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LARGE-SCALE MULTIMEDIA MODELING APPLICATIONS

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ABSTRACT

Over the past decade, the U.S. Department of Energy (DOE) and other agencies have faced increasing scrutiny for a wide range of environmental issues related to past and current practices. A number of large-scale applications have been undertaken that required analysis of large numbers of potential environmental issues over a wide range of environmental conditions and contaminants.

Several of these applications, referred to here as large-scale applications, have addressed long-term public health risks using a holistic approach for assessing impacts from potential waterborne and airborne transport pathways. Multimedia models such as the Multimedia Environmental Pollutant Assessment System (MEPAS) were designed for use in such applications. MEPAS integrates radioactive and hazardous contaminants impact computations for major exposure routes via air, surface water, ground water, and overland flow transport. A number of large-scale applications of MEPAS have been conducted to assess various endpoints for environmental and human health impacts. These applications are described in terms of lessons learned in the development of an effective approach for large-scale applications.

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INTRODUCTION

Environmental and public health impacts have, and are being, considered as part of the environmental restoration and waste management activities by the U.S. Department of Energy (DOE). The assessments for specific sites are driven by a range of regulatory requirements. Major actions often require environmental impact statements to meet National Environmental Protection Act (NEPA) requirements. Operating facilities are covered under the Resource Comprehensive Recovery Act (RCRA) and activities at inactive sites are covered under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The guidance for the required regulatory impact evaluations varies from state-to-state, from region-to-region, and agency-to-agency.

In addition to impact assessment activities aimed at specific regulatory requirements, the DOE has conducted several efforts aimed at cross-cutting a wide range of environmental issues in a single consistent framework. A major common element of the efforts described here is the selection of a multimedia model to evaluate the potential transport and fate of contaminants in the environment. The multimedia model is only one of several modeling approaches that could be used.

The modeling requirements for large-scale applications are that environmental releases to air, ground water, surface water, and soil need to be addressed. Effects of either, or both, radioactive contaminants and hazardous wastes need to be involved. For hazardous wastes, carcinogenic and noncarcinogenic impacts need to be included. For each of these, the major pathways of interest for exposure need to be defined and evaluated.

The selected multimedia model, the Multimedia Environmental Pollutant Assessment System (MEPAS), is an integrated computer implementation of formulations for the release, transport, dispersion, and intermedia transfer for contaminants in various forms in waterborne and airborne media. The major transport pathways of MEPAS are illustrated in Figure 1. The endpoints for a MEPAS analysis can be environmental concentrations, exposures, and human health impacts.

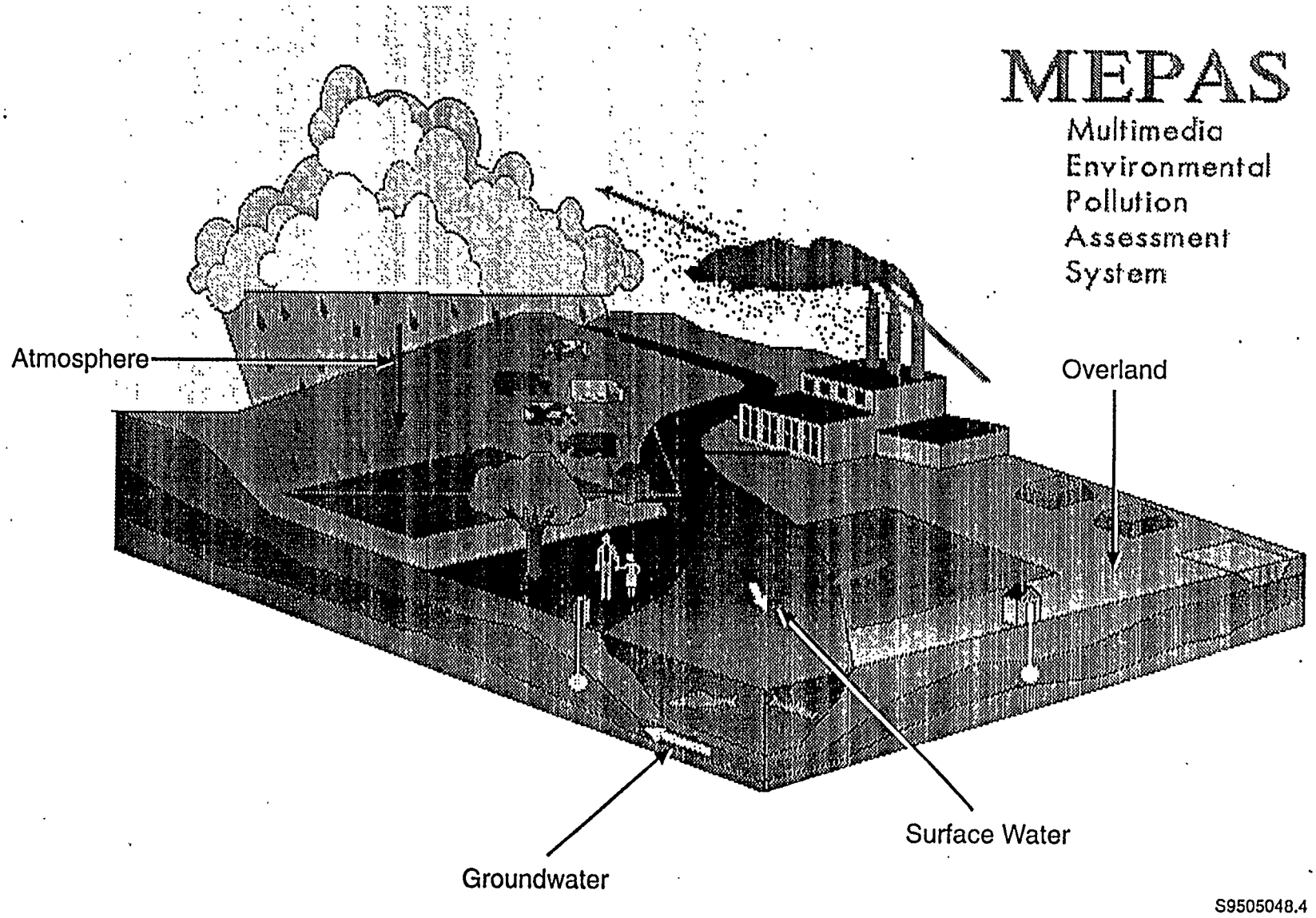

Figure 1. Illustration of the Multiple Pathways Considered in the Multimedia Model, MEPAS

MEPAS is a tool designed for use in intermediate risk analyses that are typically conducted for prioritization and ranking environmental applications (Figure 2). The MEPAS formulations are based on mathematic solutions to the underlying physical, chemical, and impact principles and processes (Whelan et al. 1988; Droppo et al. 1989a; Whelan et al. 1992). The types of multimedia models range from the box-approach fugacity models to environmental transport and fate models; MEPAS is the latter type of model.

As shown in Figure 2, qualitative rule-based systems, such as the U.S. Environmental Protection Agency's (EPA's) revised Hazard Ranking System, are an alternative approach for large-scale applications that generally require less input data but have more uncertainty in the output parameters. Such systems are designed for identifying potential problems that need further consideration based on minimal site data. The qualitative rule-based approaches did not meet the requirement for quantitative data for input to the prioritization and ranking efforts.

On the other end of the spectrum from rule-based systems is the approach of using detailed site-specific models for each potential problem (Figure 2). This approach has the appeal of doing the "best" analysis for each potential impact end-point. However the logistics of data acquisition, the extended analysis time required, and the cost of doing such an analysis for a large number of cases precluded selecting this approach as a practical method of addressing a large number of potential impacts.

Instead of a multimedia model, a suite of different general-purpose regulatory models also could have been used to do the same intermediate risk analysis computations. The suite-of-models approach for prioritization/ranking applications has the advantage of allowing the use of models specifically designed for each of the various issues. This approach was not selected in the case studies described below because of the considerable additional effort (related to the logistics of running and combining the outputs from many models) required with this approach compared to a multimedia

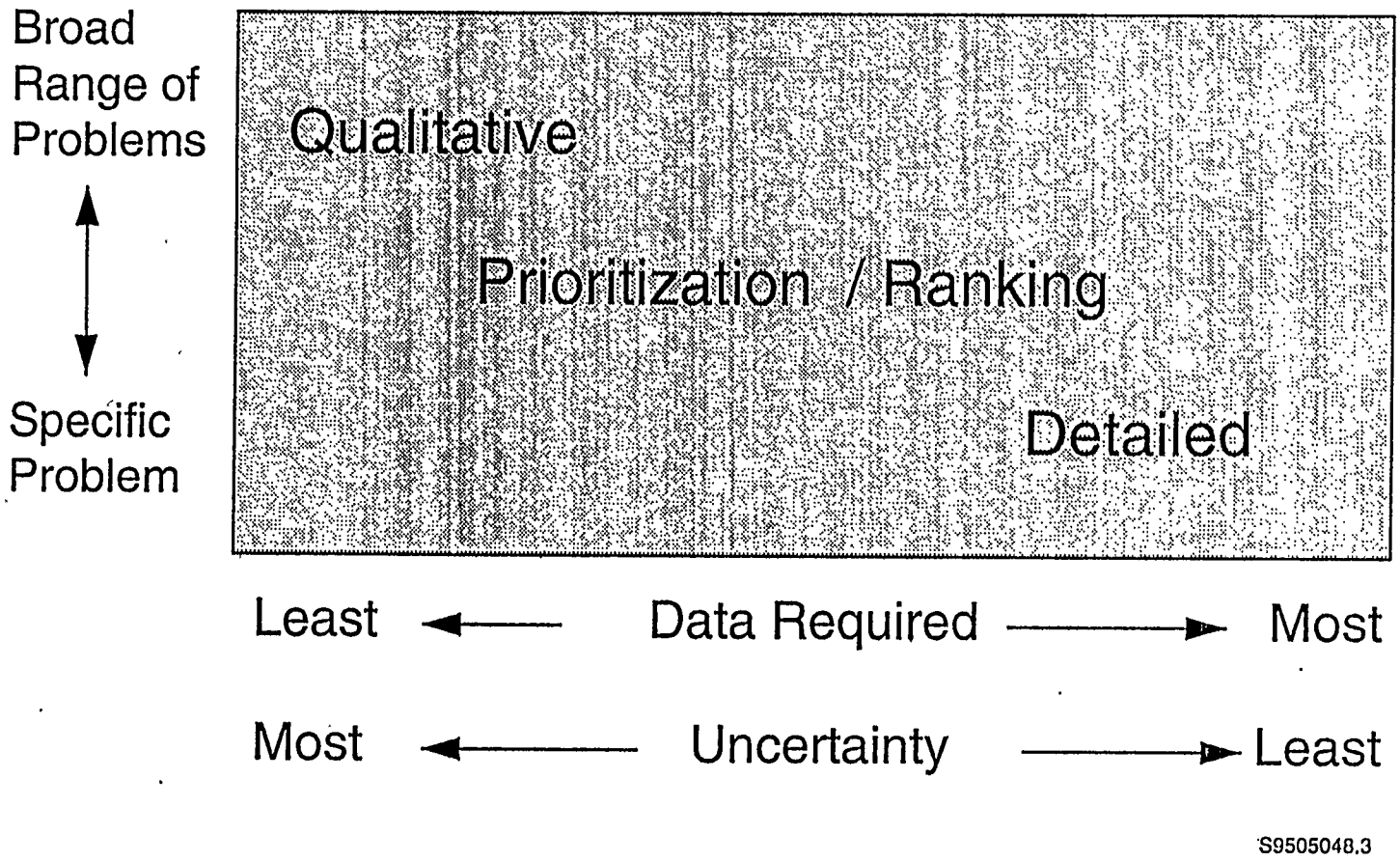

Figure 2. Types of Risk Analyses In Terms of Range of Problem Applications, Data Requirements, and Uncertainty

model. Also the question of the comparability of results arises when different codes are used for different types of impacts.

The best modeling approach depends mainly on the objectives of an application. The selected model(s) must be able to address the range of potential problems associated with that particular application. In practice, for large-scale applications, more than one model is normally required. Using a multimedia model can greatly reduce the number of models required by coupling codes into an integrated system as shown in Figure 2. No one model will fill all the modeling needs and some combination of models is normally used.

Large-scale applications of MEPAS that consider major pathways for human exposures are described below. In these evaluations, the evaluation are mainly for human impacts, either as a risk of cancer or as a ratio representing proximity to a "safe" level. Although not addressed in this paper, several of the applications did consider ecological endpoints. The lessons and experiences for these large-scale applications discussed below should be applicable to other applications of similar scale.

MULTIMEDIA MODEL DESCRIPTION

Computer models provide a consistent means of estimating a wide range of potential impacts using available information. A number of multimedia and single-media models are used in estimating these potential impacts. This paper considers the use of a multimedia model to provide estimates of various endpoints as input to various DOE large-scale applications.

The approach taken by the DOE was to develop a computer program for addressing a broad range of issues for applications at large complex sites (DOE 1988; Droppo et al. 1990). By addressing a broad range of regulatory issues with a uniform level of detail, MEPAS allows relative comparisons of risks for contaminants across media, types of impacts, types of release sites, time, environmental settings, and space.

The result is MEPAS: a collection of models based on standard computational methods for various environmental media that are integrated into a single system. The use of an integrated system overcomes the fragmentation of effort problems associated with using a series of separate unlinked models that often have inconsistent units, spatial scales, and time scales.

MEPAS was developed for the DOE by the Pacific Northwest Laboratory. The MEPAS software is a tool for computing human-health impacts based on environmental pathway analysis. MEPAS integrates standard physics-based impact estimation methods involving source-term, waterborne and airborne transport, exposure, and consequence models. These MEPAS models are configured to do site-specific assessments using readily available information. A design requirement was that detailed guidance be provided for estimating site-specific values for each and every input value.

These MEPAS models address a range of environmental problems using air, groundwater (vadose and saturated zones), surface water, overland, and exposure computations. These major components and their linkages are shown schematically in Figure 3. Whenever available and appropriate, EPA guidance and models are used to facilitate compatibility and acceptance.

Each of the major MEPAS models underwent a "reality" check as a model performance verification. By comparing model outputs with monitoring data and other modeled values, the ability of the models to reasonably simulate the fate and transport processes was demonstrated. A number of benchmarking efforts with other multimedia models are underway.

Although based on relatively standard transport and exposure computation approaches, the unique feature of MEPAS is that these approaches are integrated into a single system. Risk values are computed using a consistent approach for chemicals and radioactive carcinogens. Hazard quotients, based on reference doses, are computed for noncarcinogens. By using consistent approaches for potential problems (Whelan et al. 1987; Droppo et al. 1989a) along with detailed model application

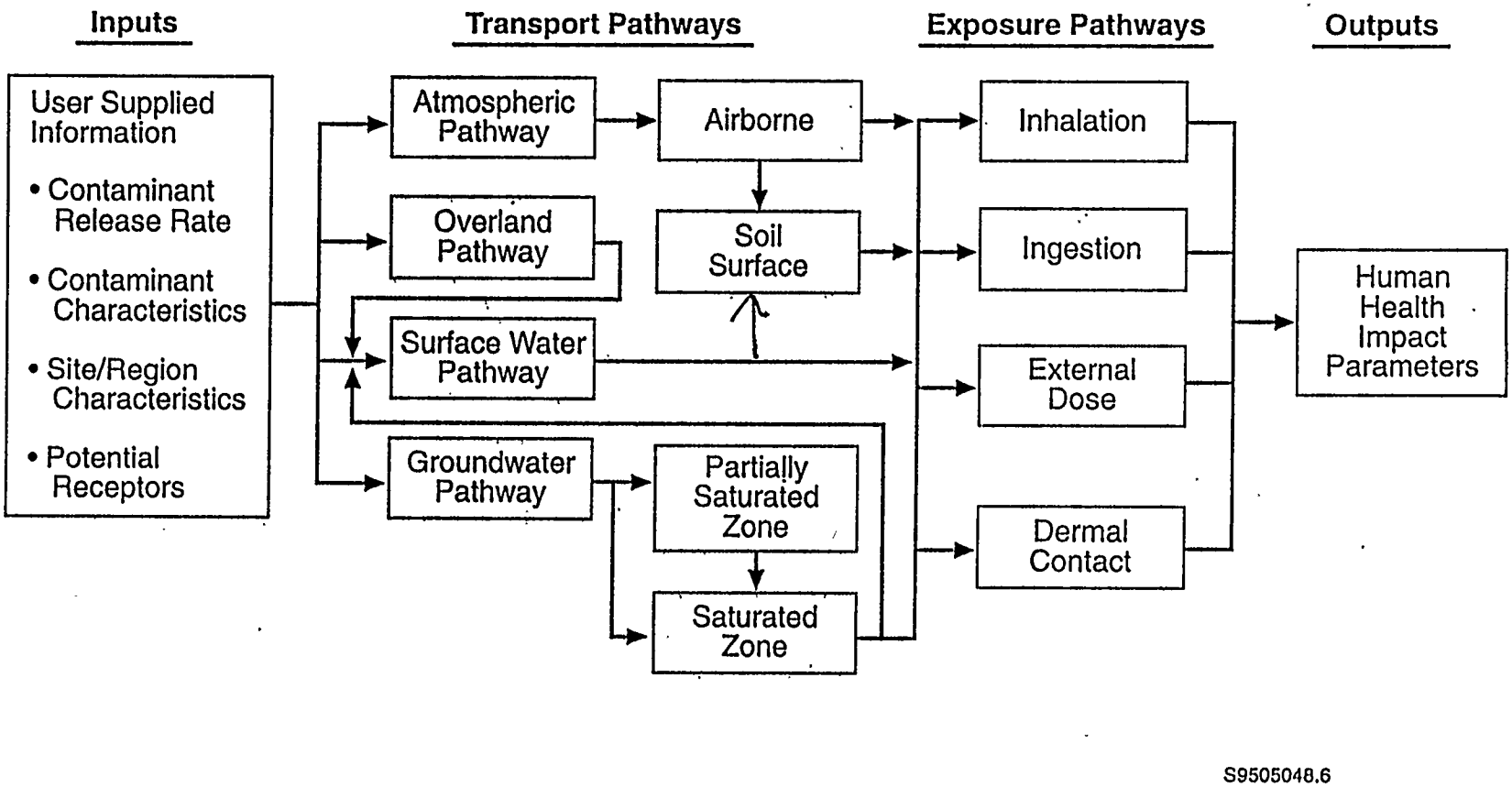

Figure 3. MEPAS Release Transport and Exposure Pathways

guidance (Droppo et al. 1989b,1989c; Strenge and Peterson 1989; Buck et al. 1995), the effects of model and application differences on risk values are minimized. The use of a single system provides a consistent basis for evaluating health impacts for a large number of problems and sites.

When ranking or comparing different sites in large-scale applications using computed human health effects, it is essential to consider the inherent uncertainty in the computed values. Although a single-value deterministic approach can rank problems in broad groups separated by many orders of magnitude, a ranking of risks closer in magnitude requires consideration of the inherent uncertainty (Doctor et al. 1990; Droppo et al. 1990). For such applications, a sensitivity- uncertainty MEPAS module was developed.

Although no one computer model is appropriate for all situations, multimedia computer models such as MEPAS cover a wide range of potential problems. These models find their niche in the type of large-scale programmatic risk-based, multiple-issue applications described below.

LARGE-SCALE APPLICATIONS

While a wide variety of models address specific site characteristics, transport media, and impact type, only a few models have been developed to address the broad range of long-term public health issues. As noted above, MEPAS integrates radioactive and hazardous materials risk computations for major exposure routes via air, surface water, ground water, and overland flow transport (Whelan et al. 1992). This section details experiences in applying MEPAS to DOE large-scale applications.

Although the underlying computer software has remained essentially the same, the overall approach of using the MEPAS software has undergone an evolution in the following applications. The major limitation faced has been the large amount of resources required to evaluate impacts for a large number of potential problems.

The first major large-scale application of MEPAS was in DOE's Environmental Survey. That effort involved a nationwide comparison of DOE potential environmental problems at 36 facilities (DOE 1988). Although the resources required for certain data could be reduced though the use of an integrated system with detailed parameter-by-parameter guidance, the analysis was still too data-intensive to be applied for every potential problem. This effort started with the approach of conducting a source to receptor analysis for each problem and evolved to a consideration of aggregated groups of problems. The aggregated approach did allow DOE to generate preliminary Environmental Survey risk estimates for 16 major DOE facilities involving about 500 potential problems with about 1000 transport pathways (DOE 1988, Droppo et al. 1990). As an example of the Environmental Survey results, Figure 4 shows a scatter plot of the survey's population risk ranking parameter, Hazard Protection Index (HPI). The HPI on the x-axis is based on the contaminant with the highest risk whereby the HPI on the y-axis is based on the sum of risks for the multiple contaminants associated with a potential problem (Droppo et al. 1990). The plot shows that adding or not adding the risks is not an important issue for ranking of the range of risks estimated in this large-scale application. Also, the many orders of magnitude ranges (each ten HPI points represents an order of magnitude change) allowed DOE to place the potential problems into broad ranges of categories of concern (DOE 1988).

A subsequent effort was aimed at providing a risk computation tool that could be used to generate data inputs to a system designed to optimize risk reduction in DOE's environmental remediation efforts (Longo et al. 1990). In this effort, the logistics of using MEPAS at a detailed problem-by-problem level was recognized as a serious limitation. Prohibitively extensive resources in terms of time and cost would be required to apply the model to every environmental remediation site. As a result, a wide-scale application of the multimedia model was never implemented for the DOE environmental restoration prioritization system. This prioritization system was used for several years

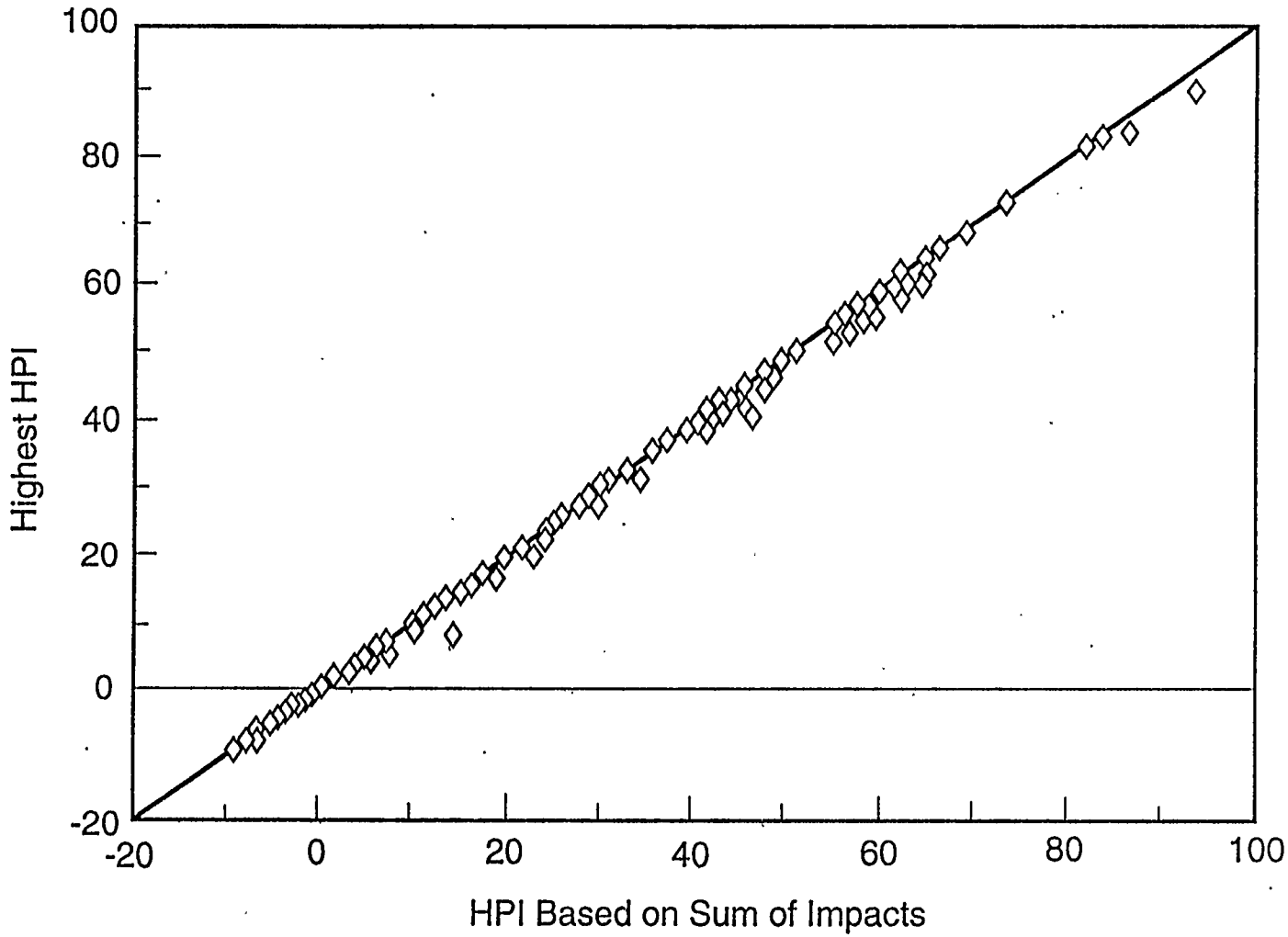

Figure 4. Comparison of Summed and Unsummed Population Impact Parameter (Hazard Potential Index, or HPI) for the Preliminary DOE Environmental Survey Effort

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using site estimates of risk reduction; the system is not currently being used by DOE.

The next major large-scale application considered for MEPAS was for the DOE Programmatic Environmental Impact Statement (PEIS). The unit-factor approach for evaluating sites with a large number of potential problems was developed and applied in this application. Instead of evaluating aggregated problems as was done in earlier applications, the unit-factor approach allows roll-up of risks computed for each potential problem. In the PEIS application, unit-risk factors were generated for each type of potential environmental problem at eight of DOE's major facilities. Several models were used to generate the unit factors; MEPAS for the multimedia transport and other models for certain on-site exposures not addressed by MEPAS. The overall potential impacts for a site were estimated by combining the unit factors and the contaminant inventories for each potential problem.

The next large-scale application expanded and enhanced the unit-factor approach. The Hanford Remedial Action Environmental Impact Statement (DOE 1994) expanded the approach to consider separate unit factors for the transport (unit transfer factor [UTF]) and impact (unit risk factor [URF]; Strenge and Chamberlain 1994). Figure 5 illustrates the range of URF's for air and soil computed for one part of a large-scale application (Gelston et al. 1995).

Unit risk factors such as these were used to compute risk estimates across a large complex DOE facility (Hanford) for onsite land uses at different time periods. Figure 6 shows the resulting spatial distribution of risk for one time period generated using the unit factor approach and porting the results to a graphical interface system for plotting. The risk levels are associated with assumptions of routine direct use and contact with the contaminated media.

The unit factor approach was further refined in the next large-scale application. In an effort to provide risk-based cost-drivers for the DOE Baseline Environmental Management Report (BEMR) (DOE 1995) to Congress, the unit factor approach was further expanded to consider a series of unit factors that start with the source and progress to the risk computation.

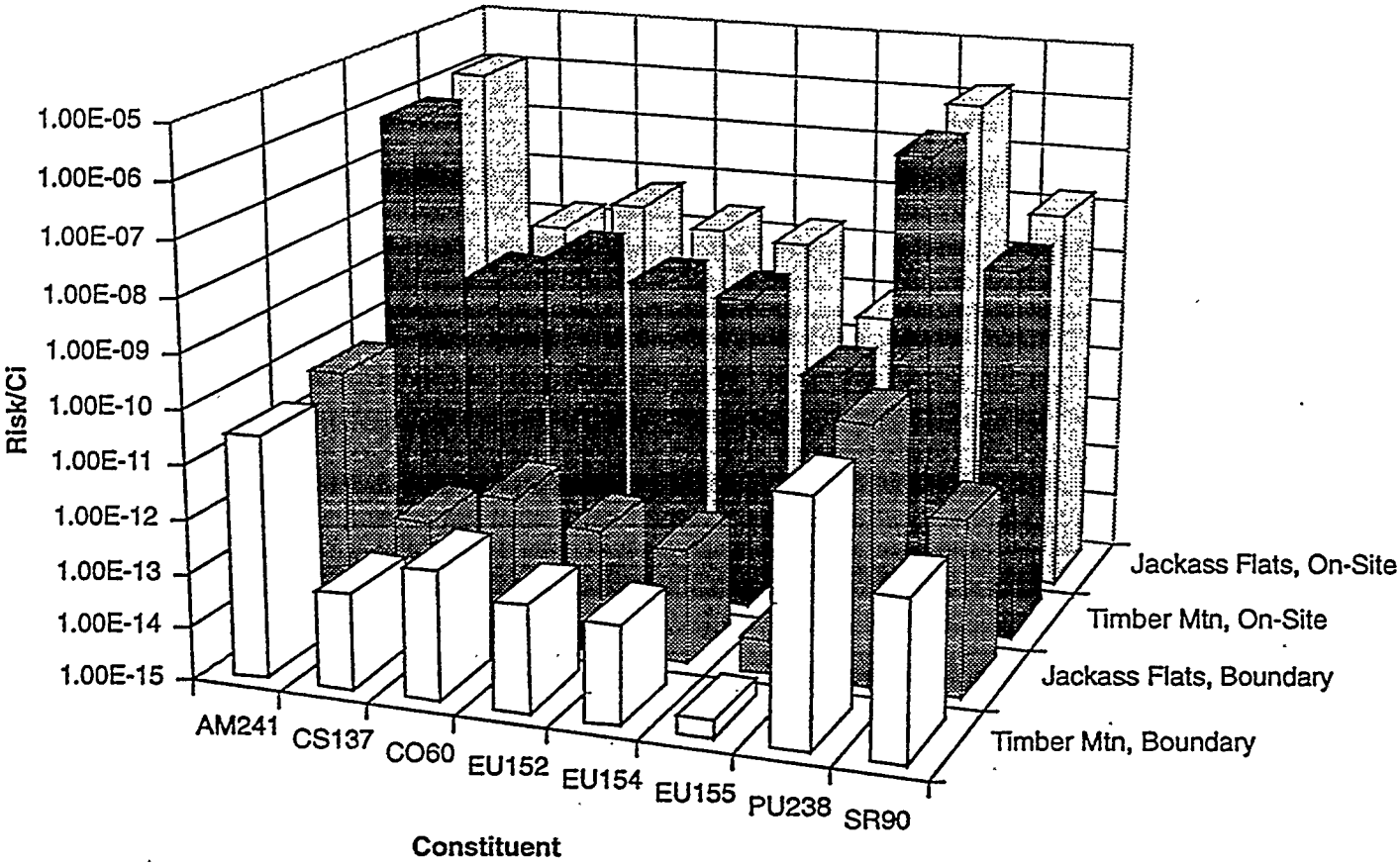

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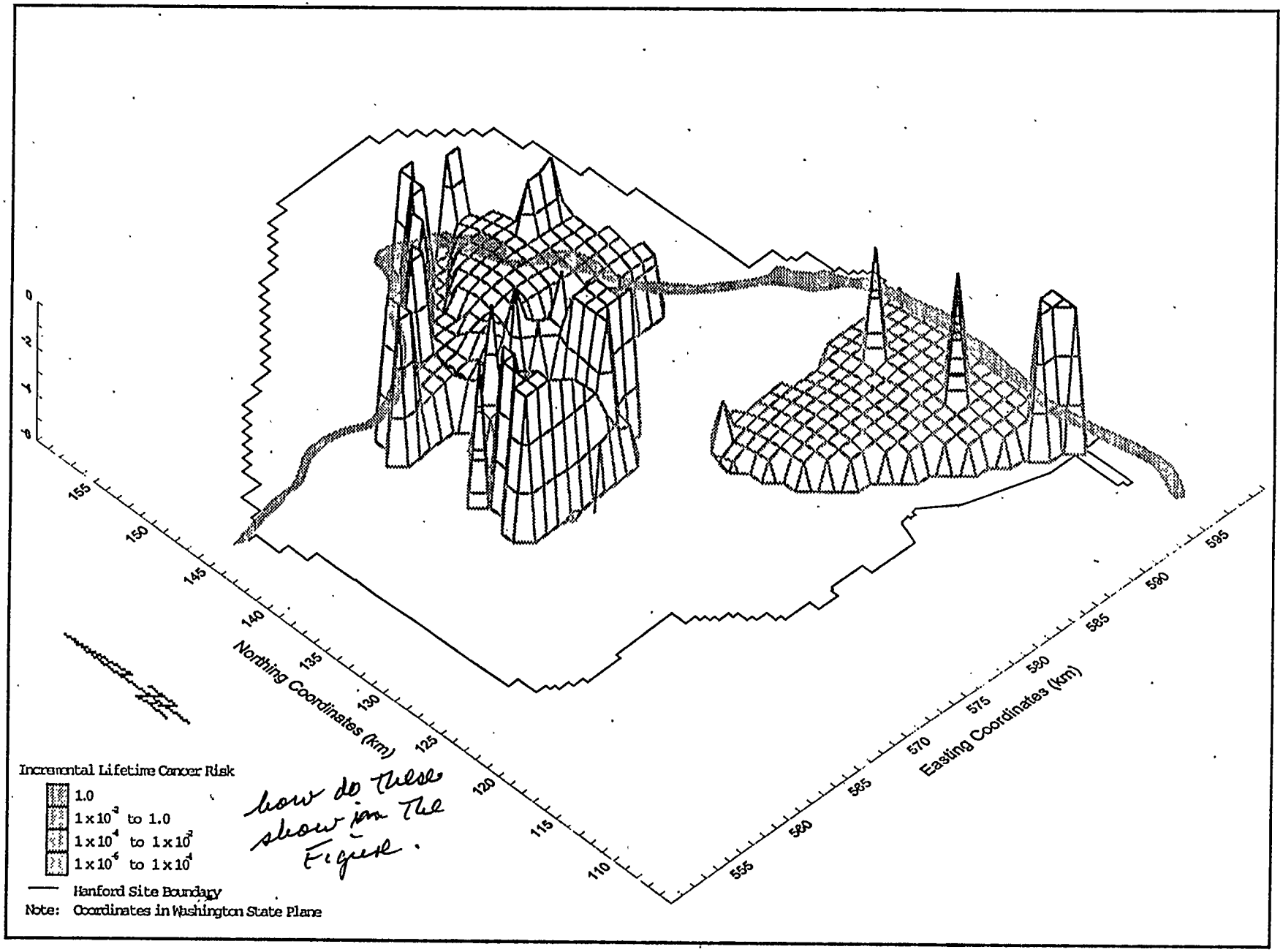
Figure 5. Large-Scale Application Computed Unit Risk Factors Example; Air and Soil Deposition Factors for the Nevada Test Site.

Figure 6. Large-Scale Application Risk Results Example: Site-Wide Baseline Risk for Hypothetical Residential Activities at the Hanford Site.



how do these show in the Figure.

An important aspect of the unit-factor approaches that merits some discussion here is the "anchoring" of the computations to available site concentration and risk data. By demonstrating that the estimated risk values are consistent with site data, a level of validation for the site is provided for the analysis. The anchoring requires that the estimated risks be the same when differences in assumptions are accounted for. The effort typically involves recomputing the modular risk assessment risks for specific problems using the same assumptions as a previous detailed risk analysis. This anchoring effort has the advantage of being a formal mechanism to explain any differences between applications in the risks estimated for a site (Gelston et al. 1995).

Although still a major effort, these approaches (the unit-factor approach and its successor, the modular risk assessment approach) can be applied much faster and for less cost than a detailed site-by-site analysis. For example, the entire HRA-EIS impact computations for the Hanford site were completed in about a 3-month period. Also, these approaches allow a fast recomputation of overall risk for alternative assumptions when the strength of the source, the land use scenario, and the exposure/uptake/toxicity factors are altered.

DISCUSSION

These large-scale applications identified a number of advantages specifically related to using an integrated multimedia system such as MEPAS. The consistency of analysis provides the ability to compare human health impacts between sites which are not normally possible with separate analyses for those sites.

The multimedia analysis often has some unexpected results in terms of pathway importance. For example, many were surprised in the first major application that chemical carcinogens turned out to have potential impacts on the same order as radioactive contaminants. By being able to easily evaluate the range of possible waterborne and airborne pathways, the impact estimates at a number of sites resulted in new information as to the relative importance of pathways. At one site in the applications described above, the headquarters staff felt the ground-water pathway was most important and site staff felt the air pathway was most important. The multimedia results led to an understanding that both the water and air pathways were important. At other sites, the analysis identified previously unsuspected pathways. At several of these sites, changes were made in the operations as a result of the multimedia analysis.

The environmental site, regional characterization, and contaminant data are collected for the potential problems. An important aspect of the large-scale applications is generating a database of information in this analysis. The database of model inputs and outputs can be an invaluable resource for other analyses. This aspect has been an important factor in allowing the large-scale applications described in this paper to build on the data collected by the preceding effort. Typically, the database provides a starting point for data review and collection efforts on a subsequent project. This use of the database was facilitated when the application used the MEPAS option of adding a reference

citation for each data point.[3]

A major aspect of these applications was dealing with external and internal reviews. A number of efforts had formal external reviews that provided useful inputs. A formal scientific peer review was conducted in the Environmental Survey (Whelan et al. 1988). The U.S. Environmental Protection Agency (EPA) has conducted two reviews of MEPAS. EPA reviewed an early version as part of an EPA review of models for their use listing sites on the National Priority List (NPL) (IE, 1987). EPA also reviewed MEPAS as part of a public review of DOE's priority system effort described above. Health and Welfare, Canada, commissioned an independent review of multimedia models (Intera Information Technologies Corporation 1992). Currently EPA and DOE are conducting a benchmarking effort to compare the functionality of their multimedia models.

In each of the above large-scale applications, varying degrees of internal institutional resistance had to be addressed. One source of resistance resulted from internal politics related to which agency, or laboratory, or group at the laboratory should be conducting the analysis. The cross-cutting multimedia analysis appears to maximize the concerns over these types of issues. In other cases, reactions appeared to be based in protecting projects and programs. A typical fear was that problems that are important from a regulatory standpoint, or other framework, may not appear to be as important from an overall risk standpoint. Given that the multimedia analysis may well show such results, the concern was quite understandable. The anchoring efforts described above can be invaluable in addressing concerns related to the comparability of risk estimates. The authors consider this possible resistance as being related to a reluctance to shift from traditional separate independent media analyses to a holistic multimedia approach.

Experience with large-scale applications has also shown that one model cannot apply to all

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[3]Warren and Strenge, 1994, *Multimedia-Modeling Environmental Database Editor (MMEDE) User Manual*, developed by Pacific Northwest Laboratory and currently licensed to WindowChem for distribution.

situations. For each application, certain new special situations arose that were not covered by the current MEPAS formulations. Some cases were covered with model updates and others by using an alternative model. As a result of the cases where the MEPAS model was updated, each progressive large-scale application has resulted in a model with wider applicability.

SUMMARY

Multimedia models that integrate waterborne and airborne pathways into a single system for estimating various impact end points have proven to be an effective tool in large-scale applications. A multimedia model, such as MEPAS, greatly reduces the number of different software systems required for the analysis. The advantage is that fewer separate models greatly reduces the logistics of conducting large-scale applications.

Although this use of an integrated multimedia model results in a significant reduction in the time and cost, the application of the multimedia software to a large number of potential problems can still be a prohibitively large effort. A modular risk estimation approach based on unit factors was an effective solution to this limitation. The modular approach allows a large-scale application to be completed for a reasonable level-of-effort within a relatively short time period. The modular approach is not limited to use with a multimedia model; the approach can be used with any appropriate model, or set of models.

ACKNOWLEDGMENTS

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