	33

(a) "RU" = ranking unit, "GW" = groundwater, "SW" = surface water, "OL" = overland, "precip" = release by precipitation-driven flux, "known flux" = known flux, and "K_d" is distribution coefficient with low defined as being less than 1 mL/g.

TABLE 5.2. Baseline HPI Ranges for Airborne Transport Scenarios and Constituent Types for the MEPAS Methodology[a]

Transport Linkage	Constituent with a short half-life	Radioactive, organic, or inorganic constituent
RU->AIR stack(DW)	1	1
RU->AIR stack(NDW)	2	3
RU->AIR resusp	3	2
RU->AIR volatil	not modeled	17

(a) "RU" = ranking unit, "AIR" = airborne, "DW" = case with building downwash, "NDW" = case without building downwash, "resusp" = area suspension particles and "volatil" = area volatilization of gases.

TABLE 5.3. Estimated HPI Ranges as a Function of Transport Scenarios and Constituent Types for the MEPAS Methodology[a]

Transport scenario linkage	Radioactive constituent with a short half-life		Radioactive, inorganic, or inorganic constituent	
	low K_d	high K_d	low K_d	high K_d
RU->GW precip	2	28	3	28
RU->GW known flux	4	32	2	18
RU->GW->SW precip	2	28	3	28
RU->GW->SW known flux	4	32	2	18
RU->OL->SW precip	22	30	29	33
RU->OL->SW known flux	1	1	1	1
RU->SW direct	1	1	1	1
RU->AIR stack(DW)	1		1	
RU->AIR stack(NDW)	2		3	
RU->AIR resusp	3		2	
RU->AIR volatil	not modeled		17	

(a) "RU" = ranking unit, "GW" = groundwater, "SW" = surface water, "OL" = overland, "AIR" = airborne, "precip" = release by precipitation-driven flux, "known flux" = known flux, "direct" = direct discharge to media, "DW" = case with downwash, "NDW" = case without building downwash, "resusp" = area suspension of particles, and "volatil" = area volatilization of gases, and "K_d" is distribution coefficient with "low" defined as being less than 1 mL/g.

TABLE 5.4. Baseline HPI Variability Groups for MEPAS and Constituent Types for the MEPAS Methodology[a]

Transport scenario linkage	Radioactive constituent with a short half-life		Radioactive, inorganic, or inorganic constituent	
	low K_d	high K_d	low K_d	high K_d
RU->GW precip	0	3	0	3
RU->GW known flux	0	3	0	2
RU->GW->SW precip	0	3	0	3
RU->GW->SW known flux	3	3	0	2
RU->OL->SW precip	3	3	3	3
RU->OL->SW known flux	0	0	0	0
RU->SW direct	0	0	0	0
RU->AIR stack(DW)	0		0	
RU->AIR stack(NDW)	0		0	
RU->AIR resusp	0		0	
RU->AIR volatil	not modeled		2	

(a) See footnote in Table 5.3 for definition of terms.

Given that only a finite number of transport pathways and exposure scenarios could be considered in the sensitivity analysis, the pathways were chosen to maximize applicability of the information in Tables 5.1 and 5.2 to DOE's ranking units.

Table 5.3 gives the HPI ranges for all possible transport pathways contained in MEPAS based on extrapolation from the ranges given in Tables 5.1 and 5.2. Based on the discussion in Section 1.1 of Doctor et al. (1990), the HPI ranges in Tables 5.1 and 5.2 were extrapolated to additional pathways (Table 5.3). The HPI ranges for known flux and precipitation-driven "ranking unit to groundwater" (RU -> GW) pathways were assumed to be approximately the same as those for the comparable known flux and precipitation-driven "ranking unit to groundwater to surface water" (RU -> GW -> SW) pathways. This assumption was based on the fact that the variability from the longer pathway includes both that from the RU -> GW component and that from the GW -> SW component. The latter may be thought of as analogous to the (RU -> SW) pathway in having a relatively small uncertainty. Because the sensitivity results in Doctor et al. (1990) show GW component variables generally contributing a large fraction of the computed variability, the RU -> GW pathway is assumed to have the same HPI range as the longer RU -> GW -> SW pathway. Thus the values in the first row of Table 5.3 are identical to the values in the third row, and the values in the second row are identical to those in the fourth row.

A short half-life for groundwater travel times is considered to be less than 140 years because the constituents would decay significantly during the first two, and most highly weighted, 70-year time periods. The HPI ranges for the known flux groundwater pathway are based on sensitivity runs for a case with minimal K_d (Case 2 in Doctor et al. 1990) and a case with realistic K_d (Case 5 in Doctor et al. 1990). The baseline HPI range in Table 5.3 is that expected for a well-characterized site. Less well-characterized sites will have greater variability.

Cases with direct discharge to surface water are expected to have a lower variability than are the three sensitivity cases with inflow linkages from groundwater and precipitation-driven overland flow considered in Doctor

et al. (1990). The surface water variables generally contribute to a small fraction of the variability in these cases. Assuming a known flux source term for an ideal well characterized site, an HPI range of approximately 1 unit was estimated for direct discharge to surface water (row 7 of Table 5.3). This 1-HPI-unit range is the minimum observed for the other pathways. The ranges for the different constituents were all chosen to be the same because the travel times in the river pathways would not be different.

The known flux RU -> OL -> SW pathway (row 6 of Table 5.3) is equivalent in MEPAS to a direct discharge into a river. Hence the HPI variability for the direct discharge to surface water has been used for this pathway. The variability for the precipitation-driven pathway (row 5 of Table 5.3) was inappropriate because that pathway includes variability from the constituent either reaching or not reaching a river - an effect not included in a known flux computation.

In the RIS, the baseline HPI variability is represented using variability groups derived from the HPI ranges in Table 5.3. These groups were selected to represent ranges of uncertainty as follows:

Group 0 for HPI range of $\leq$ 4
Group 1 for HPI range of 5 to 14
Group 2 for HPI range of 15 to 24
Group 3 for HPI range of $\geq$ 25

Table 5.4 gives the HPI baseline variability as group classifications for each of the constituent types and transport pathways. The translation of Table 5.3 into groups uses the grouping definition listed above except for the precipitation-driven RU -> OL -> SW pathway. In this transport pathway, it was felt that the differences in computed variabilities were likely mainly reflecting differences in transport computations not related to differences in constituent properties. Hence although one constituent type (radionuclides with short life with low K_d) had slightly lower variability, all constituent types for this pathway were assigned to Group 3, based on the average variability.

5.1.2 Data Quality Categories

The baseline variability discussed in the previous section represents only a minimum level of HPI uncertainty based on input parameter ranges for a well-characterized site. The RIS also includes a categorization of the uncertainty in the input parameters for each problem.

The Survey found a range in the quality of characterization of environmental problems at DOE sites. This range was expressed in terms of estimates of input data quality. Each of the ranking units was placed in one of three categories based on the number and type of assumptions used in deriving those input data that most influence the rankings. The data quality categories for each ranking unit are defined in Table 5.5.

Figure 5.1 shows DOE's preliminary rankings sorted by data quality groups expressed in terms of occurrences in HPI Levels (See Table 1.2). Both number of ranking units and percentage of cases within each data quality category are shown. The tendency is for poorly characterized sites to tend to group at the bottom of the rankings (HPI Level V) and well-characterized sites to group at the top of the rankings (HPI Level I). This tendency likely reflects the fact that characterization efforts have focused on the environmental problems with the greatest potential impacts.

TABLE 5.5. Definition of Data Quality Categories[a]

Category	Definition
A	Good data quality; mainly monitoring data and sampling data
B	Average data quality; a few assumptions
C	Poor data quality; many assumptions used

(a) Table was taken from DOE (1988).

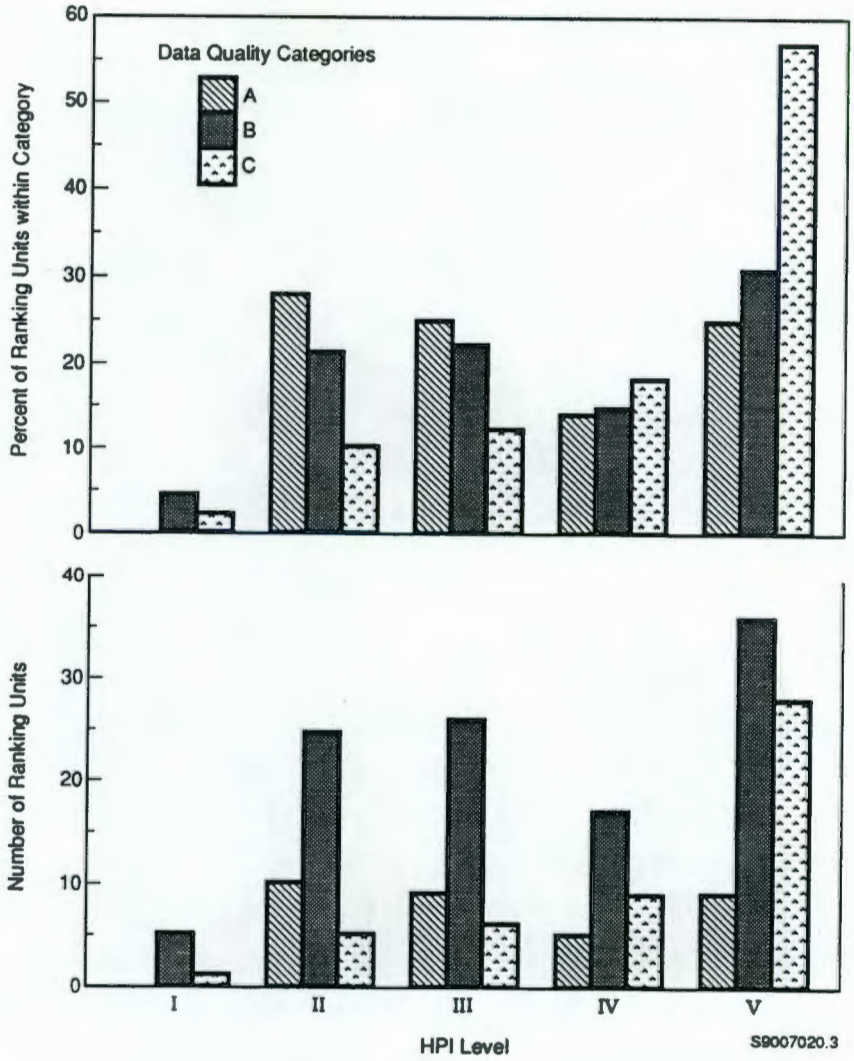

FIGURE 5.1. Frequency of Data Quality Categories by HPI Levels (HPI levels are defined in Table 1.2)

6.0 CONCLUSIONS

The analysis demonstrates the complexity of the use of impact-based parameters as risk measures for ranking environmental problems. The HPI, a time-weighted measure of population impact, represents only one of many possible measures of risk. Examples of other measures are individual impacts and time of impact. The comparison of rankings with HPI and other impact parameters demonstrates the complexity of using these parameters as ranking criteria.

An important factor in generating ranking parameters is shown to be the time weighting factor used to progressively discount future impact. The discounted HPI value, as compared to the undiscounted HPI, greatly decreases the relative importance of future impacts occurring by groundwater transport compared to current impacts.

This analysis indicates that important impact information may be lost by the use of a single impact parameter to represent public health risk. Instead, a series of parameters are required to characterize each environmental problem. The multiple aspects of potential health impacts include population risk, maximum individual risk, and timing of impacts. The design of the RIS allows differences in these and other aspects of risk to be considered.

Indicators of the uncertainty in the computed risk parameters are included in the RIS. A baseline uncertainty for HPIs resulting from data input uncertainties is estimated based on the constituent and pathway sensitivity analysis (Doctor et al. 1990). The uncertainty from input variability at most sites will be larger than this minimum baseline variability. Therefore the baseline uncertainty is supplemented with a qualitative measure of data quality for critical data inputs at each ranking unit. The preliminary rankings (DOE 1988) indicates that data quality factors do not dominate the overall rankings.

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8.0 GLOSSARY

constituent pathway	the transport and exposure pathway that a constituent travels through to impact human health. An example of a constituent pathway is transport through the groundwater to impact human health through the ingestion of contaminated drinking water from a well. Each release unit (defined in a separate entry) normally involves multiple constituent pathways.
environmental problem	for DOE's Environmental Survey, the existence of contaminants in the air, surface water, groundwater, or soil resulting from DOE operations that poses or may pose a hazard to human health or the environment. It can also include the existence of conditions at a DOE facility that poses or may in the future pose a hazard to human health or the environment.
Environmental Survey	effort conducted by DOE to identify and prioritize their environmental problems.
exposure	contact of an organism with a chemical or physical agent. Exposure is quantified as the amount of the agent available at the exchange boundaries of the organism (e.g., skin, lungs, gut) and available for absorption (EPA 1989b).
exposure pathway	the pathway by which the human population can be exposed to a constituent. Pathways include drinking water, showers, ingestion of aquatic food, crops, animals, water immersion, soil ingestion, and inhalation. It should be noted that the U.S. Environmental Protection Agency (EPA 1989b) defines exposure pathway slightly differently. EPA defines exposure pathway as the course a constituent takes from the source to the exposed organism.
exposure route	the course by which a constituent enters the human body. This includes ingestion, inhalation, dermal contact, and external exposure and corresponds to the definition given by EPA (1989b).

exposure scenario	one or more exposure pathways associated with a receptor. An example of an exposure scenario at a well receptor would be drinking of water, consumption of irrigated crops, and showering.
facility	a collection of ranking units and/or release units considered as a single entity. The elements of a facility may be defined in terms of political, economic, or geographical divisions.
Hazard Potential Index (HPI)	a composite index risk parameter that is computed by MEPAS to evaluate the relative importance of environmental problems. An HPI is generated for each constituent that is being evaluated for each identified transport and exposure scenario. The HPI is population based and varies with the environmental concentration at the receptor and toxicity of the constituent. Whelan et al. (1987) provide a detailed mathematical description of the HPI.
intake	a term used as a measure of exposure expressed as the mass of a substance in contact with the exchange boundary per unit body weight per unit time (e.g., mg chemical/kg/day). Also termed the normalized exposure rate; equivalent to administered dose (EPA 1989b).
lifetime average daily intake	a measure of exposure that is expressed as the mass of a substance contacted per unit body weight per unit time, averaged over a lifetime (EPA 1989b).
Maximum Individual Index (MII)	a risk parameter calculated by MEPAS that represents the maximum exposure to a hypothetical individual. The total intake for the individual is the sum of the highest intakes for each exposure pathway over all 70-year time periods. An MII of 1.0 represents exposure at the Reference Dose (RfD) level for noncarcinogenic constituents and exposure giving a lifetime individual cancer risk of 10^{-6} for radionuclides and carcinogenic constituents.

MEPAS	the Multimedia Environmental Pollutant Assessment System, a computer-based methodology for evaluating potential impacts resulting from releases of hazardous materials to the environment. MEPAS is based on a physics-based multimedia transport and exposure pathway analysis.
MIX combination parameter	an alternative impact parameter designed to illustrate an approach to combining the population impact (HPI) and maximum individual impact (MII).
normalized peak concentration	an impact parameter that represents a drinking water concentration at the receptor. This parameter is calculated by dividing the environmental water concentration by a constant water concentration corresponding to a level of concern (10^{-6} risk for carcinogens and radionuclides and 1.0 RfD ratio for noncarcinogens) for that constituent.
ranking unit	an environmental problem or issue such as a landfill or underground storage tanks. A ranking unit can consist of multiple release units. Although not always equivalent on a one-to-one basis, the ranking unit is roughly comparable to an operable unit as defined by EPA. For DOE's Environmental Survey, ranking units consisted of parts or sets of individual environmental problems.
receptor or usage location	a point in space where contamination could potentially expose a population through groundwater, surface water, soil, or air. Populations and exposure scenarios are defined for each receptor.
Reference Dose (RfD) Level	defined as chronic Reference Dose, this is an estimate of a daily exposure of a noncarcinogenic compound to a human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime (EPA 1989b).

	With an uncertainty spanning perhaps an order of magnitude or greater, this chronic RfD was specifically developed by EPA to be protective for long-term exposure to a compound.
release unit	a place where a specific type of release occurs, or may occur, to the environment (air, groundwater, and/or surface water). Release units are components of a ranking unit. For example, a ranking unit may be underground storage tanks, and the release unit could be a specific tank. At least one transport and exposure scenario is associated with each release unit.
RIS	acronym for DOE's Risk Information System, which is a two-step process for prioritizing environmental problems. Referred to as R-I-S, this system was used by the DOE Environmental Survey to prioritize their findings of environmental problems.
risk	in risk assessment, the possibility of suffering harm from a hazard (Cohrssen and Covello 1989)
source term	the rate of release of a contaminant to the environment. For active operations, the source term is the emission or discharge rate. For inactive ranking units, the source term is the rate of movement into the media of concern.
Time Of Arrival (TOA)	the time (in years) at which the environmental concentrations exceed a designated level of concern at a specific location for that constituent.
transport pathway	the environmental medium (groundwater, surface water, overland, or atmosphere) through which a contaminant can migrate. A source term links with the transport pathway, which then links with an exposure pathway. A transport pathway is equivalent to the EPA (1989b) definition of an environmental pathway.

transport scenario	one or several linked transport pathways. An example of a transport scenario would be ranking unit to groundwater to surface water.

APPENDIX A

MASS BUDGETS UNCERTAINTY

APPENDIX A

MASS BUDGETS UNCERTAINTY

A possible source of uncertainty in any simulation of environmental transport is the definition of contaminant mass within and between different media. This appendix provides information on the influence of mass budgets on the computed health impact parameters.

MEPAS automatically accounts for mass budgets within a waterborne or airborne pathway when the total mass is defined for a pathway. In cases where mass inventories were not defined as inputs, checks were made by the Survey to ensure total emissions were not greater than the total amount of available contaminants.

As part of its design as a screening tool, MEPAS does not allocate mass between transport scenarios. This approach is taken to 1) allow for evaluation of multiple transport scenarios in the same media where mass depletion between scenarios would be problematic (e.g., groundwater transport to a well and groundwater transport linked to surface water transport), and 2) avoid having one transport scenario incorrectly depleting the mass potentially available for a transport scenario in a different media (e.g., a conservative air emission computation based on leakage of a clay cap could eliminate the source term for possible groundwater contamination). This user definition of mass allocations provides flexibility for screening applications.

The main source of mass budget uncertainty is associated with the user's uncertainty in the definition of the inventory of material available for release into each transport media. This uncertainty will be reflected in compiled health impact parameters in cases where the releases rates, or total release, is dependent on this inventory estimate.

APPENDIX B

HEALTH IMPACT PARAMETER UNCERTAINTY

APPENDIX B

HEALTH IMPACT PARAMETER UNCERTAINTY

The MEPAS constituent database contains physical, chemical, and health impact data for each constituent (Strenge and Petersen 1989). The health impact evaluation parameters are in the constituent database and thus are not input by the user. For the database used in the Survey's final Summary Report, the contents were fixed in mid-1989 to allow applications to proceed based on a consistent set of information. There are 393 constituents in this MEPAS database, which includes the most appropriate and correct data available. In general, the physical and chemical properties of the constituents are not difficult to obtain, and the values are reliable (i.e., small amount of uncertainty). The health impact parameters are more difficult to obtain, and the uncertainty associated with them is greater than for the constituents' physical properties.

Of these health impact parameters, the toxicity parameters are considered the most critical parameters contributing to uncertainty in the HPI values. Sources for toxicity data are EPA's Integrated Risk Information System (IRIS) database, Threshold Limit Values (TLVs), Registry of Toxic Effects of Chemical Substances (RTECS), and the toxicity values from other constituents of similar structure and properties. The primary source of constituent toxicity parameters is EPA's IRIS, which is an on-line computer information system. When data are not available from IRIS for a chemical constituent, other methods must be used to estimate toxicity parameter values.

The toxicity parameters are required for constituents to relate exposure level to relative risk. For chemical constituents, the toxicity factors are the cancer potency factors (for carcinogens) or reference doses (for noncarcinogens). MEPAS uses cancer potency factors to evaluate risk from carcinogenic constituents and RfD to evaluate relative risks from exposure to noncarcinogenic constituents. At least one of these parameters must be defined for inhalation exposure and one for ingestion (oral) exposure. The

general hierarchy in evaluating toxicity parameters is given by the following criteria:

1. Use values from IRIS if available for inhalation and ingestion.

2. If IRIS values are only available for one intake route (inhalation or ingestion), use the IRIS value for both routes.

3. When IRIS values are not available, use TLVs, if available, to estimate an effective inhalation reference dose. Use of TLVs to estimate inhalation reference doses is discussed below. Use the inhalation reference dose for ingestion also.

4. When IRIS and TLV values are not available, use acute exposure data for small animals from RTECS. Use of RTECS data is discussed below. Data from Sax and Lewis (1989) may also be used in the same manner as RTECS data.

5. If these sources of data do not provide estimates of toxicity parameters, then base toxicity estimates on constituents of similar structure and properties.

The toxicity parameters for radionuclides are the internal and external dose factors. Radiation dosimetry factors are defined for radionuclides to relate intake to dose, which is then converted to relative risk using a constant factor for all radionuclides. Dose factors for radionuclides are based on models and methods of the International Commission on Radiological Protection (ICRP) and are all of comparable accuracy.

A "toxicity indicator" can be defined for each constituent in the MEPAS database. The purpose of the toxicity indicator is to provide a semi-quantitative indication of the accuracy of the toxicity parameter contained in the constituent database based on the source of toxicity data. Toxicity indicators are provided for both inhalation and ingestion exposure routes. The indicator represents the approximate range of HPI points (about the reported HPI value) within which the true HPI may be contained, considering the uncertainty in the various methods for estimating the toxicity parameters.

General criteria presented in Table B.1 is used to establish the toxicity indices in the constituent database. The main information that these indices provide is an indication of the source of toxicity information. These index values have been scaled only to reflect greater uncertainty for

less certain sources. The values generated for specific constituents, are not meant to represent absolute estimates of actual toxicity uncertainty values.

Radionuclide constituent pathways are assumed to have less uncertainty in the predicted HPI value than chemical pathways as a result of the larger body of health-effects data available for radionuclides. Noncarcinogenic constituents with toxicity data based on LD_{50} have the greatest uncertainty. Data from EPA studies are considered the best source of information and therefore are thus assumed to have the lowest uncertainty for toxicity parameters for chemicals.

An order-of-magnitude change in health impact corresponds to a range of 10 HPI points. An index value of 5 is used to roughly span an order-of-magnitude uncertainty in relative health impacts. Thus Table B.1 provides an index based on approximate ranges of uncertainty for the HPI parameter.

TABLE B.1. Criteria for Defining Toxicity Indices For Specific Constituents

Toxicity Index Value	Application
5	for radionuclides for all exposure routes
5	for carcinogenic and noncarcinogenic constituents with toxicity parameters evaluated by EPA (as reported in various EPA references)
10	for noncarcinogenic constituents with inhalation toxicity parameters based on Threshold Limit Values Time Weighted Average (TLV/TWA) for occupational exposure
20	for noncarcinogenic constituents with ingestion toxicity parameters based on animal acute dose information (e.g., LD_{50} values) as provided
5	for carcinogenic and noncarcinogenic constituents that have inhalation toxicity parameters estimated from ingestion data (same for ingestion toxicity parameters based on inhalation data)

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