ARMY RISK ASSESSMENT MODELING SYSTEM (ARAMS)

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1. Introduction

U.S. Department of Defense (DoD) operations of munition plants, bases, training ranges, and other facilities have resulted in the release of military relevant compounds (MRCs) and other contaminants to soil, groundwater, surface water, and air. The risks to both human and ecological health associated with multimedia exposure to these compounds must be evaluated. The Army utilizes risk assessment procedures to determine cleanup target levels and to evaluate remediation alternatives to provide the most cost-effective approach to reach these levels. Currently, risk assessment procedures are plagued by high levels of uncertainty in both the estimate of effects of the contaminants as well as the probability of exposure. This uncertainty results in excessively conservative risk estimates and levels of cleanup, driving the cost of the cleanup to prohibitive levels.

The U.S. Army Engineer Research and Development Center (ERDC) is developing a computer-based, modeling and database analysis system for estimating human and ecological health risks associated with MRCs. The Army Risk Assessment Modeling System (ARAMS) is based on the widely accepted risk paradigm, where exposure and effects assessments are integrated to characterize risk. The development of ARAMS is expected to significantly reduce the time required to conduct risk assessments, thus, significantly reducing cost. Additionally, substantial cost savings for cleanup are expected by reducing the influence of uncertainty in setting cleanup targets. This paper describes ARAMS and its development, which is ongoing and being accomplished in phases.

2. Requirements

A workshop was held in New Orleans, LA, May 1-15, 1998, to determine the requirements for ARAMS. Findings from that workshop are described by Deliman et al. [1]. These requirements, which are summarized in Table 1, were used to plan the conceptual design and specifications for ARAMS development.

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Table 1. User and System Requirements

User Requirements	System Requirements
Provide an object-oriented, conceptual site modeling, graphical, user interface	Provide network empowered heterogeneous computing when required
Address military relevant compounds	Provide standards for seamless model and data linkages
Integrate exposure and effects models and databases	Allow integration of legacy models to leverage existing models
Provide human & ecological (aquatic & terrestrial) probabilistic risks	Provide modularity to add new models/science
Allow screening-level & focused assessments	Provide user interfaces and self-defensive software
Allow multi-level ecological assessments	PC based, Pentium 200 or higher
Allow for spatially explicit analysis	Operates with Windows NT or 2000
Provide time-variable analysis (exposure, dose, uptake, effects, risk)	Can access Web-based, network services and remote data
Allow multimedia pathways	Provide data/file/web security
Include uncertainty analysis	
Provide linkages to other tools and databases	
Provide flexibility to start anywhere in the procedure and use measured data	

The overall objective of ARAMS is to develop a computer-based decision support system that integrates multi-media fate/transport, exposure, uptake, and effects of MRCs to assess human and ecological health impacts. There is also the need to conduct both screening-level and focused assessments. Screening-level assessments are those that can be conducted rather quickly and are used to help narrow the scope of analysis, whereas focused assessments require more time but should be more definitive and provide more information.

3. Development Strategy

Thus, the overall strategy for ARAMS development is to build the system in stages, for screening-level assessments first, then for focused assessments. Screening-level assessments will be accomplished through the use of rather simplistic (e.g., zero, one-, and quasi-two-dimensional analytical models) fate/transport exposure models, measured exposure concentrations, and effects databases. The focused assessments will involve the use of more sophisticated fate/transport models (e.g., multi-dimensional numerical models) coupled to effects databases and potentially to effects models, such as population models and food chain models should data permit. The first release version of ARAMS is scheduled during 2001 and will feature only screening-level capabilities.

The overall development strategy can be summarized by the following three concepts: 1) use object-oriented (icons), conceptual-site modeling to construct environmental pathways; 2) link various existing models or databases for exposure and effects through common data constructs and application programming interfaces (APIs); and 3) integrate exposure and effects to produce risk. Existing databases and models for exposure, uptake, and effects are linked to the system such that each remains in its legacy form without alteration. The conceptual site model (CSM) interface is based on the Framework for Risk Analysis in Multi-media Environmental System (FRAMES) developed by the Pacific Northwest National Laboratory (PNNL) of the U.S. Department of Energy (DOE) in cooperation with the U.S. Environmental Protection Agency (EPA) [2]. The CSM enables the user to visually specify, through objects, the pathways and risk scenarios. Also, the user can choose which particular model or database to use for each object.

Most health impacts assessments tend to use exposure values that are static over time, whereas the objective here is to allow time-varying exposure concentrations and health impacts. Additionally, probabilistic risks will be computed whenever data permit, as Figure 1 illustrates. In this example, the probability distribution for exposure is combined with the effects or response distribution as related to exposure concentrations. In this case, the response is mortality, where LC_{50} is the concentration at which 50 % of the population died. Using concentration as the variable common to both exposure and effects, it is possible to construct the cumulative probability distribution for mortality shown in the bottom panel.

4. ARAMS Components

ARAMS will contain the following basic components, some of which are implemented and some to be implemented in later versions:

- object-oriented, graphical, CSM framework user interface;
- databases for chemical environmental properties, including bio-accumulation characteristics;
- screening-level fate/transport models, exposure assessment models, and options for specifying measured exposures;
- focused (i.e., comprehensive) fate/transport models and exposure assessment models (e.g., food chain models);
- databases for human and ecological toxicity effects and options for specifying effects based upon toxicity tests;
- human health impacts assessment module;
- ecological health impacts assessment module;
- comprehensive ecological effects models, e.g., meta-population models;

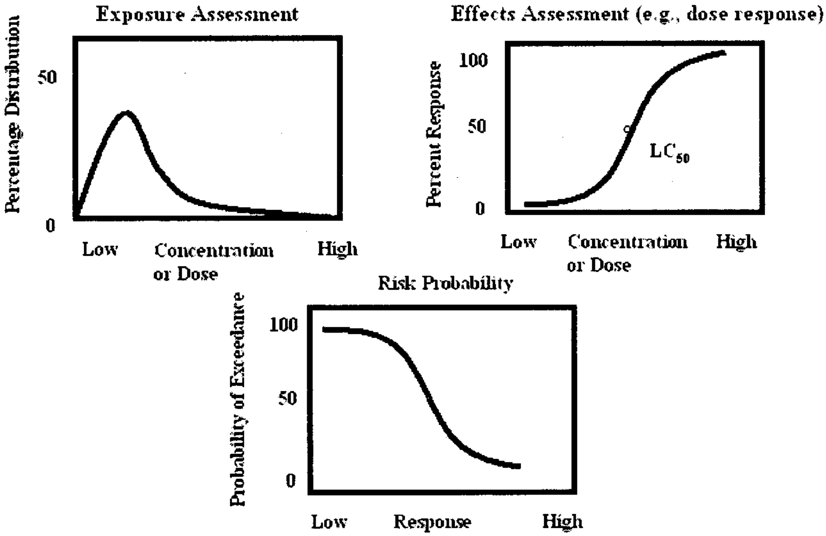

Figure 1. Obtaining the risk probability curve

- uncertainty analysis engine;
- report generator; and
- visualization and GIS packages.

Each of these components is described briefly below.

Within the Frames-bases CSM, objects are used to denote different modules. For example, each primary exposure module (or media, i.e., air, land or soil, surface water, vadose zone, and groundwater) is represented by an object or icon. Similarly, there are objects representing the sources of contamination, the intermediate exposure pathways (e.g., crops, water supply usage, fish, animals, etc.), uptake, and health impact assessment. The objects are connected to denote the exposure pathways, thus forming a conceptual site model that fits the case under study. Originally, FRAMES handled only human health assessment. However, an ecological health assessment module was added during year 2000, and the system was modified to allow the user to start at any point in conducting the risk assessment analysis (commensurate with available data), rather than always having to start with the source term specification.

Drop-down menus exist for each object that allow the user to select the model or database of choice for describing that object's process. For example, there are presently four alternatives for modeling or specifying sources. As another example, for the groundwater module, there are choices for entering measured concentrations, using screening-level models like MEPAS (Multi-media Environmental Pollutant Assessment System [3]) or comprehensive models like those in the DoD Groundwater Modeling System (GMS). Models can be added to an object module. For example, the surface water contaminant fate model, RECOVERY [4], and the Hydrologic Evaluation of Landfill Program (HELP) [5] were recently added as modeling options under the surface water and source term modules, respectively. HELP will also be added as an overland runoff modeling option. Each model or database linked into the FRAMES system is required to have a user interface for entering information or data specific to that model or database. After selecting the particular model or database for an object, the user can launch the user interface for that model or database. For example, if MEPAS is selected for the vadose zone module, the interface for the MEPAS vadose zone model is launched to begin model setup. It is also possible to link, via the import/export object, model output that was developed *a priori* outside the ARAMS application.

FRAMES has a database for chemical properties. The FRAMES database was recently modified to allow the user to select the chemical of concern by its CAS (Chemical Abstracts Service) number to reduce errors in choosing chemicals. Also, a chemical database developed for RECOVERY was included as an option. For aquatic bio-accumulation, the biota-sediment accumulation factors (BSAF) database [6] is being added. Similarly, other databases will be added later, or linked via the Internet, as necessary. The BSAF database is used to estimate theoretical bio-accumulation potential (TBP) which is an option in the aquatic exposure module. The TBP estimates are based on sediment contaminant concentration, organism lipid content, BSAF, and sediment organic carbon.

MEPAS provides various screening-level models needed for ARAMS, including models for describing the following: sources; fate/transport in air, streams, vadose zone, and groundwater; uptake through crops and farm animals; and human uptake/exposure and impacts models. The MEPAS fate/transport models are typically analytical solutions to one- and quasi-two-dimensional transport equations for each media. As mentioned earlier, others screening-level models (i.e., RECOVERY and HELP) have been added, and others can be added later as necessary.

Comprehensive fate/transport models are generally numerical solutions to multi-dimensional flow/transport equations. DoD (through ERDC in cooperation with Brigham Young University) has developed three graphical user environments to facilitate application of comprehensive hydro-environmental models: the GMS [7], the Watershed Modeling System (WMS) [8], and the Surface Water Modeling System (SMS) [9]. The GMS has a variety of multi-dimensional groundwater flow and reactive contaminant transport models. Water quality and contaminant models are being added to the SMS, and the WMS contains the popular HSPF [10] watershed model for simulating contaminant runoff. For focused ecological exposure modeling, it is envisioned that food chain models could be linked in ARAMS.

A number of toxicity (or effects) databases will be available to ARAMS, some of which will be available through Web access to provide up-to-date information. FRAMES contains the IRIS and HEAST human health databases. Options for obtaining recent updates to human toxicity databases via the Web will be available in

ARAMS. During year 2000, the ERDC's Web-based Environmental Residue Effects Database (ERED) (http://www.wes.army.mil/el/ered/index.html#misc) was linked to ARAMS. ERED is stored in Microsoft's ACCESS, is online, and can be queried via a web-based user interface. However, the ARAMS linkage to ERED will provide seamless extraction of information required for the assessment. ERED contains over 2000 toxicity records for over 200 chemicals for various species. Other effects databases are being considered for future additions to ARAMS, such as the ECOTOX batabases (http://www.epa.gov/ecotox/ecotox_home.htm) for ecological effects.

FRAMES includes a MEPAS module for human health impacts assessment. A Wildlife Ecological Assessment Program (WEAP) was modified and added to the ARAMS/FRAMES system during 2000 for ecological health impact calculations. In addition to providing hazard quotients, WEAP allows calculation of cumulative distribution functions (CDF) to relate various levels of effects (e.g., dose-response data) with exceedence probabilities. For example, a CDF could show the probability of exceeding the LC_{90}, LC_{50}, LC_{10}, etc. for a given exposure scenario.

Population and meta-population models are being considered to provide another tier of ecological health impacts assessment. When data permits linkage of population parameters (e.g., reproduction and survivability) to exposure or body burden concentrations, population models could be utilized to project future population level.

Uncertainty analysis can be performed with the ARAMS/FRAMES sensitivity and uncertainty module which conducts Monte Carlo realizations using Latin Hypercube sampling and user specified distributions for stochastic parameters. A Microsoft Excel-based plotting package provides time-series output for any of the objects and risk probability plots. Also, the modeling systems being linked to ARAMS (e.g., GMS) have comprehensive graphics packages. A report generator for the risk assessment guidance for Superfund (RAGS) will be developed to aid in reporting results in a form that is compatible with existing procedures.

During FY01, work will be focused on linking with the system GIS capability and Tier I terrestrial ecological health impacts assessment. The first version will be released following extensive testing during FY01.

5. Conclusions

ARAMS is versatile allowing screening-level assessment or more focused assessments for both human and ecological health impacts. The CSM is the hub or framework on which all components of ARAMS are founded. The approach has the advantage of making assessments more intuitive since they are based on a conceptualization of the problem. Also, this approach makes the system modular, allowing new models, databases, and science to be added fairly easily.

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