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EXECUTIVE SUMMARY

Many pathways exist for transportation agencies and other public and private agencies to become responsible for sites contaminated by hazardous wastes. As a result, agencies frequently face a multitude of legal, regulatory, financial, technical, and health risk problems. When transportation agencies become involved in the remediation of hazardous waste sites, the common practice is to hire consultants and contractors for the clean up process. Because the field of hazardous waste site remediation is changing so rapidly, agency personnel evaluating the consultant's recommendations need to have access to the most recent regulatory and remediation information.

Early stages of the remediation process typically involve site assessment, and the identification of feasible technologies for treatment. The objective of this study was to develop a user friendly computerized methodology for screening out the most inappropriate treatment technologies for a specific waste at a specific site. The STEP model was developed for this purpose using knowledge-base expert system techniques. Object oriented programming was used to interface multiple rule-bases, databases, and a simulation model.

The STEP model was applied to a case study involving the spillage of 27,000 gallons of JP-4 jet fuel, due to the failure of an automatic shut-off valve, at an air facility. The recommendations produced by the model agreed with the actual remedial action taken at the site. STEP is a prototype model that, if developed to its potential, could be used to promote nation-wide consistency, provide the framework for building a shared base of knowledge about successful and unsuccessful solution techniques, allow non-experts to do preliminary screening of appropriate technologies, and provide a training tool for in-house personnel.

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CHAPTER 1

INTRODUCTION

The motivation for this study was the need of transportation agencies to quickly evaluate the appropriateness of a wide variety of hazardous waste remediation technologies for a specific waste at a specific site. The strategy was to develop a user-friendly computerized methodology utilizing published procedures. The process of hazardous waste site remediation includes site characterization, risk assessment, remedial alternative design, and implementation.

The site remediation process is very comprehensive and most often is time consuming and expensive. Expert systems techniques have been proposed to guide an analyst through this process. An "expert system" is a computer implementation that emulates a human expert. It queries the user for information, accesses databases containing facts, and provides specific advice based on uncertain and incomplete information. One of the essential characteristics of an expert system is the capability to explain why each decision is reached, even in a series of decisions leading to the resolution of a complex problem. Typically, these systems contain the established knowledge about a rather narrow field of study (e.g., remedial technology alternatives) and contain logic that guides a less experienced analyst to arrive at the same solution (e.g., selection of a particular remedial technology) that would have been reached by a human expert under the same circumstances.

The decision-making process in an expert system is guided by a knowledge base, which consists of a series of cause-effect type rules. One of the benefits of the expert system approach is that the knowledge-base can be modified and expanded without any reprogramming of the computer code. The terms "knowledge-base" or "rule-base" are used interchangeably.

A rule-based decision-support system (RBDSS) was developed for this study. A RBDSS is similar to an expert system in that it contains a knowledge-base; however, it is different in that it lacks the capability to immediately provide extensive on-line explanations to the user about why each decision was made. The RBDSS for hazardous waste site remediation is intended to optimize resources in terms of time and money by allowing the site remediation personnel to focus on the most appropriate remedial alternatives at an early stage of site remediation. Additionally, it is an approach that in the future may help to provide broad benefits by promoting consistency and transferability of information among users, providing an efficient medium for updating technological information in a rapidly changing field, providing expert advice when a human expert is unavailable due to cost or time, and enhancing training procedures for agency personnel.

The Soil Treatment Evaluation Program (STEP) decision-support system is a prototype to demonstrate the benefits of applying expert-system methodologies to hazardous waste site remediation. STEP was developed to specifically aid a user with the preliminary screening of treatment technologies applicable to the treatment of hazardous waste contaminated soils with special emphasis on the needs of transportation agencies.

This chapter presents the literature reviewed pertinent to expert-system hazardous waste applications for transportation agencies. It includes a brief description of the treatment technologies that are incorporated in the screening process by the STEP prototype. Chapter 2 describes the STEP methodology and the computer implementation. Chapter 3 describes the application of the STEP methodology to a case study involving a spill of 27,000 gallons of JP-4 jet fuel at an airport facility. Chapter 4 is comprised of the summary and conclusions followed by references in Chapter 5. The appendices contain the bibliography and the rule-base files used for the prototype model.

Literature on Expert System Applications

Friend and Connery (1988) undertook a comprehensive research effort in response to highway agency concerns about hazardous waste site discoveries. Their goal was to develop a compendium of information that could be used by highway officials to understand the liabilities and risks they face and provide policies and procedures that would help them avoid agency liability. In addition they provided an overview of the techniques, technologies, and terminology associated with the identification and remediation of a hazardous waste site.

Biggs et al. (1989) explained that the Cost Of Remedial Actions (CORA) model has two components: an expert system to determine applicable treatment technologies, and a cost model to provide cost estimates for 40 proven treatment technologies. The recommended treatment technologies have to be placed into treatment alternatives by the user of the system. This model was developed in response to U.S. EPA needs for having a consistent and traceable methodology of remedial selection, and a methodology for generating site-specific cost estimates.

The remedial action assessment system (RAAS) computer methodology is being developed by the Pacific Northwest Laboratory (PNL) for the U.S. Department of Energy (DOE) (Buelt et al., 1991). The authors note that the RAAS methodology will be used for screening and linking demonstrated technologies and evaluating the generated remedial alternatives. This methodology will be used for feasibility studies under CERCLA and RCRA corrective actions. The RAAS methodology aims at evaluating the remedial alternatives in terms of effectiveness, implementability, and cost. Other mentioned features of the RAAS model include: user-friendly features, a risk assessment model to evaluate the effectiveness of the generated remedial alternatives in terms of risk reduction and a technology information system which provides information on technologies in a graphical manner. Development of the first usable prototypes of the RAAS methodology and the RAAS Technology Information System is proposed to be completed in FY 1991 for testing by users in the field.

The computer-aided response technologies selector (CARTS) is an expert system being developed by the U.S. EPA's environmental response team (ERT) in Edison, New Jersey (Subramanian et al., 1991). It has been noted by Subramanian et al. that CARTS will: 1) assist the remedial project managers (RPMs) and on-scene coordinators (OSCs) in developing treatment trains, 2) identify data requirements, 3) allow users to evaluate different scenarios, and 4) include a vendor database providing information on the vendors that are available with demonstrated ability to implement the generated treatment alternatives. In addition, it is noted that CARTS documents its reasoning behind generation of treatment alternatives for the RPMs to maintain consistency and defensibility.

Clements and Greathouse (1989) conducted a review of the expert systems development under the Risk Reduction Engineering Laboratory (RREL) Expert Systems Development Project. They listed TECHSCRN as a rapid prototype expert system that prompts the user for site and contaminant characteristics and, from the 35 technologies in its database, filters out those technologies that are inappropriate for site remediation. Further development of this model is currently underway.

Technology Description

Eleven most appropriate soil remediation technologies were selected for the STEP prototype. The prototype was developed for easy modification and expansion and additional treatment technologies can be readily incorporated into the model's rule-base. Following are the descriptions of the most appropriate technologies.

In Situ Soil Venting

This technology is also referred to as soil vapor extraction and in situ air stripping. It is primarily applied to recover volatile organic compounds from the unsaturated (vadose) zone of the soil. Either vapor extraction wells alone or in combination with air injection wells are used to collect the contaminant vapors. In most cases, the contaminant vapors must be collected at the surface and either recovered or destroyed in order to control the air emissions at the site and to meet the safe air discharge limitations for that contaminant (Electric Power Research Institute and Edison Electric Institute, 1988).

This technology is applicable to volatile organic compounds with high vapor pressure and low water solubility (Electric Power and Edison, 1988; U.S. EPA, 1991). The soil should be porous and permeable to allow vapor movement and should contain low sorption capacity and organic content so that the waste can volatilize without significant sorption onto the soil. Environmental factors like high temperature, high wind, high surface evaporation at the site, and low precipitation will enhance the success of this technology. The concentration of the contaminant and the volume of soil contaminated also influence the success of this technology. The vapors collected by this technology may be further treated by activated carbon adsorption, thermal destruction, or condensation by refrigeration.

In Situ Bioremediation

This technology is a process where oxygen and nutrients are supplied to the existing soil microorganisms (usually bacteria) to breakdown the organic contaminants into less harmful products or mineralize them into the safe end products of carbon dioxide and water (U.S. EPA 1990a). Specially acclimated, commercially available microorganisms are also used for the remediation of contaminated subsurface. The bacteria that are used could be either aerobic or anaerobic. Typically this technology is used in conjunction with a ground-water pumping and re-injection system to circulate nutrients and oxygen through the contaminated aquifer and the soil system (U.S. EPA, 1986; Electric Power and Edison, 1988; U.S. EPA, 1988a).

This technology is applicable only to the degradation of organic compounds. Availability of the organic contaminant to the microorganisms (microorganisms inhabit soil moisture or need soil moisture to obtain nutrients), the concentration of the contaminant, the water solubility of the contaminant and the biodegradability of the contaminant are important chemical factors. Soil factors such as high permeability, moisture content (50-75% field capacity), optimal or neutral pH, and favorable temperature to the microorganisms effect the feasibility of this technology (U.S. EPA, 1986; U.S. EPA, 1988a; Electric Power Research Institute and Edison Electric Institute, 1988; Noyes Data Corporation, 1988; U.S. EPA, 1990a).

Soil Washing and Soil Flushing

Soil washing and soil flushing are two different names for similar technologies. Whereas soil washing refers to above-ground treatment of excavated soil, soil flushing refers to in situ treatment of the contaminated soil. The process of soil flushing involves flooding the contaminated zone at the waste site with a flushing agent to dissolve the contaminants. Subsequently the contaminants are brought above ground through strategically placed extraction wells. Proper hydraulic control is necessary to prevent ground water pollution which could be incidentally caused by the leaching of the contaminants away from the site (U.S. EPA, 1990a).

Soil washing technology is used to decontaminate the soil after it has been excavated. Soil washing removes the contaminants in one of the two ways (U.S. EPA, 1990b): by dissolving or suspending the contaminants in the wash solution (similar to soil flushing) or by concentrating the contaminants into a smaller volume through particle size separation (fine particles of clay and silt separated from the coarser sand fractions). The particle size separation is effective because organic contaminants are more readily sorbed by the fine particles than by the coarse particles.

The washing fluids used by these two technologies may be composed of (U.S. EPA, 1986): water, organic solvents, water/chelating agents, water/surfactants, and acids or bases. After processing, the washing fluid containing the contaminants must be treated or appropriately disposed. In case of soil flushing the treated water is sometimes re-used and re-injected into the soil via a recirculation system.

These technologies may be applied to a variety of waste groups (U.S. EPA, 1990a): heavy metals (e.g., lead, copper, zinc), halogenated solvents (e.g., TCE, trichloroethane), aromatics (e.g., benzene, toluene, cresol, phenol), gasoline and fuel oils, and PCBs and chlorinated compounds.

Soil washing and soil flushing technologies are feasible only if one waste type is present in the soil. In general these technologies are applicable to wastes that have low organic content, low cation exchange capacity, and a high permeability (Noyes Data Corporation, 1988; U.S. EPA, 1986; U.S. EPA, 1990b). Sandy porous soils are more amenable to these technologies than soil consisting of silt and clay. The type of washing or flushing agents used, the characteristics of the contaminants, and the interactions of the agents with the soil determine the feasibility of these technologies and should be evaluated on a site/soil specific basis. Soil washing has advantage over soil flushing in that the two important site restrictions of low hydraulic conductivity and non-uniform contaminant contact due to preferred flow paths are overcome (U.S. EPA, 1990a). Thus, hydrogeologic conditions at a site play an important role in determining the feasibility of soil flushing versus soil washing.

In Situ Vitrification

In situ vitrification (Superfund University Training Institute, 1991; U.S. EPA, 1988a; Electric Power Research Institute and Edison Electric Institute, 1988) converts contaminated soil into an obsidian using electricity. Large electrodes are inserted into the soil and graphite and glass frit are placed among the electrodes on the soil surface to act as a starter path for the electric circuit. Electricity is passed through the electrodes and graphite to create a "melt." The melt gradually works downward through the soil to a predetermined depth. Non-volatile elements are incorporated into the melt and organic compounds are destroyed by pyrolysis. The melt cools down into an obsidian once electric current ceases. A hood placed over the processing area traps the combustion gases, drawing the gases into an "off-gas" treatment unit.

This technology is very versatile in that it can be applied to a variety of waste groups. It pyrolyses organics and immobilizes inorganics. This technology is feasible for contaminated soils with low permeability and moisture content, and where the depth to ground water is great. The U.S. Environmental Protection Agency (1988a) lists characteristics that impact the process feasibility. They are: buried metals (drums) occupying over 90% of linear distance between electrodes, loosely packed rubbish, buried coal, combustible liquids (greater than 9600 lb/yd of depth), combustible solids (greater than 6400 lb/yd of depth, including 30% soil with the solids), combustible packages (greater than 1.2 cubic yards or 32 cubic feet), presence of volatile metals and their depth, and void volumes not exceeding 5-6 cubic yards or 152 cubic feet.

In Situ Stabilization/Solidification

Stabilization, solidification, fixation, and encapsulation are terms that refer to the process of adding materials that combine with the contaminants to decrease their mobility (Ehrenfeld and Bass, 1984; U.S. EPA, 1986; Rich and Cherry, 1987). Stabilization can be performed either above-ground (in tanks) or in situ. The U.S. Environmental Protection Agency (1988a) describes the in situ stabilization process where stabilization agents are applied directly using mixing paddles and augers that blend the soil with a stabilizing agent which is fed through the center of each shaft. The treated block of soil is left behind.

Stabilization processes are classified by the primary stabilizing agent used: cement-based, pozzolanic- or silicate-based, thermoplastic-based, or organic polymer-based. On a commercial basis cement-based and pozzolanic-based technologies have been found to be very successful.

The U.S. Environmental Protection Agency (1986) lists the following waste types that are handled by stabilization techniques: heavy metals, inorganics such as sulfides, organics (no more than 20% by volume), asbestos, and solidified plastic, resins and latex. The Superfund University Training Institute (1991) identifies uniform mixing of the stabilizing/solidifying agent as the most significant difficulty in applying this technology. The applicability of this technology is based primarily on the agents that are used, the contaminants that are present, and the soil conditions.

Soil Excavation

Soil excavation is a removal action rather than a treatment technology where the contaminated soil is excavated and is either treated on-site, off-site or is disposed off. Soil excavation is appropriate for emergency measures or for quick remediation of the contaminated soil. The volume and depth of soil contaminated determine the feasibility of soil excavation. Other factors that determine the applicability of excavation include proximity to business, structures (above-ground and under-ground), and traffic. Excavation of soil contaminated with volatile chemicals may pose a health risk to the surrounding human population. In addition, the excavated soil needs a disposal site and a source of backfill is needed for filling the excavation (Noyes Data Corporation, 1988; U.S. EPA, 1990a).

Incineration

Incineration is a thermal treatment process using high temperatures to either destroy or detoxify wastes primarily consisting of organics (U.S. EPA, 1986; U.S. EPA, 1988a). Incineration has high contaminant destruction and removal efficiency under proper operational conditions. Air pollution control technologies are normally integrated with incinerators to control particulate and harmful gaseous emissions. Rotary kiln incineration uses slightly inclined, refractory-lined cylinders. Wastes and auxiliary fuel are introduced into the high-end of the kiln. As the wastes pass through the rotating kiln they are substantially oxidized to gases and ash. Ash is removed at the lower end of the kiln and gases are further treated in a secondary combustion chamber and are passed through air pollution control devices for particulate and acid gas removal.

Fluidized bed incinerators have refractory-lined vessels containing an inert, granular, sand-like medium. The heated bed material is suspended by the combustion air forced upward through the bed. Waste is injected radially and mixes with the hot fluidized bed material. Heat is transferred from the bed material to the waste causing the combustion of the waste. When the waste is burnt, heat is transferred back to the bed. Secondary combustion chambers are included for combustion of volatiles. Off-gas treatment following the secondary chamber may include wet scrubber, baghouse or electrostatic precipitator.

Infrared incineration systems use infrared energy as the auxiliary heat source. Wastes are fed to the tightly enclosed systems on conveyor belts and are destroyed by the infrared radiation. Ash is discharged into a hopper and is collected by an automatic collection system. Secondary combustion chambers are provided for complete combustion. Pollution control equipment is used to trap the exhaust gases.

Pyrolysis incineration involves the destruction of organic wastes in the absence of oxygen at high temperatures. The waste is reduced to elemental gas and water. The absence of oxygen facilitates the separation of the waste into two separate fractions: organic (gas), and inorganic (salts, metals, particulates). The gases and ash are collected and properly disposed.

Incineration is primarily applicable to organic wastes (U.S. EPA, 1986; U.S. EPA, 1988a). The general characteristics impacting the feasibility of the four incinerators are high moisture content, elevated levels of halogenated organic compounds, presence of PCBs, dioxins, presence of metals, elevated levels of organic phosphorus compounds. The characteristics impacting process feasibility for the individual incineration technologies are

1. Rotary kiln incineration - oversized debris, presence of volatile metals, alkali metal salts, fine particles, spherical or cylindrical wastes, ash fusion temperature and heating value of wastes;
2. Fluidized bed incineration - feed particle size, low-melting point wastes, particularly alkali metal salts, ash content of the waste, waste density, and presence of chlorinated or sulfonated wastes;
3. Infrared thermal treatment - nonhomogeneous feed size, and moisture content; and
4. Pyrolytic incineration - high BTU organic waste and high temperature requirements.

CHAPTER 2

MODEL DESCRIPTION

STEP is constructed from a C++ object oriented programming (OOP) library on an IBM-compatible microcomputer. The library was developed by Grenney (1993) to provide a toolbox of class objects (programming modules) specifically for creating RBDSS. The source code derived from the class objects simply provides the functionality and communications for rule-bases, databases, and numerical procedures. In other words, it provides an empty shell which may be filled with knowledge specific to the application at hand. The model may be modified and expanded without recompiling the source code; all that is required is editing a rule base, changing values in a database, or specifying new coefficients for a numerical algorithm.

METHODOLOGY

In order to effectively implement a rule-base decision-support system (RBDSS) for this study, the system must possess the following features:

1) Lead a novice user through a step-by-step process to reach a reasonable conclusion.
2) Display tables and graphics quickly and concisely for experienced users.
3) Provide optional supplemental information to assist with the interpretation of displayed data.
4) Interface with commercial data base products such as PARADOX™[1].
5) Interface with commercial spreadsheets such as EXCEL™[2].

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[1] PARADOX™ is a registered trade mark of Borland International®, Scotts Valley, CA.

[2] EXCEL™ is a registered trade mark of Microsoft®, Redmond, WA.

6) Utilize Dynamic Data Exchange (DDE) links to interface with commercial products as well as macros and specific software modules for analyzing data and simulating "what-if" scenarios.

We distinguish between two fundamental approaches for providing these features: 1) formulating the application in a declarative architecture which utilizes and coordinates procedural modules and 2) formulating the application in a procedural architecture which utilizes and coordinates knowledge-base objects. The decision making and informative aspects of the application lend themselves to the knowledge-base approach. The data manipulation aspects are best suited to the procedural approach. We require a hybrid tool that provides the flexibility of both approaches.

The Prolog programming language and commercial expert system shells are declarative approaches that permit interfacing with procedural modules. However, in order to better interface with other products and to provide better portability, Grenney (1993) designed a tool composed of a procedural "wrapper" which has the capability to instantiate multiple knowledge-base objects. Information exchange (data and commands) is accomplished by messages sent between the wrapper and knowledge-base objects. A library of C++ classes, called TRIPOD (Grenney 1993), was created to facilitate the incorporation of different kinds of objects into the wrapper. The library is implemented on IBM compatible microcomputers.

Figure 1 illustrates the model structure. The wrapper is a typical C++ program with the standard Input/Output and procedural capabilities. It may use classes from the TRIPOD library to generate one or more knowledge-base objects to perform specific functions that can best be performed by a knowledge-base construct. The types of knowledge-base functions that are included in the TRIPOD library provide the features listed above.

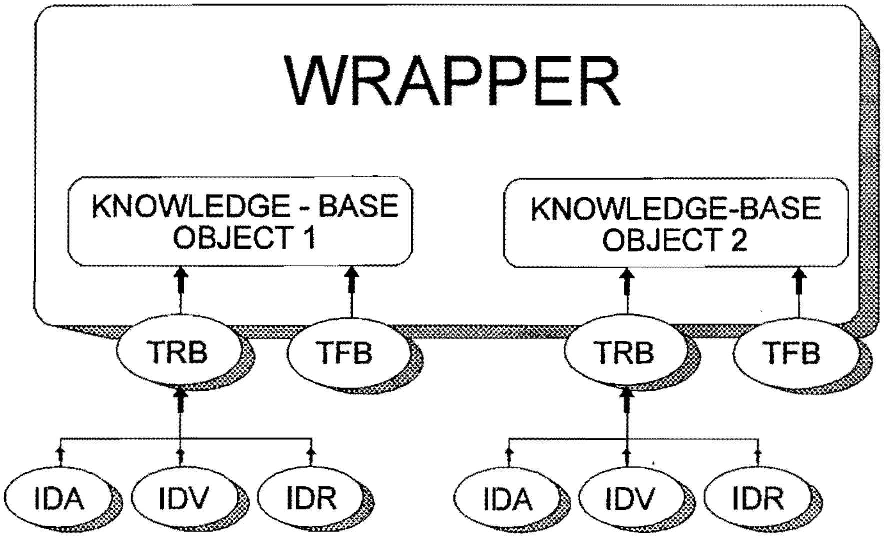


Figure 1. Typical Structure of an Application using TRIPOD Classes.

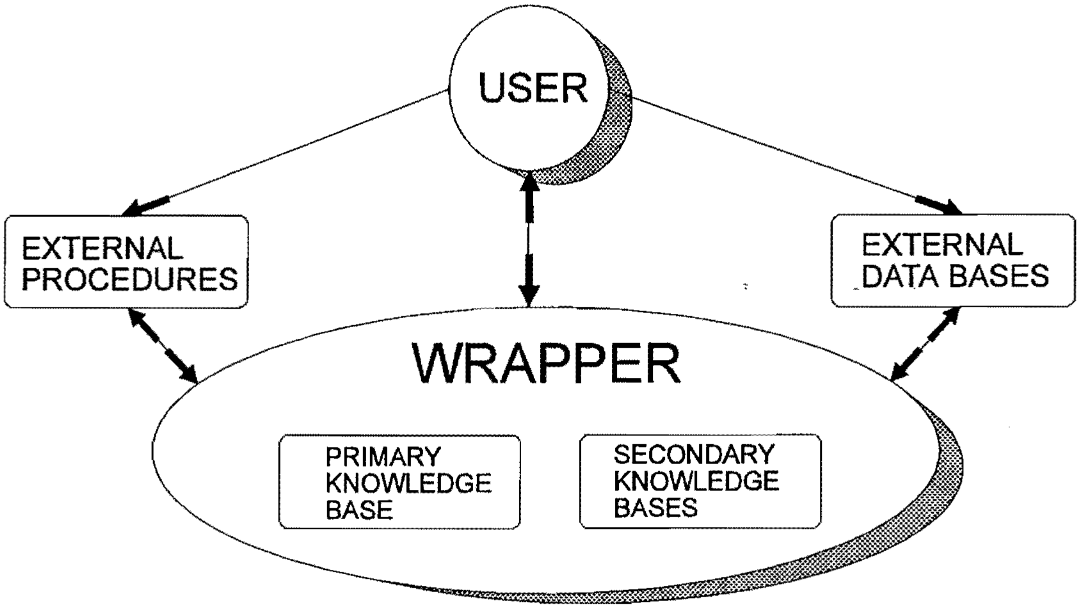


Figure 2. Implementation Strategy.

The ovals in Figure 1 represent disk files. When instantiated, each knowledge-base object receives its knowledge from two files: the TRIPOD Rule-Base file (TRB) and the TRIPOD Fact Base file (TFB). The TRB file contains facts for the rules, auxiliary data, text, and visual images for the object. Data in the TFB file may be set to automatically fire rules in an object at the time it is instantiated. The TRB file is constructed by a preprocessor from three files: The "Actions file" (IDA), the "Variables file" (IDV), and the "Rules file" (IDR) as illustrated in Figure 1. These are ASCII files which may be created by the developer using a standard text editor.

The Variables File.

A variable is a quantifiable characteristic of the system. The state of the system at any time is defined by the values of the variables. The variables file contains a list of unique identification symbols and associated information for each variable. Several different types of variables may be specified including integer, real, logical, string, list, and visual. The variables may take on values from the fact base, from the wrapper, and from interaction with the user.

The Actions File.

An action is a consequence that is invoked when an associated rule fires (e.g., evaluates true). The actions file contains a list of unique identification symbols and associated information for each action. A variety of actions can be performed including text display, arithmetic on data, data base access, spreadsheet access, remote sensor access, audio/video presentations, instantiation of other knowledge-base objects, etc.

The Rules File.

A rule is an IF-THEN statement specifying the appropriate action for a particular state of the system, as defined by the values of the variables. The antecedent of the rule (the IF part) is made up of a series of "tests." For a test, if the value of the variable satisfies the specified comparison, then the test is true. If all of the tests for a rule are true, then the rule is true and the associated action is invoked.

The Inference Engine.

Each knowledge-base object contains an inference engine to evaluate the rules and to trigger appropriate actions. The inference engine is basically a forward chaining algorithm with the added capabilities to branch, loop, and efficiently evaluate nested rules. The inference engine is described by Grenney (1993).

TRIPOD IMPLEMENTATION STRATEGY

Figure 2 illustrates a possible implementation strategy. A procedural wrapper is created that instantiates a primary knowledge-base object. A knowledge-base is composed of the rule-base file and the fact base file defined above. The primary knowledge-base object contains the information and logic necessary to assist a novice user reach a reasonable conclusion. Secondary knowledge-base objects may be instantiated by the wrapper or by the primary knowledge-base object during this process. Secondary knowledge-bases are useful for evaluating subsets of a problem; for example, several small knowledge-bases may be coordinated in place of one large partitioned knowledge-base. This architecture permits easier updating of the system.

The knowledge-base objects may access data from a data base as illustrated in Figure 2. They can be provided direct access or they can gain access through the wrapper. Access can be accomplished by Direct Data Exchange (DDE) mechanisms, by commercial drivers such as the PARADOX™ Engine, or by other special methods incorporated in the objects. Knowledge-base objects may also interface with external procedures as indicated in Figure 2. These procedures may be stand-alone executable modules or they may be in the form of Dynamic Link Libraries (DLLs).

The decision-support system may be bypassed by an experienced user who wishes to go directly to the data base or to a specific external procedure. The wrapper provides such a bypass mechanism. However, provisions can also be made to allow the user to completely bypass the wrapper, as indicated in Figure 2, by the lines connecting the user to the external procedures and data bases, depending on the application.

Because of the flexibility of the development tools, the final application may be configured in any one of a tremendous number of constructs. Careful attention must be paid to the needs and abilities of the potential users in order to configure the most effective product.

STEP IMPLEMENTATION

The STEP prototype was established by defining specific rule-bases, databases, and numerical algorithms that aid the user in screening treatment technologies applicable to the remediation of hazardous waste contaminated soils. It could be useful to RPMs, OSCs, environmental consultants and other parties interested in hazardous waste soil remediation. The STEP system has potential applicability for screening underground storage tank (UST) corrective action technologies, and technologies applicable for the remediation of superfund sites. The system considers technologies applicable to the unsaturated zone, including surface soils.

The methodology of screening used by STEP consists of site assessment and technology screening and is patterned after the United States Environmental Protection Agency's site and technology assessment procedure (1990a).

This chapter provides a brief discussion of the incorporation of the STEP methodology into the U.S. EPA's hazardous waste site remediation process, the methodology of STEP consisting of site assessment and technology screening, and the model components.

Site Remediation Process

The basic approach for the cleanup of a hazardous waste site includes pre-scoping, project scoping, remedial investigation and feasibility studies, and implementation of the selected remedy as depicted in Figure 3A.

Pre-scoping includes preliminary assessment, site inspection, and national priority list (NPL) listing. This crucial step in the remediation process is carried out to determine whether a hazardous waste site needs further investigations and remediation.

Project scoping involves the development of a conceptual site model, identification of remedial action objectives, applicable or relevant and appropriate requirements (ARARs), initial data quality objectives, and the preparation of project plans.

Remedial investigation includes identification of the environmental media contaminated, the nature and extent of contamination, the risk to the human population and the environment exposed to the contaminants, the environmental media pollutant migration control measures, initial identification of cleanup requirements and potential applicable remedial treatment technologies.

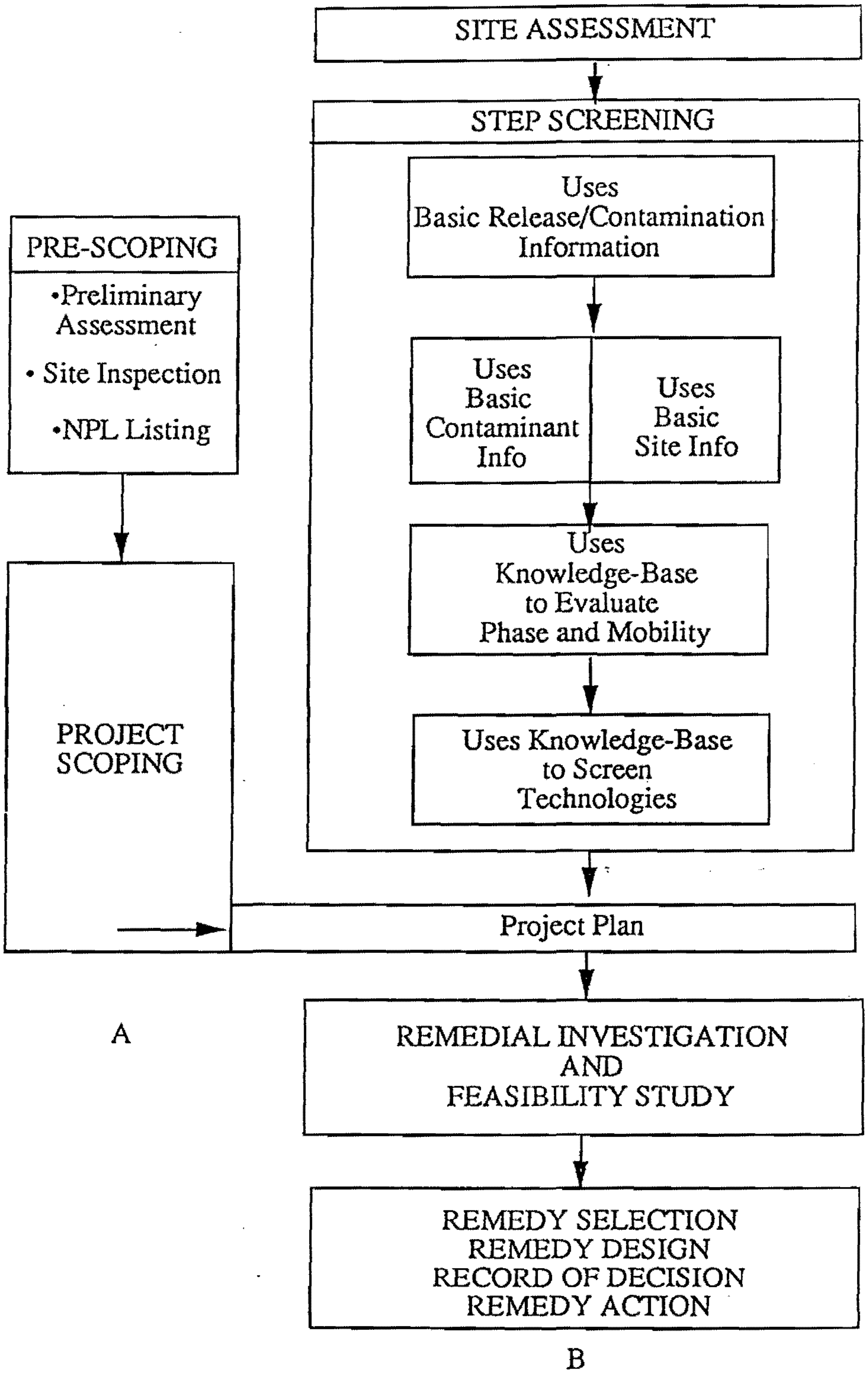


Figure 3. **The STEP Methodology in the Site Remediation Process (after U.S. EPA, 1988b).**

The remedial investigation sets the stage for feasibility studies (potentially an iterative process) during which treatment technologies are grouped together into remedial alternatives for the specific site. These grouped alternatives are then evaluated based upon criteria including protection of human health and the environment, compliance with ARARs, long-term effectiveness and permanence, reduction of toxicity, mobility, or volume, and short-term effectiveness, implementability, and cost (U.S. EPA, 1990c). Treatability studies may be conducted to test the feasibility of a particular technology at a site or to obtain its performance and cost data. The final step in the remediation process is remedy selection, remedy design, record of decision, and remedy action.

Other features included as part of the hazardous waste site cleanup activities are (Sidley & Austin and ENSR Corporation, 1989; Weck, 1987)

1. Work plan, which describes the anticipated future tasks to be done;
2. Sampling and analysis plan, which includes the quality assurance and field sampling plans;
3. Health and safety plan, which incorporates measures for worker and surrounding population safety;
4. Community relations plan, which disseminates information on site activities and results;
5. Emergency and contingency plan, which presents counter measures should an emergency event such as a toxic gas release occur; and
6. Ongoing monitoring program, which ensures that the site has been remediated to the appropriate cleanup levels and that no further treatment is necessary.

Figure 3B shows the incorporation of STEP methodology into the site remediation process. STEP uses the information gathered in both the pre-scoping and project scoping stage of U.S. EPA's site remediation process (Figure 3A).

Site Assessment

Site assessment is normally the first step in identifying and evaluating soil treatment technologies for remediation. The STEP model queries the user to obtain information needed to define the problem, shown in PROBLEM DEFINITION block in Figure 4. Steps in the assessment process are shown in the ASSESSMENT block in Figure 4. The information presented in this section is primarily applicable to in situ treatment technologies. As presented in Figure 4, STEP utilizes information on 1) contaminant release and current extent of contamination, 2) soil characteristics, 3) contaminant characteristics, 4) phase of the contaminants, and 5) mobility of the contaminants.

Release and Current Extent of Contamination

There is a need for information about the release rates of contaminants, the extent of contamination, and time since last release. The current and projected levels of contamination affect not only the types of remedial technology appropriate for the site, but also the urgency and difficulty of implementation.

Soil Characteristics

This information pertains to both the soil and the hydrologic characteristics of the site. Important site/soil information considered by this methodology are soil porosity, temperature, moisture content, pH, bulk density, hydraulic conductivity, air conductivity, and permeability, organic content, depth to ground water, soil surface area, rock fractures, subsurface homogeneity/heterogeneity, and average infiltration rate (local precipitation).

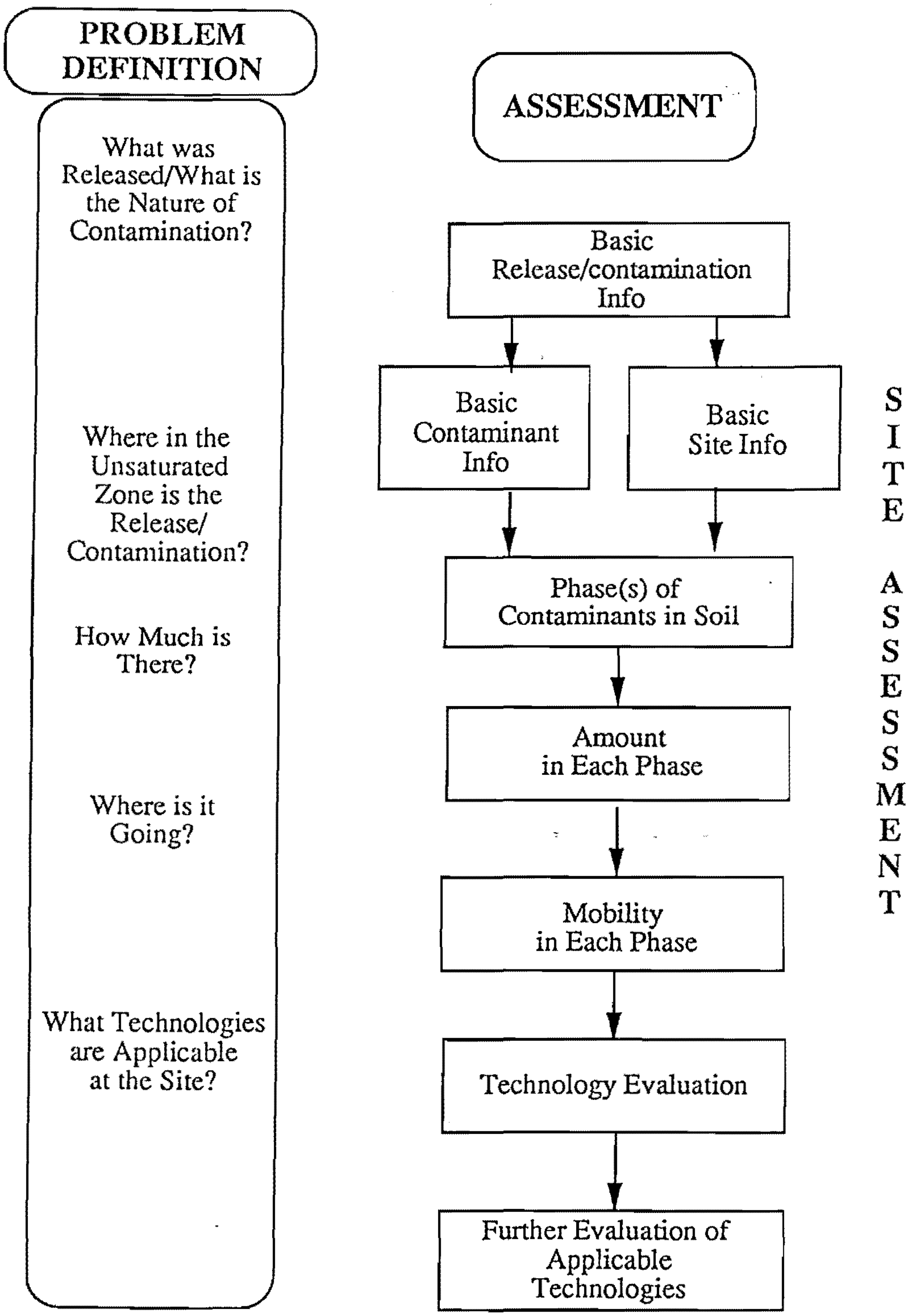


Figure 4. Site and Technology Assessment (after U.S. EPA, 1990a).

Contaminant Characteristics

The physical and chemical properties of contaminants considered by STEP include: pure vapor pressure, water solubility, liquid viscosity and density, melting point, Henry's law constant, soil sorption coefficient, and aerobic biodegradability. These data are used to help determine partitioning and persistence in the subsurface environment.

Phase of the Contaminants

Based on the site assessment, the STEP system guides an analyst in evaluating the phase of the contaminant (U.S. EPA, 1990a). The predominant three or four phase system of adsorbed solid, pore water, vapor, and/or non-aqueous phase liquid (NAPL) is considered. Evaluation of the phase of the contaminant is essential for determining the applicability of treatment technologies. For example, in situ vapor extraction system is applicable only to contaminants in the vapor phase.

Mobility of the Contaminants

Knowledge on contaminant mobility through the unsaturated zone and between phases is critical for the evaluation of applicable treatment technologies. In particular, many in situ treatment technologies rely on either mobilizing or immobilizing contaminants. For example, bioremediation relies on transporting nutrients to the microorganisms through the soil pore volume. Soil venting relies on mobilizing contaminant vapors, and also in transferring and mobilizing contaminants present in other phases into the vapor phase.

Technology Screening

The treatment technologies considered by the current prototype version of STEP include both above-ground and in situ treatment technologies. Above-ground technologies are:

1. Fluidized bed incineration,
2. Rotary kiln incineration,
3. Infrared thermal treatment,
4. Pyrolysis - incineration, and
5. Soil washing.

In situ technologies are:

1. Soil flushing,
2. Vacuum extraction,
3. Stabilization - solidification,
4. Vitrification, and
5. Bioremediation.

Excavation is also included as a technology. STEP screens technologies for specific site, soil, and waste conditions. STEP evaluates the in situ technologies for screening first, followed by the evaluation of the feasibility of excavation at the site. Above-ground technologies are then evaluated if either excavation at the site is determined to be feasible or the user prompts.

Each technology is applicable to specific site, soil, and waste parameters (some of which have been identified in the section on site assessment). Information on these parameters for each of the above technologies is contained in the main knowledge-base file of STEP. STEP queries the user for site-specific information on each of the parameters. The sequence in which information is input to STEP is site-specific. STEP evaluates each of the technologies for screening by comparing the site-specific values of the parameters with their optimal values contained in the knowledge-base file.

The output of the STEP system after the evaluation is a recommendation regarding whether the technologies are: a) feasible, b) somewhat feasible, c) not feasible, or d) highly uncertain in feasibility. Table 1 is reproduced from the U.S. EPA's procedure (1990a) for site assessment and selection of unsaturated zone treatment technologies. This particular table is for the evaluation of soil vacuum extraction. The first column lists the site, soil, and contaminant or waste specific parameters referred to as a critical success factors. The third, fourth, and fifth columns in the table contain ranges of values or qualitative statements for each of the critical success factors.

If the values of all of the critical success factors at a particular site (obtained from the site assessment) fall in column five, then vacuum extraction is "highly feasible" for the site. However, vacuum extraction is only "somewhat feasible" if the critical success factors have values in either column four or scattered in both columns four and five. Vacuum extraction is considered not feasible if all of the critical success factors have values in the column identified as "not feasible." Finally, a technology is highly uncertain in feasibility if the values of the critical success factors are scattered in the third, fourth, and fifth columns of Table 1. For technologies falling into the last category, a summary of the most critical parameters is provided. By comparing the optimal values of these parameters with the values at the site, the analyst can make judgments about modifying site characteristics or providing pretreatment in order to improve the feasibility of a technology. Currently, the above-ground technologies are evaluated by the prototype STEP system as being only highly feasible, not feasible, and uncertain due to the limited screening guidelines available on these technologies.

Table 1. Table Showing the Evaluation of Soil Vacuum Extraction (after U.S. EPA, 1990a)

CRITICAL SUCCESS FACTORS	UNITS	NOT FEASIBLE	SOMEWHAT FEASIBLE	FEASIBLE
Dominant Contaminant Phase	Phase	Sorbed to Soil ○	Liquid ○	Vapor ●
Soil Temperature	Degree Celsius	Low (< 10) ○	Medium (10 -20) ●	High (> 20) ○
Soil Air Conductivity	cm/sec	Low (< 10-06) ○	Medium (10-06 - 10-04) ○	High (> 10-04) ●
Moisture Content	% volume	Moist (> 30) ○	Moderate (10 - 30) ●	Dry (< 10) ○
Geological Conditions	-----	Hetero-geneous ○	Mixed ○	Homo-geneous ●
Soil Sorption Constant - Surface Area	sq.m/g	High (> 1) ○	Medium (0.1 - 1.0) ○	Low (< 0.1) ●
Depth to Ground Water	meters	Low (< 1) ○	Medium (1 - 5) ○	High (> 5) ●
Vapor Pressure	mm Hg	Low < 10 ○	Medium (10 - 100) ●	High (> 100) ○
Water Solubility	mg/L	High (> 1000) ○	Medium (100 - 1000) ○	Low (< 100) ●

Model Components

Figure 5 depicts the components of the STEP model. The model is programmed in C++ using an object oriented structure based on a class module called Tripod (Grenney, 1993). The main program is referred to as the "wrapper." It is a relatively simple program which instantiates (calls) Tripod rule-base objects and provides the interface to specific internal and external procedures. The Tripod rule-base objects contain information on the eleven treatment technologies considered by STEP, and methods for interfacing with the user, operating on the rule-base, and communicating with the wrapper.

The wrapper initiates an action by sending a message to the Tripod object. The object operates on the rule base in accordance with the task assigned in the message. Under certain conditions the object may suspend the task and return control to the wrapper. The wrapper may perform internal or external procedures based on a status code received from the object, and then return control to the object to resume the task where it left off.

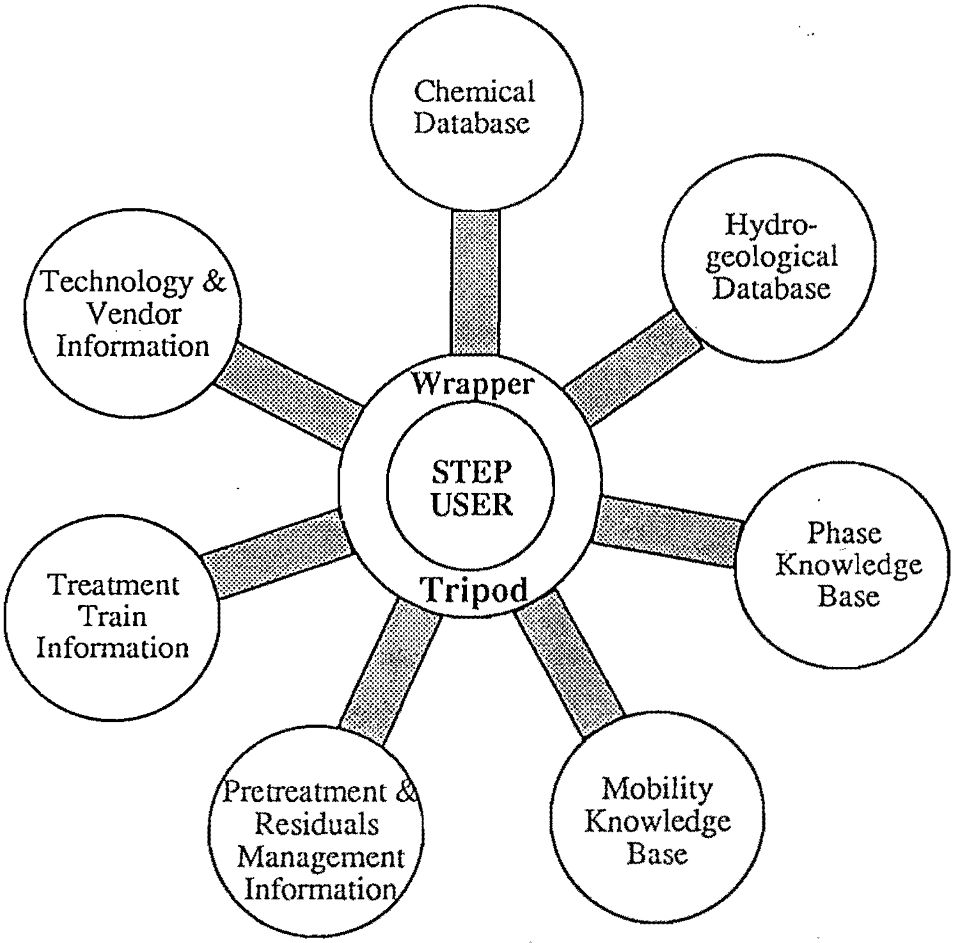


Figure 5. Components of the STEP Model.

For example, suppose the rule-base object encounters a situation where the chemical characteristics of a specific compound are needed. Control and a status code are returned to the wrapper which executes the chemical database. The user then has direct access to the database from which the appropriate information can be extracted. When the database is terminated, the wrapper returns control to the rule-base object which may retrieve the needed information either by asking the user or by means of a message received from the wrapper.

As indicated in Figure 5, the user has access through the wrapper to seven support procedures as well as to the Tripod rule-base. A discussion of the seven support procedures follows.

Chemical Database

This database provides the most commonly found superfund and UST corrective action chemical waste groups, the chemicals therein, and their properties, including: melting point, water solubility, vapor pressure, Henry's law constant, density, dynamic viscosity, kinematic viscosity, partition coefficients and aerobic biodegradability (U.S. EPA, 1990a; U.S. EPA, 1990d; U.S. EPA, 1990e; U.S. EPA, 1990f). The analyst has a choice of specifically selecting either a Superfund chemical database or an UST corrective action chemical database (U.S. EPA 1990a).

Hydrogeological Database

This database was implemented simply as a text file that can be examined by the user. The file contains information on the physicochemical properties of rocks and soils (U.S. EPA, 1990a). Properties like porosity, particle density, bulk density, saturated hydraulic conductivity, permeability, air conductivity, and diameters of particles and surface area are provided.

Phase Knowledge-Base

If the analyst has no information on the phase of the contaminants, STEP provides access to this knowledge-base thereby guiding him in determining the phase of the contaminants. In the model procedures, this is an example of one rule-base instantiating another.

The phase knowledge-base queries the user about site-specific values of site, soil, and waste parameters. The phase of a specific contaminant at a specific site is evaluated using a procedure similar to that used for technology screening (Table 1).

The predominant three-phase system of pore water, vapor, and solid is considered. The output provided by the phase knowledge-base is whether 1) the contaminant is present in a particular phase, 2) there is likelihood of the contaminant being present in a particular phase, 3) there is no likelihood of the contaminant's presence in a particular phase, and 4) uncertainty in the determination of a particular phase of the contaminant. If the output of STEP falls under the fourth category, a summary of the most critical parameters with their optimal values is provided. By comparing the optimal values of these parameters with the values at the site, the user can assume the phase of the contaminant.

Mobility Knowledge-Base

The mobility knowledge-base operates the same way as the phase knowledge-base with the output as whether 1) there is likelihood of the contaminant mobility in a particular phase; 2) there is no likelihood of the contaminant mobility in a particular phase; and 3) uncertainty in the determination of the mobility of the contaminant. Parameters that determine the mobility of the contaminant have been incorporated in the main knowledge-base. Access to the mobility knowledge-base is therefore currently not provided. Access could be provided in the future with the expansion of the main knowledge-base.

Pretreatment/Materials Handling and Residuals Management Information-Base

The restrictive characteristics of the site and/or the contaminants may be eliminated or reduced through pretreatment. In addition, wastes may be excavated and/or transported in order to be treated above-ground. Pretreatment, treatment and post-treatment are relative terms and may encompass a range of management options like containment, removal, institutional controls, treatment and disposal. The pretreatment/materials handling and residuals management file consists of information regarding these alternatives (Superfund University Training Institute, 1991; U.S. EPA, 1988a).

Treatment Train Information

Treatment train refers to one or more treatment technologies being operated in sequence or in parallel for remediating a site. Often at hazardous waste sites, particularly at mixed waste sites or at sites with complex hydrogeological environments, two or more technologies are combined in sequence to achieve efficient and cost-effective remediation. A very simple example of treatment train for in situ remediation is bioventing which is a combination of soil venting and bioremediation in the unsaturated zone. This file contains treatment train information on each of the primary technologies based on current literature. Currently, information contained in this file is part of the information in the pretreatment/materials handling and residuals management information-base file.

Help Utility File

This file was not completed for the current prototype because of the lack of time. However the wrapper has the facility and the file can easily be included if the prototype is expanded into a full application. The help file will contain information explaining why a particular question was asked by the STEP system. For example, if information on soil pH was requested by the STEP system, the analyst could ask for help. The system would then display the reason why such a question was asked, for example, pH is needed as a suitability criterion for biological activity.

Technology and Vendor Information

This file consists of the function, applicability, description, limitations, residuals, cost and current status of a technology. Information on vendors who have developed and demonstrated the use of the treatment technologies at hazardous waste sites either pilot-plant or field-scale is provided (Superfund University Training Institute, 1991; U.S. EPA, 1988a).

CHAPTER 3

MODEL APPLICATION AND RESULTS

The STEP model was applied to a case study to demonstrate its utility for federal and state transportation agencies. The following topics are covered in this chapter: background for the use of the model for transportation agency needs, enhancement of the model, application of the model to the case study, results, and discussion.

Utility for Transportation Agencies

Many pathways exist for federal and state transportation agencies to become responsible for sites contaminated with hazardous wastes. For example, agencies may purchase contaminated property, discover previous contamination on their property, or become aware of new depositions of contaminants on their property by their personnel, by tenants, or by illegal disposal by unknown parties. As a result, agencies frequently face a multitude of legal, regulatory, financial, technical, and health risk problems.

When transportation agencies become involved in the remediation of hazardous wastes, the most common procedure is to hire consultants and contractors. Friend and Connery (1988) concluded that agencies need to learn more about hazardous waste detection, site remediation techniques, and preliminary estimates of the cost of remediation. This information would assist in-house personnel in the selection of consultant expertise, and in the evaluation of the appropriateness of the remediation alternatives that may be recommended. Because the field of hazardous waste site remediation is changing rapidly, consultants and regulatory agency personnel evaluating the consultant's recommendations need to have access to the most recent regulatory and remediation information.

An expert systems approach, implemented as a RBDSS could benefit transportation agencies. In general, decision-support systems contain established knowledge about a particular field of study together with logic that guides a non-expert to arrive at solutions similar to those that would have been proposed by an expert under the same circumstances. Use of a remediation RBDSS by transportation agencies would promote consistency, provide the framework for building a shared base of knowledge about successful and non-successful solution techniques, allow non-experts to do preliminary screening of appropriate technologies, and provide a training tool for in-house personnel.

Enhancements to STEP

The RBDSS developed during this study introduces a new programming technique and links automatically to the secondary rule-bases, databases, and information text files as described in the preceding chapter. The STEP prototype RBDSS was modified and expanded to enhance its performance for low cost preliminary screening of appropriate technologies for soil remediation. Figure 4 depicts the modified layout of the model. The main program is referred to as the "wrapper," and is composed of programming modules form the C++ Tripod class library (Grenney, 1993). It is a relatively simple program which instantiates rule-base objects and provides the interface to auxiliary features including separate databases, information files, and numerical algorithms. The user interacts through the wrapper with the principle rule-base to access the auxiliary features. The information in the rule-bases and databases may be updated or modified without reprogramming the wrapper. The expanded text information in Figure 6 represents all but the phase and mobility knowledge-base component of STEP presented in Figure 5.

STEP was expanded by interfacing with the vadoze zone interactive processes (VIP) simulation model and the soil transport and fate (STF) database. The VIP model is used for predicting contaminant mobility in the soil. The model is available for evaluating the fate of a hazardous substance in the unsaturated zone of the soil. The model simulates vadose zone processes including volatilization, degradation, adsorption/desorption, advection, and dispersion. The model also simulates oxygen transport in the unsaturated zone which includes transport by air, water, and free hydrocarbon phases with exchange between each phase and losses due to biodegradation.

The STF database is a tool for EPA personnel involved with contaminated site assessment and remediation activities. The STF database may be used to provide input data concerning degradation rates, partition coefficients, and chemical property data for mathematical models simulating the behavior and fate of chemical constituents in contaminated surface and subsurface soils.

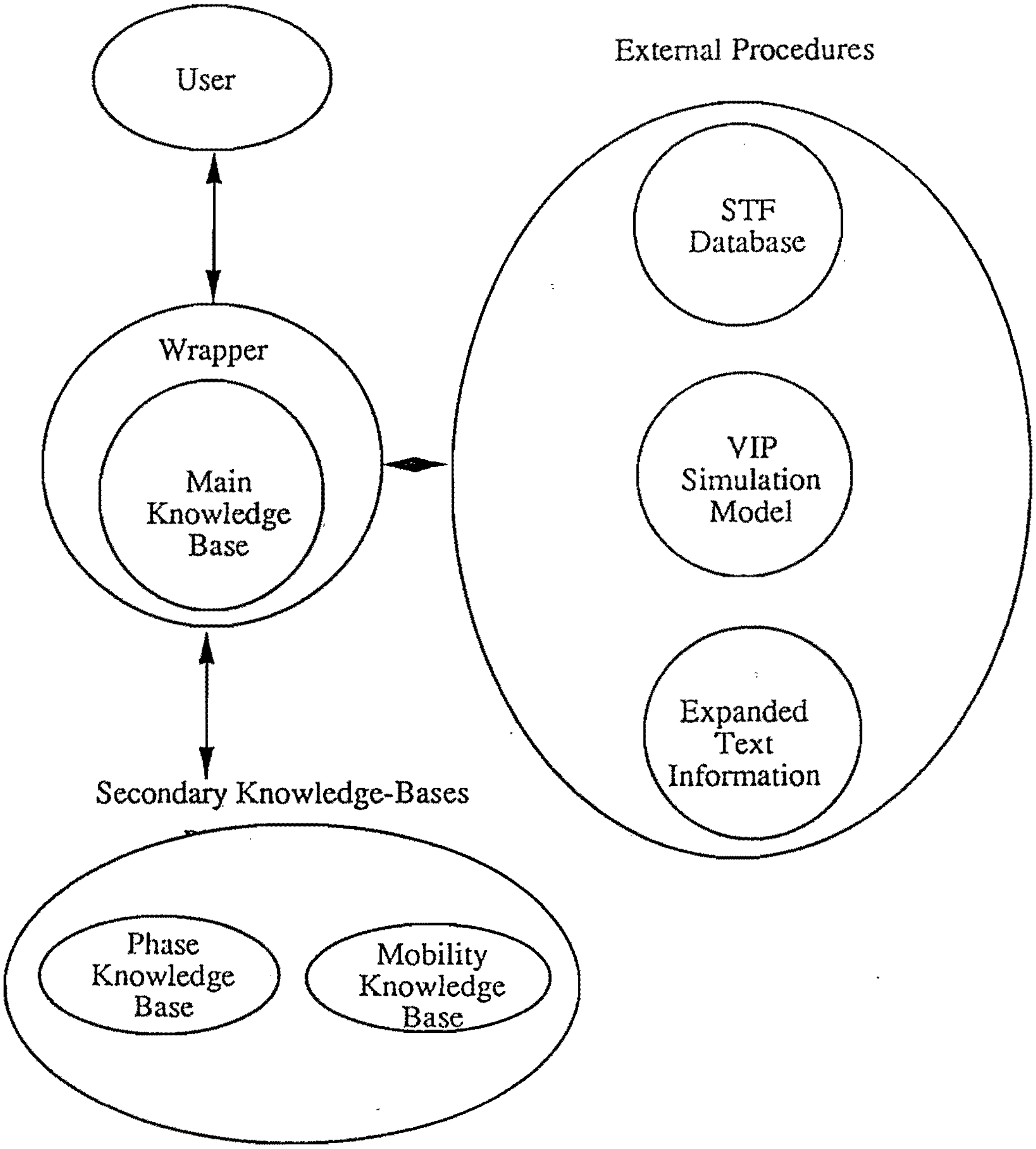


Figure 6. The Layout of the STEP Model.

The information in the database is also useful for providing assistance in determining treatment potential at contaminated sites using in situ techniques. Chemicals may be evaluated with respect to the importance of natural processes in controlling persistence and transport potential, and, therefore the susceptibility to degradation or retardation within a subsurface environment.

Model Application

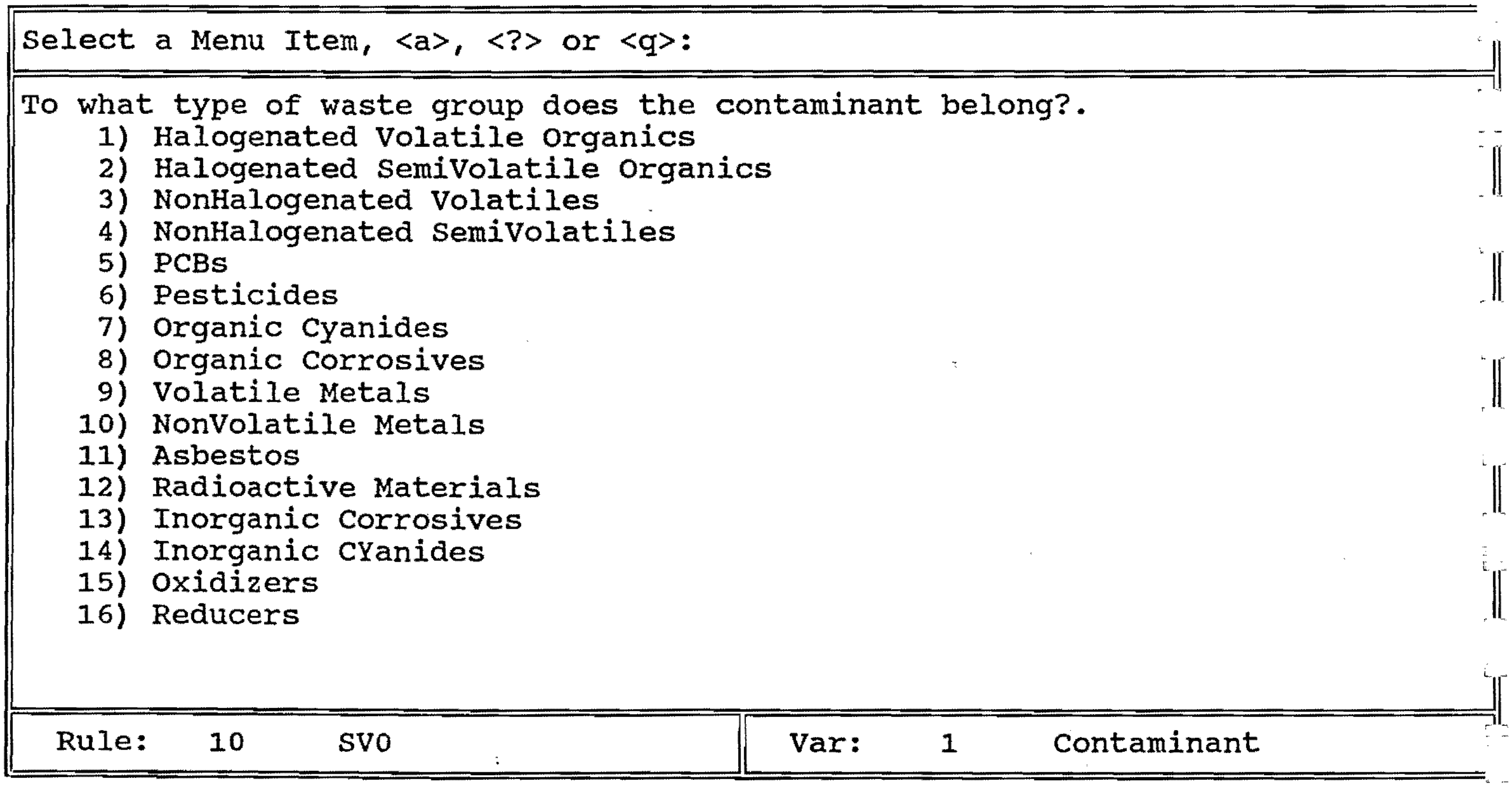
The methodology was applied to a case study of an air force base where approximately 27,000 gallons of JP-4 jet fuel were spilled in 1985 due to the failure of an automatic shut-off valve (Dupont and Doucette, 1991). Immediate site activities included excavation of the tank, and refurbishing and replacement of tanks in above ground concrete vaults.

The following information was known about the site: The contaminant was JP-4 fuel and the volume of the contaminant released was approximately 27,000 gallons. The soil was mixed coarse sand and gravel deposits with interspersed clay stringers. The depth to ground water was approximately 600 ft. Average precipitation was about 10 inches per year. The site had a total petroleum hydrocarbon (TPH) level as high as 15,000 ppm with average levels of 1500 ppm. High evaporation rates, low soil moisture content (< 6%), and an even distribution of contaminants to a depth of 50 ft characterized the site.

Case Results

The STEP model was applied with the known information about the site. Figure 7 is the first screen displayed by the STEP model. Menu item number 4 is the appropriate selection for this case study.

Table 2 traces the step-by-step interaction of the user with the model for the case study. Step numbers in column one represent the sequence of interactions with the system. The "Question" in column two is the model's request for information. The



```
Select a Menu Item, <a>, <?> or <q>:

To what type of waste group does the contaminant belong?.
    1) Halogenated Volatile Organics
    2) Halogenated SemiVolatile Organics
    3) NonHalogenated Volatiles
    4) NonHalogenated SemiVolatiles
    5) PCBs
    6) Pesticides
    7) Organic Cyanides
    8) Organic Corrosives
    9) Volatile Metals
   10) NonVolatile Metals
   11) Asbestos
   12) Radioactive Materials
   13) Inorganic Corrosives
   14) Inorganic CYanides
   15) Oxidizers
   16) Reducers

  Rule:    10      SVO                   Var:     1      Contaminant
```

Figure 7. Screen Display Query for Chemical Group.

"Reply" in column three is the user's response to the request. For example, the first question from the model (Figure 5) is shown in Table 2 as the "Question" for step 1. The reply to this question by the user is "non-halogenated semivolatile organics" (column three of Table 2) or menu item number 4 in Figure 7.

The fourth column in Table 2 is the response of the model to the user's reply. Most often this response is to go on to the next step (indicated by ****). However, when the user requests exceptional action, the model will perform a function before continuing to the next question in the rule base. For example, in step 2 the user requested advice from the model to help him decide how to reply to the question "What is the dominant phase of the contaminant?". The model responded by suspending the main knowledge-base and triggering the phase knowledge-base.

The fifth column in Table 2 contains general comments about such things as assumptions or why particular data selections were made. Comments are also included about system behavior.

Table 2. Table Showing User-Model Interaction for the Case Study.

Step	Question	Reply	STEP Response	Comments
1	To what type of waste group does the contaminant belong?	Non-halogenated semi-volatile organics	*****	*****
2	What is the dominant phase of the contaminant?	Advice sought	Accessed phase knowledge-base	*****
3	What is the amount of release of the contaminant in gallons?	Large-greater than 1000 gallons	*****	*****
4	What is the rate of release of the contaminant?	Instantaneous	*****	Assumed to be instantaneous because of the failure of automatic shut-off valve
5	What is the time since release of the contaminant?	Long-greater than 12 months	Uncertainty in the determination of the phase of the contaminant (JP-4) and its presence in the unsaturated zone	STEP quit the phase knowledge-base. Accessed the main-knowledge base. Phase was assumed to be vapor based on guidelines provided by STEP

Table 2. Table Showing User-Model Interaction for the Case Study (cont.).

Step	Question	Reply	STEP Response	Comments
6	What is the temperature of the soil (celsius scale)?	Medium-between 10 and 20	*****	Was assumed to be medium temperature at the site
7	What is the soil air conductivity (cm/sec)?	Greater than 1/10000	*****	From the hydrogeological database for mixed gravel and coarse sand
8	What is the moisture content of the soil (%volume)?	Dry-less than 10%	*****	*****
9	Identify the geologic conditions of the site	Homogeneous	*****	*****
10	What is the depth to ground water?	High-greater than 5 meters	*****	*****
11	What is the vapor pressure of the contaminant?	Medium-Between 10 and 100	*****	From the hydrogeological database
12	What is the water solubility of the contaminant?	Low-less than 100 mg/L	Soil Venting is somewhat feasible	System gave response after question 12
13	*****	*****	Uncertainty in the feasibility of bioremediation	System gave the critical success factors

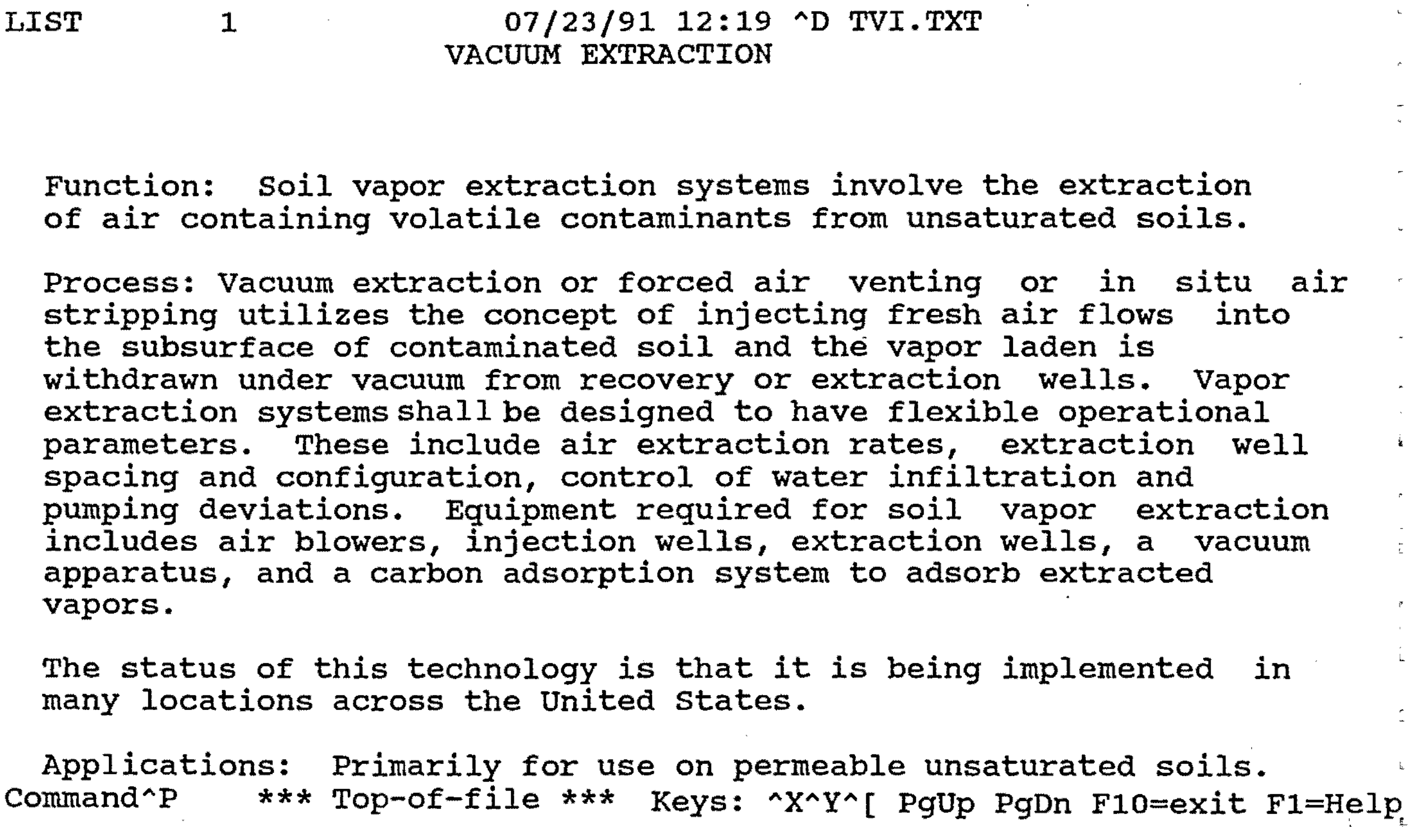
Table 2. Table Showing User-Model Interaction for the Case Study (cont.).

Step	Question	Reply	STEP Response	Comments
14	*****	*****	Uncertainty in the feasibility of soil flushing	System gave the critical success factors
15	What is the permeability of the soil (cm/sec)?	High-greater than 1/100000	*****	From hydrogeological database
16	Is there a presence of buried metals?	No	Uncertainty in the feasibility of In situ Vitrification	System gave response after question 16
17	What is the organic content of the soil matrix at your site?	Low-less than 20-25%	*****	*****
18	What is the amount of semi-volatile organics at your site?	High-greater than 10,000 ppm	Uncertainty in the feasibility of In situ stabilization / solidification	Concentration input as maximum concentration at the site-15,000 ppm. System responded after question 18
19	What is the proximity of structures to the site?	Near	*****	Answer based on familiarity of the site

Table 2. Table Showing User-Model Interaction for the Case Study (cont.).

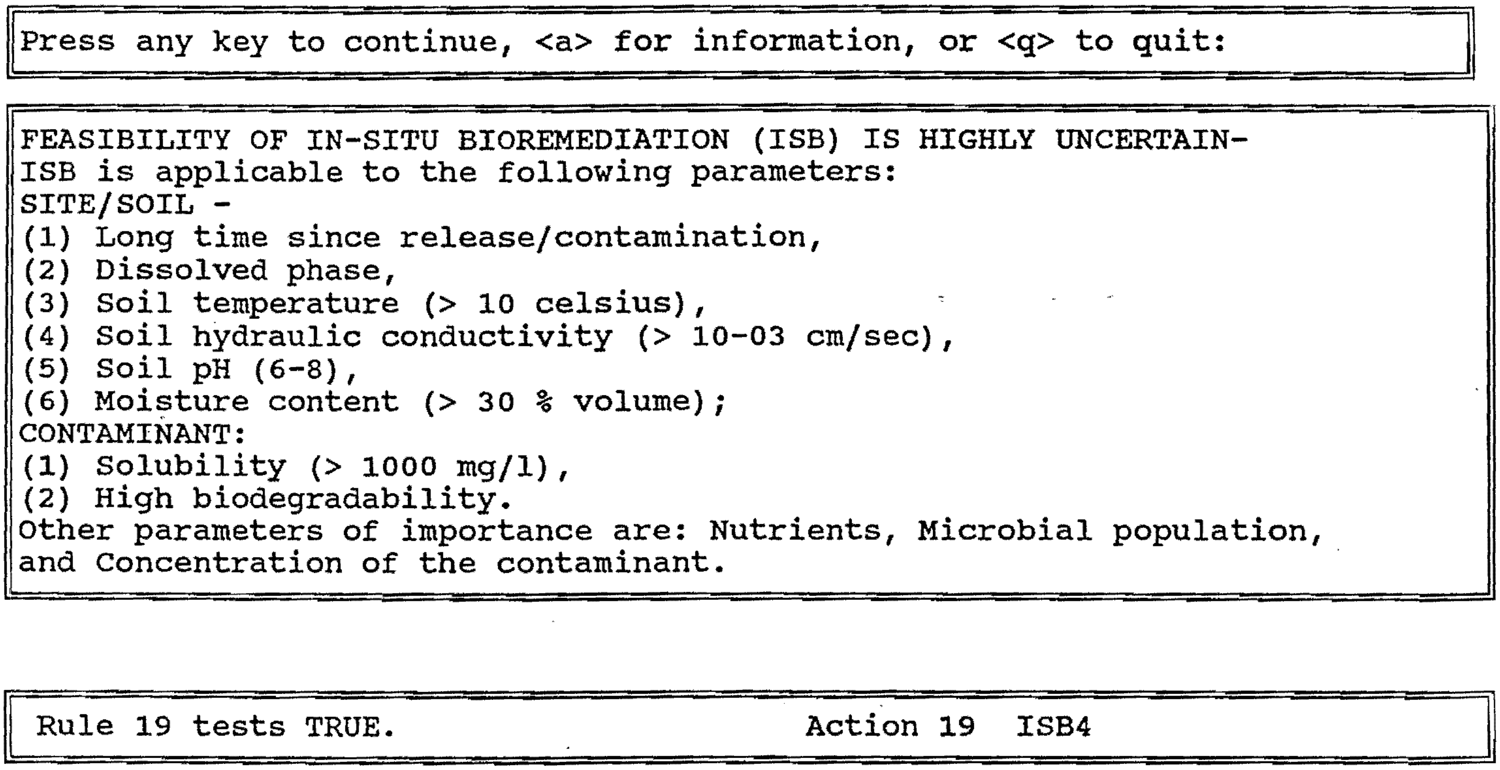
Step	Question	Reply	STEP Response	Comments
20	What is the volume of soil contaminated (m3)?	Large-greater than 1000 m3	*****	*****
21	What is the depth of contamination?	Deep	*****	*****
22	What is the proximity of business to the site?	Near	*****	Answer based on familiarity of the site
23	What is the proximity of disposal site?	Far	*****	Response Assumed
24	What is the proximity of the backfill source?	Far	*****	Response Assumed
25	*****	*****	Excavation not feasible-above ground technologies cannot be evaluated	Session ended with the system-quit the system

Table 2 continues through step number 25 when the session ended. Sample screens of the information on soil venting (Figure 8) and the system evaluation of in situ bioremediation (Figure 9) are provided.



```
LIST        1                07/23/91 12:19 ^D TVI.TXT
                          VACUUM EXTRACTION


  Function:  Soil vapor extraction systems involve the extraction
  of air containing volatile contaminants from unsaturated soils.

  Process: Vacuum extraction or forced air  venting  or  in  situ  air
  stripping utilizes the concept of injecting fresh air flows  into
  the subsurface of contaminated soil and the vapor laden is
  withdrawn under vacuum from recovery or extraction  wells.  Vapor
  extraction systems shall be designed to have flexible operational
  parameters.  These include air extraction rates,  extraction  well
  spacing and configuration, control of water infiltration and
  pumping deviations.  Equipment required for soil  vapor  extraction
  includes air blowers, injection wells, extraction wells, a  vacuum
  apparatus, and a carbon adsorption system to adsorb extracted
  vapors.

  The status of this technology is that it is being implemented  in
  many locations across the United States.

  Applications:  Primarily for use on permeable unsaturated soils.
Command^P     *** Top-of-file ***  Keys: ^X^Y^[ PgUp PgDn F10=exit F1=Help
```

Figure 8. Screen Display Showing Auxiliary Information.



```
Press any key to continue, <a> for information, or <q> to quit:
```

```
FEASIBILITY OF IN-SITU BIOREMEDIATION (ISB) IS HIGHLY UNCERTAIN-
ISB is applicable to the following parameters:
SITE/SOIL -
(1) Long time since release/contamination,
(2) Dissolved phase,
(3) Soil temperature (> 10 celsius),
(4) Soil hydraulic conductivity (> 10-03 cm/sec),
(5) Soil pH (6-8),
(6) Moisture content (> 30 % volume);
CONTAMINANT:
(1) Solubility (> 1000 mg/l),
(2) High biodegradability.
Other parameters of importance are: Nutrients, Microbial population,
and Concentration of the contaminant.
```

```
 Rule 19 tests TRUE.                          Action 19  ISB4
```

Figure 9. Screen Display Showing Session Results for Bioremediation Technology.

Case Discussion

Results were compared with the analysis that had been reported by the case study in which soil venting was selected as the best alternative. The STEP model suggested that soil venting would be somewhat feasible (Table 2, step number 12). STEP recommended that excavation was not feasible because structures were near the site, volume of contaminated soil was large (greater than 1000 cubic meters), depth of contamination was greater than 5 m, site had a close proximity to business, and the disposal site and backfill source were far away from the site. STEP did not evaluate the above-ground technologies as excavation of the contaminated soil was not feasible at the site. The remaining technologies were evaluated as being highly uncertain in feasibility as the site values of the critical success factors for these technologies were scattered. STEP responded with high uncertainty in feasibility of the in situ technologies of soil flushing (phase of the contaminant was vapor, and vapor pressure was medium), vitrification (permeability of the site was greater than 10-05 cm/sec, and buried metals were not present), stabilization/solidification (the amount of semi-volatile organics was high [greater than 10,000 ppm], and the organic content of the soil matrix was low), and bioremediation (the moisture content for the site was very low, and the water solubility of the contaminant was very low).

These recommendations by STEP were appropriate for the site conditions for preliminary screening.

The current prototype version of STEP is based on information primarily available from the U.S. Environmental Protection Agency (1988a and 1990a). While many other documents were reviewed for information on screening guidelines and specific information on the technologies, these two documents were representative of the current guidelines and information available on screening of technologies for hazardous waste soil remediation. Accordingly, decision logic for the prototype STEP system was based on these documents. The information contained in the U.S. EPA document (1990a) was used for the in situ technologies of bioremediation, soil venting, soil flushing; and for soil excavation. This document provides information on the critical parameters and their optimal values needed to evaluate the success of each of the technologies. However, information on technology feasibility based on the combination of various site/soil/waste parameters (critical success factors) is not available. The other technologies incorporated into STEP were based on the information from the U.S. Environmental Protection Agency (1988a). Although this document delineates the data needs for the determination of the feasibility of a particular technology at a site, information on optimal values for each of the critical success factors (or factors impacting the technology feasibility) and their combination is not available.

The STEP rule base decision support system is limited by current information (U.S. EPA, 1988a; U.S. EPA, 1990a) which assumes independence among critical success factors and gives equal weighing to each of them. This limitation adds uncertainty in screening technologies when the critical success factors for a site are scattered (Table 1). The decision logic of STEP is provided by a rule-base which was constructed for easy modification and expansion. The current prototype system could be easily upgraded with the availability of proper technology screening guidelines and information

.

CHAPTER 4
SUMMARY AND CONCLUSIONS

Many pathways exist for transportation agencies and other public and private agencies to become responsible for sites contaminated by hazardous wastes. As a result, agencies frequently face a multitude of legal, regulatory, financial, technical, and health risk problems.

When transportation agencies become involved in the remediation of hazardous waste sites, the common practice is to hire consultants and contractors. Friend and Connery (1988) concluded that agencies need to learn more about hazardous waste detection, site remediation techniques, and preliminary estimates of the cost of remediation. This information world assist in-house personnel in the selection of consultant expertise, and the evaluation of the appropriateness of the remediation alternatives that may be recommended. Because the field of hazardous waste site remediation is changing rapidly, consultants and regulatory agency personnel evaluating the consultant's recommendations need to have access to the most recent regulatory and remediation information.

Early stages of the remediation of hazardous waste contaminated sites typically involves site assessment, and the identification of feasible technologies for treatment. The prototype STEP system was developed for screening out the most inappropriate technologies early in the evaluation process. The system was developed using object oriented programming techniques to interface with multiple rule-bases and databases and to allow easy modification and expansion.

The STEP model was applied to a case study involving the spillage of 27,000 gallons of JP-4 jet fuel at an air facility that experienced failure of an automatic shut-off valve. The system produced recommendations that agreed with the actual remedial action taken at the site.

The following observations were made during the development of the model and the application to the case study.

1. Quality assurance and quality control on information that is incorporated into a RBDSS is extremely important. The following is an example of data inconsistency: U.S. EPA (1990a) suggests that a contaminant with vapor pressure greater than 100 mm Hg has the potential for vapor extraction, whereas U.S. EPA (1991) suggests that the contaminants with vapor pressure greater than 0.5 mm Hg will tend to volatilize considerably and are amenable to soil venting (vapor extraction).
2. Technology feasibility must be established based upon interdependence of various site/soil/waste parameters. Such an approach must be incorporated into the RBDSS to enhance its technology screening capability.
3. Operating parameters must be included in the RBDSS. For example, moisture content (as an operating parameter) can be modified at a site to make bioremediation practical.
4. Soil and groundwater contamination is typical at many hazardous waste sites. The RBDSS must address soil and groundwater remediation simultaneously.
5. The use of two or more technologies (treatment train) for technology screening process would aid in the evaluation of various alternatives and increase the probability of a potentially feasible technology. For example, for sites consisting of hazardous metals and organics, a combination of solvent extraction of metals and above-ground treatment of the extracted metal followed by in situ bioremediation of the remaining organics can be evaluated.

6. A RBDSS used for screening and later for selecting remedial alternatives can be linked to chemical fate and transport models, risk assessment models, treatment process design models, and various databases to produce a comprehensive computer methodology. Such a methodology can be used to provide consistent, cost-efficient, and timely solutions to hazardous waste site remediation.

The Soil Treatment Evaluation Program was developed in response to the needs of transportation agencies. It is a prototype model that, if developed to its potential, could be used to promote nation-wide consistency, provide the framework for building a shared base of knowledge about successful and unsuccessful solution techniques, allow non-experts to do preliminary screening of appropriate technologies, and provide a training tool for in-house personnel.

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APPENDICES

Appendix A

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Appendix B

Computer Files for the Main Rule-base in STEP

```
                      STEP EXPERT SYSTEM
     DECISION ACTIONS FOR THE MAIN KNOWLEDGE-BASE (STEP.IDA)


(1)    firstScreen       .00   2    14

                  Soil Treatment Evaluation Program (STEP)

                                  by

                      R.K. Penmetsa and W.J. Grenney

                     Civil & Environmental Engineering
                          UTAH STATE UNIVERSITY
                          Logan, UT  84322-4110


Press the "a" key to obtain detail information about STEP.

(010)  SV0              .00   1    5
Soil venting applicable to the following waste groups only:
(1) Halogenated volatiles,
(2) Halogenated semivolatiles,
(3) Nonhalogenated volatiles, and
(4) Nonhalogenated semivolatiles.

(011)  SV1              .00   1    1
Soil  Venting  feasible:   Strongly  recommended  for  further
evaluation.

(012)  SV2              .00   1    1
Soil  venting  somewhat  feasible:   Recommended  for  further
screening.

(013)  SV3              .00   1    1
Soil  venting  not  feasible:   Not  recommended  for  further
evaluation.

(014)  SV4              .00   1    15
HIGH  UNCERTAINTY  -  Soil  venting  is  amenable  to  the  following
conditions:
SITE/SOIL -
(1) vapor phase,
(2) High soil temperature (>20 celsius),
```

(3) High soil air conductivity (> 10-04 cm/sec),
(4) Low moisture(< 10%),
(5) Homogeneous geological conditions,
(6) Low soil sorption capacity (<0.1 m2/g),
(7) Greater depth to ground water (>5m);
CONTAMINANT -
(8) High contaminant vapor pressure (>100 mmHg),
(9) Low contaminant water solubility (<100 mg/L).

Other conditions with approximate values include concentration of contaminant greater than 1 ppm, volume of contaminated soil greater than 500 yd3.

```
(015)   ISB0                .00   1   4
```

In-situ bioremediation is not applicable to the following:
(1) Organic corrosives,
(2) Inorganics, and
(3) Reactives.

```
(016)   ISB1                .00   1   2
```

In-situ bioremediation feasible: Strongly recommended for further evaluation.

```
(017)   ISB2                .00   1   2
```

In-situ bioremediation somewhat feasible: Recommended for further screening.

```
(018)   ISB3                .00   1   2
```

In-situ bioremediation not feasible: Not recommended for further evaluation.

```
(019)   ISB4                .00   1   14
```

HIGH UNCERTAINTY - In-situ Bioremediation is applicable to the following parameters:
SITE/SOIL -
(1) Long time since release/contamination,
(2) Dissolved phase,
(3) Soil temperature (> 10 celsius),
(4) Soil hydraulic conductivity (> 10-03 cm/sec),
(5) Soil pH (6-8),
(6) Moisture content (> 30 % volume);
CONTAMINANT:
(1) Solubility (> 1000 mg/l),
(2) High biodegradability.

Other parameters of importance are: Nutrients, Microbial population, and Concentration of the contaminant.

(020) SF0 .00 1 6
Soil flushing is not applicable to the following waste groups:
(1) Organic cyanides,
(2) Asbestos,
(3) Radioactive materials,
(4) Inorganic cyanides, and
(5) Reactives.

(021) SF1 .00 1 1
Soil flushing feasible: Strongly recommended for further evaluation.

(022) SF2 .00 1 1
Soil flushing somewhat feasible: Recommended for further screening.

(023) SF3 .00 1 1
Soil flushing not feasible: Not recommended for further evaluation.

(024) SF4 .00 1 15
HIGH UNCERTAINTY - Soil flushing is amenable to the following conditions:
SITE/SOIL -
(1) Dissolved phase,
(2) High soil hydraulic conductivity (> 10-03),
(3) Small soil surface area (<0.1),
(4) Low carbon content (< 1%),
(5) No presence of fractures in rock at the site;
CONTAMINANT -
(6) High water solubility (>1,000 mg/L),
(7) Low soil sorption constant (< 100 L/kg),
(8) Low vapor pressure (< 10 mmHG),
(9) Low liquid viscosity (for liquid contaminants, <2 cPoise), and
(10)High liquid density (for liquid contaminants, >2 g/cm3).
The use of surfactants may increase effectiveness. Effluent requires
separation techniques such as distillation, evaporation, centrifugation.

(025) ISV1 .00 1 1
In-situ vitrification feasible: Recommended for further evaluation.

(026) ISV2 .00 1 2
In-situ vitrification not feasible: Not recommended for further evaluation.

(027) ISV3 .00 1 14
HIGH UNCERTAINTY - In-situ vitrification is amenable to the following
conditions:

SITE/SOIL -
(1) Soil permeability (< 10-05 cm/sec),
(2) Unsaturated zone only,
(3) Buried metals occupying less than 90% of linear distance between electrodes,
(4) Combustible liquids (5-10% wt),
(5) Void volumes (individual < 150 ft3),
(6) Rubble (10-20% wt), Metal (5-15% wt),
(7) Combustible solids (5-10% wt),
(8) Combustible packages (individual < 30 ft3),
(9) Flat surface to support equipment (< 5% slope).
Technology is very tolerant to a range of contaminant characteristics.

(028) SS1 .00 1 2
Stabilization/solidification feasible: Strongly recommended for further evaluation.

(029) SS2 .00 1 2
Stabilization/solidification not feasible: Not recommended for further evaluation.

(030) SS3 .00 1 15
HIGH UNCERTAINTY - In-situ Stabilization/Solidification is amenable to:
SITE/SOIL -
(1) Organic content (< 20-45% wt) when using cement based technologies,
(2) Semivolatile organics < 10,000 ppm,
(3) Wastes with less than 50% solids,
(4) Oil and Grease content (< 10% wt),
Absence of:
(5) Fine particle size (Insoluble material passing through 200 mesh, and particle size greater than 1/4 inch in diameter); Halides; Soluble salts of manganese, tin, zinc, copper, and lead; Cyanides (>3,000ppm); Sodium arsenate, borates, phosphates, iodates, sulfide, and carbohydrates; Sulfates; Volatile organics; Leachable metals; Phenol (Concentration less than 5%); and Coal or Lignite.
Other characteristics include: Permeability and porosity of the waste materials and the soil surrounding them, and water table depth.

(031) EX1 .00 1 2

Excavation feasible: Above ground technologies could be evaluated.

```
(032)  EX2                  .00   1   2
Excavation somewhat feasible:  Above ground technologies could
be evaluated.

(033)  EX3                  .00   1   2
Excavation not feasible:  Above ground technologies cannot be
evaluated.  Please press 'q' and quit the system.

(034)  EX4                  .00   1   9
HIGH UNCERTAINTY - Excavation is feasible under the following
conditions:
(1) No nearby structures,
(2) Small volume of contaminated soil (<100 m3),
(3) Shallow depth of contamination (< 1m from the surface),
(4) No close proximity to: Traffic and Business, and
(5) Close proximity to disposal site and backfill source.
Appropriate for urgent response.  May increase health risks by
bringing
contaminants to surface.  Requires suitable means of disposal.
On-site treatment of the excavated soil is highly recommended.

(035)  Above                .00   1   1
Evaluation of above-ground technologies

(036)  Above                .00   1   1
Evaluation of above-ground technologies

(037)  Above                .00   1   1
Evaluation of above-ground technologies

(038)  SW0                  .00   1   3
Soil washing not applicable to the following contaminants:
(1)  Asbestos, and
(2) Radioactive materials.

(039)  SW1                  .00   1   1
Soil washing feasible:  Recommended for further evaluation.

(040)  SW2                  .00   1   1
Soil  washing  not  feasible:   Not  recommended  for  further
evaluation.

(041)  SW3                  .00   1   18
HIGH UNCERTAINTY - Soil washing is amenable to the following
conditions:

SITE/SOIL -
(1) Dissolved phase,
(2) High soil hydraulic conductivity (> 10-03),
(3) Small soil surface area (<0.1),
(4) Low carbon content (< 1%),
```

CONTAMINANT -
(5) High water solubility (>1,000 mg/L),
(6) Low soil sorption constant (< 100 L/kg),
(7) Low vapor pressure (< 10 mmHG),
(8) Low liquid viscosity (for liquid contaminants, <2 cPoise), and
(9) High liquid density (for liquid contaminants, >2 g/cm3).
The use of surfactants may increase effectiveness. Effluent requires separation techniques such as distillation, evaporation, centrifugation.
Other conditions include: Absence of complex mixtures of wastes; No variation in waste composition; If using solvents - easy recovery of solvent or surfactant, good treatability of washing fluid, no reduction of soil permeability, and less toxicity of washing fluid.

(042) RKI0 .00 1 6
Rotary kiln incineration not applicable to the following waste groups:
(1) Volatile metals,
(2) Nonvolatile metals,
(3) Asbestos,
(4) Radioactive materials, and
(5) Inorganic corrosives.

(043) RKI1 .00 1 2
Rotary kiln incineration feasible: Strongly recommended for further evaluation.

(044) RKI2 .00 1 2
Rotary kiln incineration not feasible: Not recommended for further evaluation.

(045) RKI3 .00 1 11
HIGH UNCERTAINTY - Rotary kiln incineration is amenable to:
(1) Low moisture content;
(2) Low levels or no presence of halogenated organic compounds;
(3) Absence of PCBs, dioxins, metals, and organic phosphorus compounds.
(4) Oversized debris,
(5) Volatile metals (Hg, Pb, Cd, Zn, Ag, Sn),
(6) Alkali metal salts, particularly sodium and potassium sulfate,
(7) Fine particles, and
(8) Spherical or cylindrical wastes.

In addition, ash fusion temperature of waste and heating value of waste also impact this technology feasibility.

(046) FBI0 .00 1 7
Fluidized bed incineration is not applicable to the following waste groups:
(1) Volatile metals,
(2) Nonvolatile metals,
(3) Asbestos,
(4) Radioactive materials, and
(5) Inorganic corrosives.

(047) FBI1 .00 1 2
Fluidized bed incineration feasible: Strongly recommended for further evaluation.

(048) FBI2 .00 1 2
Fluidized bed incineration not feasible: Not recommended for further evaluation.

(049) FBI3 .00 1 12
HIGH UNCERTAINTY - Fluidized bed incineration is amenable to the following conditions:
(1) Low moisture content;
(2) Low levels or no presence of halogenated organic compounds;
(3) Absence of PCBs, dioxins, metals, and organic phosphorus compounds.
(4) Feed particle size (Solids less than 2.5 cm, absence of fine particles like silt and clay),
(5) Absence of Low-melting point constituents (less than 1600 Fahrenheit) particularly alkali metal salts and halogens,
(6) Ash content of the waste (< 64%),
(7) Low waste density, and
(8) Absence of chlorinated or sulfonated wastes.

(050) ITT0 .00 1 6
Infrared thermal treatment not applicable to the following contaminants:
(1) Volatile metals,
(2) Nonvolatile metals,
(3) Asbestos,
(4) Radioactive materials, and
(5) Inorganic corrosives.

(051) ITT1 .00 1 2
Infrared thermal treatment feasible: Strongly recommended for further evaluation.

(052) ITT2 .00 1 2
Infrared thermal treatment not feasible: Not recommended for further evaluation.

```
(053)  ITT3                .00   1   18
HIGH UNCERTAINTY - Infrared thermal treatment is amenable to the
following
conditions:
(1) Low moisture content;
(2) Low levels or no presence of halogenated organic compounds;

(3) Absence of PCBs, dioxins, metals, and organic phosphorus
compounds.
(4) Homogeneous feed size,
(5) Low moisture content.
Important waste characteristics and the range of applicable
values
were provided by the SHIRCO infrared systems
(EPA/540/5-89/013,Nov. 1989)
as follows:
(1) Particle size, 5 microns to 2 inches,
(2) Moisture content, up to 50% wt.,
(3) Density, 30-130 lb/cf,
(4) Heating value, up to 10,000 Btu/lb,
(5) Chlorine content, up to 5% wt,
(6) Phosphorus, 0-300 ppm,
(7) pH, 5-9, and
(8) Alkali metals, up to 1% wt.

(054)  PI0                 .00   1   5
Pyrolysis Incineration is not applicable to the following
waste groups:
(1) Volatile metals,
(2) Nonvolatile metals, and
(3) Radioactive materials.

(055)  PI1                 .00   1   2
Pyrolysis Incineration feasible:  Strongly recommended for
further evaluation.

(056)  PI2                 .00   1   2
Pyrolysis Incineration not feasible:  Not recommended for
further evaluation.

(057)  PI3                 .00   1   7
HIGH UNCERTAINTY - Pyrolysis incineration is amenable to the
following
conditions:
(1) Low moisture content;
(2) Low levels or no presence of halogenated organic compounds;
(3) Absence of PCBs, dioxins, metals, and organic phosphorus
compounds.
(4) High Btu organic waste,
(5) Feasible temperature.
```

STEP EXPERT SYSTEM (STEP.IDR)
DECISION RULE INPUT FILE FOR THE MAIN KNOWLEDGE-BASE

```
(01)    firstScreen        .0    0  Display the first screen.
V   firstScreen     Yes

(10)    SV0                .0    0  Applicable contaminants.
V ! Contaminant     HVO  HSVO  NHV  NHSV

(11)    SV1                .0    0  Soil Venting feasible.
A ! SV0             10
V   Phase           Vapor
V   ST              High
V   SAC             High
V   MC              Dry
V   GC              Homogeneous
V   SSC             Low
V   DGW             High
V   VP              High
V   WS              Low

(12)    SV2                .0    0  SV somewhat feasible.
A ! SV0             10
A ! SV1             11
V   Phase           Vapor  VapLiq  All
V   ST              Medium     High
V   SAC             Medium     High
V   MC              Moderate   Dry
V   GC              Homogeneous
V   DGW             Medium     High
V   VP              Medium     High
V   WS              Medium     Low

(13)    SV3                .0    0  SV not feasible.
A ! SV0             10
A ! SV1             11
A ! SV2             12
V   Phase             Liquid  Dissolved  VapLiq  DisLiq  VapDis
All
V   ST              Low
V   SAC             Low
V   MC              Moist
V   GC              Heterogeneous
V   SSC             High
V   DGW             Low
V   VP              Low
V   WS              High

(14)    SV4                .0    0  SV uncertain.
A ! SV0             10
A ! SV1             11
```

```
A ! SV2             12
A ! SV3             13

(15)    ISB0              .0    0  Applicable contaminants.
V ! Contaminant     HVO  HSVO  NHV  NHSV  PCB  P  OCY

(16)     ISB1                   .7     0   In-Situ Bioremdiation
feasible.
A ! ISB0            15
V   Time            Long
V   Phase           Dissolved
V   ST              High
V   SHC             High
V   PH              Medium
V   MC              Moist
V   WS              High
V   RI              High

(17)    ISB2              .7    0  ISB somewhat feasible.
A ! ISB0            15
A ! ISB1            16
V   Time            Medium     Long
V   Phase           Dissolved  Vapor  VapDis  All
V   ST              Medium     High
V   SHC             Medium     High
V   PH              Medium
V   MC              Moderate
V   WS              Medium     High
V   RI              Medium     High

(18)    ISB3              .7    0  ISB not feasible.
A ! ISB0            15
A ! ISB1            16
A ! ISB2            17
V   Time            Short
V   Phase           Liquid  Vapor  VapLiq  VapDis  DisLiq All
V   ST              Low
V   SHC             Low
V   PH              Low        High
V   MC              Dry
V   WS              Low
V   RI              Low

(19)    ISB4              .0    0  ISB uncertain.
A ! ISB0            15
A ! ISB1            16
A ! ISB2            17
A ! ISB3            18

(20)    SF0               .0    0  Applicable contaminants.
V ! Contaminant     HVO  HSVO  NHV  NHSV  PCB  P  OCY  VM  NVM
IC
```

```
(21)    SF1                 .0    0  Soil Flushing feasible.
A ! SF0            20
V   Phase          Dissolved
V   SHC            High
V   SSA            Small
V   SCC            Low
V   RF             Absent
V   WS             High
V   SST            Low
V   VP             Low
V   LV             Low
V   LD             High

(22)    SF2                 .0    0  SF somewhat feasible.
A ! SF0            20
A ! SF1            21
V   Phase          Dissolved   Liquid   DisLiq  All
V   SHC            Medium     High
V   SSA            Medium     Small
V   SCC            Medium     Low
V   RF             Absent
V   WS             Medium     High
V   SST            Medium     Low
V   VP             Medium     Low
V   LV             Medium     Low
V   LD             Medium     High

(23)    SF3                 .0    0  SF not feasible.
A ! SF0            20
A ! SF1            21
A ! SF2            22
V   Phase          Vapor  VapLiq  VapDis  DisLiq  All
V   SHC            Low
V   SSA            High
V   SCC            High
V   RF             Present
V   WS             Low
V   SST            High
V   VP             High
V   LV             High
V   LD             Low

(24)    SF4                 .0    0  SF uncertain.
A ! SF0            20
A ! SF1            21
A ! SF2            22
A ! SF3            23

(25)     ISV1                    .0     0  In-Situ Vitrification
feasible.
V   Perm           Low
V   MD             No
V   CS             Low   No
```

```
V   CLV                  Low   No
V   CP                   Low   No
V   VV                   Low   No
V   Rubble               Low   No
V   VM                   N

(26)    ISV2                   .0     0  ISV not feasible.
A ! ISV1                 25
V   Perm                 High
V   MD                   Yes
V   CS                   High
V   CLV                  High
V   CP                   High
V   VV                   High
V   Rubble               High
V   VM                   Y

(27)    ISV3                   .0     0  ISV uncertain.
A ! ISV1                 25
A ! ISV2                 26

(28)    SS1                    .0     0  Stabilization/Solidification
feasible.
V   OC                   Low
V   SVO                  Low
V   Solids               N
V   OG                   N
V   FPSS                 N
V   Halides              N
V   Salts                N
V   Cyanides             N
V   OChem                N
V   Sulfates             N
V   VO                   N
V   LM                   N
V   Phenol               Y
V   CL                   N

(29)    SS2                    .0     0  SS not feasible.
V   OC                   High
V   SVO                  High
V   Solids               Y
V   OG                   Y
V   FPSS                 Y
V   Halides              Y
V   Salts                Y
V   Cyanides             Y
V   OChem                Y
V   Sulfates             Y
V   VO                   Y
V   LM                   Y
V   Phenol               N
V   CL                   Y
```

```
(30)    SS3                          .0    0  SS uncertain.
A ! SS1             28
A ! SS2             29

(31)    EX1                          .0    0  Soil Excavation feasible.
V   POS             Far
V   VOS             Small
V   DOC             Shallow
V   PTT             Far
V   PTB             Far
V   PTD             Near
V   PTF             Near

(32)    EX2                          .0    0  SE somewhat feasible.
A ! EX1             31
V   POS             Far
V   VOS             Medium      Small
V   DOC             Medium      Shallow
V   PTT             Far
V   PTB             Far
V   PTD             Near
V   PTF             Near

(33)    EX3                          .0    0  SE not feasible.
A ! EX1             31
A ! EX2             32
V   POS             Near
V   VOS             Large
V   DOC             Deep
V   PTT             Near
V   PTB             Near
V   PTD             Far
V   PTF             Far

(34)    EX4                          .0    0  SE uncertain.
A ! EX1             31
A ! EX2             32
A ! EX3             33

(35)     Above                            .0     0   Evaluate  above-ground
technologies.
A   EX1             31
V   Q1              Y

(36)     Above                            .0     0   Evaluate  above-ground
technologies.
A ! Above           35
A   EX2             32
V   Q2              Y


(37)     Above                            .0     0   Evaluate  above-ground
technologies.
```

```
A ! Above           35  36
A   EX4             34
V   Q3              Y

(38)    SW0                .0    0  Non applicable contaminants
V ! Contaminant     A  RM

(39)    SW1                .0    0  SW feasible.
A   SW0             38
V   USC             N
V   CWM             N
V   VWC             N
V   HHC             N
V   SSR             N
V   FPS             N
V   CSL             N
V   DSS             N
V   PTW             N
V   RSP             N
V   HTF             N

(40)    SW2                .0    0  SW not feasible.
A   SW0             38
A ! SW1             39
V   USC             Y
V   CWM             Y
V   VWC             Y
V   HHC             Y
V   SSR             Y
V   FPS             Y
V   CSL             Y
V   DSS             Y
V   PTW             Y
V   RSP             Y
V   HTF             Y

(41)   SW3                 .0    0  SW uncertain.
A   SW0             38
A ! SW1             39
A ! SW2             40

(42)   RKI0                .0    0  Non applicable contaminants.
V ! Contaminant     VM  NVM  A  RM  IC

(43)    RKI1                   .0     0  Rotary Kiln Incineration
feasible.
A   RKI0            42
V   OD              N
V   VMI             N
V   AMS             N
V   RFPS            N
V   SCW             N
V   AFT             N
```

```
V   HVW               Y
V   HMC               N
V   HOC               N
V   PPD               N
V   PM                N
V   OPC               N

(44)   RKI2                      .0    0  RKI not feasible.
A   RKI0              42
A ! RKI1              43
V   OD                Y
V   VMI               Y
V   AMS               Y
V   RFPS              Y
V   SCW               Y
V   AFT               Y
V   HVW               N
V   HMC               Y
V   HOC               Y
V   PPD               Y
V   PM                Y
V   OPC               Y

(45)   RKI3                      .0    0  RKI Uncertain.
A   RKI0              42
A ! RKI1              43
A ! RKI2              44

(46)   FBI0                      .0    0  Non applicable contaminants.
V ! Contaminant       VM  NVM  A  RM  IC

(47)   FBI1                        .0    0  Fluidized Bed Incineration
feasible.
A   FBI0              46
V   FFPS              N
V   LMP               N
V   AC                N
V   WD                N
V   PCSW              N
V   HMC               N
V   HOC               N
V   PPD               N
V   PM                N
V   OPC               N

(48)   FBI2                      .0    0  FBI not feasible.
A   FBI0              46
A ! FBI1              47
V   FFPS              Y
V   LMP               Y
V   AC                Y
V   WD                Y
V   PCSW              Y
```

```
V   HMC            Y
V   HOC            Y
V   PPD            Y
V   PM             Y
V   OPC            Y

(49)   FBI3                .0    0  FBI uncertain.
A   FBI0           46
A ! FBI1           47
A ! FBI2           48

(50)   ITT0                .0    0  Non applicable contaminants.
V ! Contaminant    VM  NVM  A   RM  IC

(51)   ITT1                 .0    0  Infrared Thermal Treatment
feasible.
A   ITT0           50
V   NFS            N
V   IMC            N
V   HMC            N
V   HOC            N
V   PPD            N
V   PM             N
V   OPC            N

(52)   ITT2                .0    0  ITT not feasible.
A   ITT0           50
A ! ITT1           51
V   NFS            Y
V   IMC            Y
V   HMC            Y
V   HOC            Y
V   PPD            Y
V   PM             Y
V   OPC            Y

(53)   ITT3                .0    0  ITT uncertain.
A   ITT0           50
A ! ITT1           51
A ! ITT2           52

(54)   PI0                 .0    0  Non applicable contaminants.
V ! Contaminant    VM  NVM  RM

(55)   PI1                        .0     0  Pyrolysis Incineration
feasible.
A   PI0            54
V   HOW            Y
V   HMC            N
V   HOC            N
V   PPD            N
V   PM             N
V   OPC            N
```

```
(56)   PI2                    .0    0  PI not feasible
A    PI0              54
A !  PI1              55
V    HOW              N
V    HMC              Y
V    HOC              Y
V    PPD              Y
V    PM               Y
V    OPC              Y

(57)   PI3                    .0    0  PI uncertain.
A    PI0              54
A !  PI1              55
A !  PI2              56
```

STEP EXPERT SYSTEM
DECISION VARIABLE FILE FOR THE MAIN KNOWLEDGE-BASE
(STEP.IDV)

```
(1000) firstScreen     L .000 0    1
This question should not be asked!

(001)  Contaminant     M .000 1    1
To what type of waste group does the contaminant belong?.
HVO                Halogenated Volatile Organics
HSVO               Halogenated SemiVolatile Organics
NHV                NonHalogenated Volatile Organics
NHSV               NonHalogenated Semi-volatile Organics
PCB                PCBs
P                  Pesticides
OCY                Organic Cyanides
OC                 Organic Corrosives
VM                 Volatile Metals
NVM                NonVolatile Metals
A                  Asbestos
RM                 Radioactive Materials
IC                 Inorganic Corrosives
ICY                Inorganic CYanides
O                  Oxidizers
R                  Reducers

(002)  Phase           M .000 3    1
What is the dominant phase of the Contaminant?.
Liquid             Liquid Phase
Vapor              Vapor Phase
Dissolved          Dissolved or in pore water
VapLiq             In vapor and liquid Phases
VapDis             In vapor and dissolve Phases
DisLiq             In dissloved and liquid Phases
All                In all phases
```

```
(003)  ST                 M .000 0    1
What is the temperature of the soil (celsius scale)?
Low                Low - Less than 10
Medium             Medium - Between 10 and 20
High               High - Greater than 20

(004)  SAC                M .000 2    1
What is the Soil Air Conductivity (cm/sec)?
Low                Low - Less than 10-06
Medium             Medium - Between 10-06 and 10-04
High               High - Greater than 10-04

(005)  MC                 M .000 0    1
What is the moisture content of the soil  (% volume)?
Dry                Dry - Less than 10
Moderate           Moderate - Between 10 and 30
Moist              Moist - Greater than 30

(006)  GC                 M .000 0    1
Identify the geologic conditions of the site>
Homogeneous        Homogeneous medium
Heterogeneous      Heterogeneous medium

(007)  SSC                M .000 2    1
What is the soil sorption capacity of the soil (m2/g)?
Low                Low - Less than 0.1
High               High - Greater than 1

(008)  SST                M .000 1    1
What is the soil sorption  constant of the soil (L/kg)?
Low                Low - Less than 100
Medium             Medium - Between 100 and 10000
High               High - Greater than 10000

(009)  DOC                M .000 0    1
What is the depth of contamination (meters)?
Shallow            Shallow - Less than 1
Medium             Medium - Between 1 and 5
Deep               Deep - Greater than 5

(010)  VP                 M .000 1    1
What is the vapor pressure of the contaminant (mmHg)?
Low                Low - Less than 10
Medium             Medium - Between 10 and 100
High               High - Greater than 100

(011)  WS                 M .000 1    1
What is the water solubility of the contaminant (mg/L)?
Low                Low - Less than 100
Medium             Medium - Between 100 and 1000
High               High - Greater than 1000

(012)  Time               M .000 0    1
```

```
What is the time of release/contamination (months)?
Short           Short - Less than 1
Medium          Medium - Between 1 and 12
Long            Long - Greater than 12

(013)  SHC               M .000 2    1
What is the soil hydraulic conductivity (cm/sec)?
Low             Low - Less than 10-05
Medium          Medium - Between 10-05 and 10-03
High            High - Greater than 10-03

(014)  SCC               M .000 0    1
What is the carbon content of the soil (% weight)?
Low             Low - Less than 1
Medium          Medium - Between 1 and 10
High            High - Greater than 10

(015)  LV                M .000 1    1
What is the liquid viscosity (cPoise)?
Low             Low - Less than 2
Medium          Medium - Between 2 and 20
High            High - Greater than 20

(016)  LD                M .000 1    1
What is the liquid density (g/cm3)?
Low             Low - Less than 1
Medium          Medium - Between 1 and 2
High            High - Greater than 2

(017)  POS               M .000 0    1
What is the proximity of structures to the site?
Far             Far away from the site.
Near            Near to the site.

(018)  VOS               M .000 0    1
What is the volume of soil contaminated (m3)?
Small           Small - Less than 100
Medium          Medium - Between 100 and 1000
Large           Large - Greater than 1000

(019)  PTT               M .000 0    1
What is the proximity of traffic to the site?
Far             Far away from the site.
Near            Near to the site.

(020)  PTB               M .000 0    1
What is the proximity of business to site?
Far             Far away from the site.
Near            Near to the site.

(021)  PTD               M .000 0    1
What is the proximity of disposal site?
```

```
Far                Far away from the site.
Near               Near to the site.

(022)  PTF               M .000 0    1
What is the proximity of the backfill source to the site?
Far                Far away
Near               Near

(023)  PH                M.000  0    1
What is the pH (pH units)?
Low                Less than 6.0
Medium             Between 6.0 and 8.0
High               Greater than 8

(024)  RI                M .000 1    1
What is the refractory index (dimensionless)?
Low                Less than  0.01
Medium             Between 0.01 and 0.1
High               Greater than 0.1

(025)  RF                M .000 0    1
Are there any fractures in the rock?
Present            Fractures are present in the rock
Absent             No fractures are present in the rock

(026)  DGW               M .000 0    1
What is the depth to ground water (meters)?
Low                Low - Less than 1
Medium             Medium - Between 1 and 5
High               High - Greater than 5

(027)  SSA               M .000 2    1
What is the soil surface area (m2/g)?
Small              Small - Less than 0.1
Medium             Medium - Between 0.1 and 1
High               High - Greater than 1

(028)  Perm              M .000 0    1
What is the permeability of the soil (cm/sec)?
Low                Low  - Less than 1 * 10-05
High               High - Higher than 1 * 10-05

(029)  MD                L .000 0    1
Are buried metals present at your site?

(030)  CS                M .000 0    1
What is the % of combustible solids at your site?
No                    No - if there is no presence of combustible
solids
Low                Low - Lower than 5-10 %wt
High               High - Higher than 5-10 %wt
```

```
(031)  CLV              M .000 0   1
What is the % of combustible liquids at your site?
No                 No - if there is no presence of combustible
liquids
Low               Low - Lower than 5-10 %wt
High              High - Higher than 5-10 %wt

(032)  CP               M .000 0   1
What is the volume of combustible individual packages at your
site?
No                No - if there is no presence of packages
Low               Low - Lower than 1.2 yd3 or 32 ft3
High              High - Higher than 1.2 yd3 or 32ft3

(033)  VV               M .000 0   1
What is the volume of individual voids at your site?
No                No - No voids
Low               Low - Lower than 5-6 yd3 or 152 yd3
High              High - Higher than 5-6 yd3 or 152 yd3

(034)  Rubble           M .000 0   1
What is the volume of rubble at your site?
No                No -  No rubble present
Low               Low - Lower than 10-20 %wt
High              High - Higher than 10-20 %wt

(035)  VM               L .000 0   1
Is there presence of volatile metals at the site?

(036)  OC               M .000 0   1
What is the organic content of the soil matrix at your site?
Low               Low - Lower than 20-45 %wt
High              High - Higher than 20-45 %wt

(037)  SVO              M .000 0   1
What is the amount of semi-volatile organics at your site?
Low               Low - Lower than 10,000 ppm
High              High - Higher than 10,000 ppm

(038)  Solids           L .000 0   1
Is there more than 15% solids at the waste site?

(039)  OG               L .000 0   1
Is the percent of oil & grease less than 10 at your site?

(040)  FPSS             L .000 0   2
Is there presence of small particles (passing through NO. 220
mesh)
sieve or particles of size greater than 1/4 inch in diameter?

(041)  Halides          L .000 0   1
Is there a presence of halides at your site?
```

```
(042)  Salts            L .000 0    2

Is there a presence of soluble salts (manganese, tin, zinc,
copper, and
lead) at your site?

(043)  Cyanides         L .000 0    1
Is there a presence of cyanides at your site?

(044)  OChem            L .000 0    2
Is there a presence of sodium arsenate, borates, phosphates,
iodates,
sulfide, and carbohydrates at your site?

(045)  Sulfates         L .000 0    1
Is there a presence of sulfates at your site?

(046)  VO               L .000 0    1
Is there a presence of volatile organics at your site?

(047)  LM               L .000 0    1
Is there a presence of leachable metals at your site?

(048)  Phenol           L .000 0    1
Is the concentration of phenol less than 10% at your site?

(049)  CL               L .000 0    1
Is there a presence of coal or lignite at your site?

(050)  Q1               L .000 0    3
Excavation at your site is feasible, would you like to proceed
with the evaluation of the above ground technologies?.  Press
'y' to continue or 'q' to quit the evaluation.

(051)  Q2               L .000 0    3
Excavation at your site is somewhat feasible, would you like to
proceed
with the evaluation of the above ground technologies?.   Press
'y' to
continue or 'q' to quit the evaluation.

(052)  Q3               L .000 0    3
Excavation at your site is uncertain, would you like to proceed
with the evaluation of the above ground technologies?.   Press
'y' to
continue or 'q' to quit the evaluation.

(053)  USC              L .000 0    2
Is the separation coefficient for the contaminant unfavorable at
your
site?
```

```
(054)  CWM               L .000 0    2
Is there a presence of complex mixture of wastes (for example:
metals with organics) at your site?

(055)  VWC               L .000 0    1
Is there a variation in waste composition at your site?

(056)  HHC               L .000 0    1
Is there high humic content at your site?

(057)  SSR               L .000 0    1
Are there soil, solvent reactions at your site?.

(058)  FPS               L .000 0    1
Are there fine particles (silt and clay) at your site?

(059)  CSL               L .000 0    1
Is there a presence of clay soil containing semivolatiles at
your site?

(060)  DSS               L .000 0    1
Is there a difficulty of recovery of solvent or surfactant at
your site?

(061)  PTW               L .000 0    1
Is there a poor treatability of washing fluid?

(062)  RSP               L .000 0    1
Is there a reduction of soil permeability?

(063)  HTF               L .000 0    1
Is the toxicity of the washing fluid high?

(064)  OD                L .000 0    1
Is there a presence of oversized debris in the excavated soil?

(065)  VMI               L .000 0    2
Is there a presence of volatile metals (Hg,Pb, Cd, Zn, Ag, and
Sn)
in the excavated soil?

(066)  AMS               L .000 0    2
Is there a presence of alkali metal salts (particularly sodium
and
potassium sulfate) in the excavated soil?

(067)  RFPS              L .000 0    1
Are fine particle sizes present (clay, silts) in the excavated
soil?

(068)  SCW               L .000 0    2
Is there a presence of presence of cylindrical or
spherical wastes in the excavated soil?
```

```
(069)  AFT              L .000 0   1
Is the ash fusion temperature of the waste high?

(070)  HVW              L .000 0   1
Is the heating value of waste less than 8,000 Btu content?

(071)  HVW              L .000 0   1
Is the heating value of waste less than 8,000 Btu content?

(072)  HMC              L .000 0   1
Is the moisture content of the excavated soil high?

(073)  HOC              L .000 0   1
Is there an elevated level of halogenated organic compounds?

(074)  PPD              L .000 0   1
Are PCBs and dioxins present in the excavated soil?

(075)  PM               L .000 0   1
Are heavy metals present in the excavated soil matrix?

(076)  OPC              L .000 0   1
Is there an elevated level of organic phosphorus compounds?

(077)  FFPS             L .000 0   2
Is the particle size larger than 2.5 cm (1 inch) or very fine
like silt and clay?

(078)  LMP              L .000 0   1
Is the melting point higher than 1600 on the fahrenheit scale?

(079)  AC               L .000 0   1
Is the ash content high?

(080)  WD               L .000 0   1
Is the waste density high?

(081)  PCSW             L .000 0   1
Are chlorinated or sulfonated wastes present?

(082)  NFS              L .000 0   1
Is the feed size nonhomogeneous?

(083)  IMC              L .000 0   1
Is  the  moisture  content  high  (there  should  be  atleast  22%
solids)?

(084)  HOW              L .000 0   1
Is it a high Btu organic waste?
```

APPENDIX C

Computer Files for the Phase Rule-base in STEP

```
                       STEP EXPERT SYSTEM
     DECISION ACTIONS FOR PHASE KNOWLEDGE-BASE (PHASE.IDA)

(009)  Warning            .00   00   14
YOU ARE CURRENTLY IN THE PHASE KNOWLEDGE BASE TO EVALUATE PHASE
SCOPE:  Currently the STEP system evaluates the three phase
system of (1) Pure product or non-aqueous phase liquid (NAPL),
(2) Vapor, and (3) Dissolved or pore water.  Logic has been
incorporated internally in the technology applicability to
include the sorbed phase where relevant.  In addition, the
partitioning of a contaminant into the liquid phase is not
currently evaluated.  The system has logic incorporated into it,
to test the phase and likelihood of contaminants being present
in the vadoze zone.
CURRENT LIMITATIONS:  (1) Applicable to organics only, (2) Best
suited for organic liquids.
MISCELLANEOUS:  Logic favorable to UST corrective actions than
SUPERFUND sites, but doesn't preclude the usage of STEP to
SUPERFUND sites.

(010)  Guidelines         .00   00   16
Please follow the following guidelines in answering the phase of
the contaminant:
(1)  You need to answer the phase of the contaminant after
returning to the system prompt.
(2) The system evaluates the feasibility of all the phases and
gives the result of evaluation of each of the phases.
(3)  Choose              If
     -------             -----
     Liquid          This has been evaluated to be the dominant
phase
     Vapor                          (Same as above)
     Dissolved                      (Same as above)
     Vapor and Liquid      If there is likelihood in these two
phases
     Vapor and Dissolved                    (Same as above)
     Dissolved and Liquid                   (Same as above)


If the phase was not evaluated by the system follow the critical
factors that the system provides to evaluate a phase.

(011)  Liquid1            .00   00   1
Liquid contaminants present in the vadoze zone.
```

(012) Liquid2 .00 00 2
There is likelihood of liquid contaminants being present in the vadoze zone.

(013) Liquid3 .00 00 2
There is no likelihood of liquid contaminants being present in the vadoze.

(014) Liquid4 .00 00 15
HIGH UNCERTAINTY IN THE PRESENCE OF LIQUID CONTAMINANTS IN THE VADOZE ZONE: Use the following guidelines to determine the feasibility of liquid contaminants in the unsaturated zone:
(1) Large amount of contaminant (> 1000 gallons) released,
(2) Instantaneous rate of release,
(3) Short time (< 1 month) since release,
(4) Deeper depth to groundwater (>5 m),
(5) Low hydraulic conductivity (< 10-05 cm/sec),
(6) Low rainfall infiltration rate (<0.05 cm/day),
(7) Cool soil temperature (< 10 degree celsius),
(8) High soil sorption capacity/surface area (> 1 m2/g),
(9) High liquid viscosity (> 20 cPoise),
(10) Low liquid density (<1 g/cm3),
(11) Low liquid vapor pressure (< 10 mmHG),
(12) Low water solubility (< 100 mg/L).

(015) Vapor1 .00 00 1
Contaminant vapors present in the vadoze zone.

(016) Vapor2 .00 00 2
There is likelihood of contaminant vapors being present in the vadoze zone.

(017) Vapor3 .00 00 2
There is no likelihood of contaminant vapors being present in the vadoze zone.

(018) Vapor4 .00 00 15

HIGH UNCERTAINTY IN THE PRESENCE OF CONTAMINANT VAPORS IN THE VADOZE ZONE: Use the following guidelines to determine the feasibility of liquid contaminants in the unsaturated zone:
(1) Large amount of contaminant (> 1000 gallons) released,
(2) Instantaneous rate of release,
(3) Short time (< 1 month) since release,
(4) Deeper depth to groundwater (>5 m),
(5) Low hydraulic conductivity (< 10-05 cm/sec),
(6) Low rainfall infiltration rate (<0.05 cm/day),
(7) Warm soil temperature (> 20 degree celsius),
(8) High soil sorption capacity/surface area (> 1 m2/g),
(9) Low liquid viscosity (< 2cPoise),
(10) Low liquid density (<1 g/cm3),
(11) High liquid vapor pressure (> 100mmHG),
(12) Low water solubility (<100 mg/L).

(019) Dissolved1 .00 00 1
Contaminants present in the dissolve phase.

(020) Dissolved2 .00 00 2
There is likelihood of contaminant being present in the dissolved phase.

(021) Dissolved3 .00 00 2
There is no likelihood of contaminant being present in the dissolved phase.

(022) Dissolved4 .00 00 15
HIGH UNCERTAINTY IN THE PRESENCE OF DISSOLVED CONTAMINANTS IN THE VADOZE ZONE: Use the following guidelines to determine the feasibility of liquid contaminants in the unsaturated zone:
(1) Large amount of contaminant (> 1000 gallons) released,
(2) Slow release,
(3) Short time (< 1 month) since release,
(4) Deeper depth to groundwater (>5 m),
(5) High moisture content (> 30% volume),
(6) High soil porosity (>40%volume),
(7) Low rainfall infiltration rate (<0.05 cm/day),
(8) High soil sorption capacity/surface area(> 1 m2/g),
(9) Low liquid viscosity (< 2cPoise),
(10) Low liquid density (<1 g/cm3),
(11) Low liquid vapor pressure (< 10mmHG),
(12) High water solubility (>1000 mg/L).

STEP EXPERT SYSTEM
DECISION RULE INPUT FILE FOR STEP (PHASE.IDR)

```
(09)    Warning           .0    0  Limitations of this knowledge
base.
V   Q1              Y

(10)    Guidelines         .0    0  Guidelines for evaluation of
phase.
V   Q2              Y

(11)    Liquid1           .0    0  Liquid phase very likely.
V   AR              Large
V   RR              Instantaneous
V   TR              Short
V   DGW             Deep
V   HC              Low
V   RIR             Low
V   ST              Cool
V   SSC             High
V   LV              High
V   LD              Low
V   VP              Low
V   WS              Low
```

```
(12)    Liquid2             .0    0  Liquid phase somewhat likely.
A ! Liquid1         11
V   AR              Medium     Large
V   RR              Instantaneous
V   TR              Medium     Short
V   DGW             Medium     Deep
V   HC              Medium     Low
V   RIR             Medium     Low
V   ST              Medium     Cool
V   SSC             Medium     High
V   LV              Medium     High
V   LD              Medium     Low
V   VP              Medium     Low
V   WS              Medium     Low

(13)    Liquid3             .0    0  Liquid phase not likely.
A ! Liquid1         11
A ! Liquid2         12
V   AR              Small
V   RR              Slow
V   TR              Short
V   DGW             Shallow
V   HC              High
V   RIR             High
V   ST              Warm
V   SSC             Low
V   LV              Low
V   LD              High
V   VP              High
V   WS              High

(14)    Liquid4             .0    0  Liquid phase uncertain.
A ! Liquid1         11
A ! Liquid2         12
A ! Liquid3         13

(15)    Dissolved1          .0    0  Dissolved phase very likely.
V   AR              Large
V   RR              Slow
V   TR              Short
V   DGW             Deep
V   MC              High
V   SP              High
V   RIR             Low
V   SSC             High
V   LV              Low
V   LD              Low
V   VP              Low
V   WS              High

(16)     Dissolved2         .0      0   Dissolved phase  somewhat
likely.
A ! Dissolved1      15
```

```
V   AR                  Medium     Large
V   RR                  Slow
V   TR                  Medium     Short
V   DGW                 Medium     Deep
V   MC                  Medium     High
V   SP                  Medium     High
V   RIR                 Medium     Low
V   SSC                 Medium     High
V   LV                  Medium     Low
V   LD                  Medium     Low
V   VP                  Medium     Low
V   WS                  Medium     High

(17)     Dissolved3          .0    0  Dissolved phase not likely.
A ! Dissolved1          15
A ! Dissolved2          16
V   AR                  Small
V   RR                  Instantaneous
V   TR                  Long
V   DGW                 Shallow
V   MC                  Low
V   SP                  Low
V   RIR                 High
V   SSC                 Low
V   LV                  High
V   LD                  High
V   VP                  High
V   WS                  Low

(18)     Dissolved4          .0    0  Dissolved phase uncertain.
A ! Dissolved1          15
A ! Dissolved2          16
A ! Dissolved3          17

(19)     Vapor1              .0    0  Vapor Phase very likely.
V   AR                  Large
V   RR                  Instantaneous
V   TR                  Short
V   DGW                 Deep
V   AC                  Low
V   ST                  Warm
V   RIR                 Low
V   SSC                 High
V   LV                  Low
V   LD                  Low
V   VP                  High
V   WS                  Low

(20)     Vapor2              .0    0  Vapor phase somewhat likely.
A ! Vapor1              19
V   AR                  Medium     Large
V   RR                  Instantaneous
V   TR                  Medium     Short
```

```
V   DGW              Medium     Shallow
V   AC               Medium     Low
V   ST               Medium     Warm
V   RIR              Medium     Low
V   SSC              Medium     High
V   LV               Medium     Low
V   LD               Medium     Low
V   VP               Medium     High
V   WS               Medium     Low

(21)    Vapor3             .0    0  Vapor Phase not likely.
A ! Vapor1           19
A ! Vapor2           20
V   AR               Small
V   RR               Slow
V   TR               Long
V   DGW              Shallow
V   AC               High
V   ST               Cool
V   RIR              High
V   SSC              Low
V   LV               High
V   LD               High
V   VP               Low
V   WS               High

(22)    Vapor4             .0    0  Vapor phase uncertain.
A ! Vapor1           19
A ! Vapor2           20
A ! Vapor3           21
```

STEP EXPERT SYSTEM
DECISION VARIABLE FILE FOR PHASE KNOWLEDGE-BASE (PHASE.IDV)

```
(01)   AR               M .000 0000 1
What is the amount of release of the contaminant in gallons?
Small              Small - Less than 100
Medium             Medium - Between 100 and 1000
Large              Large - Greater than 1000

(02)   RR               M .000 0000 1
What is the rate of release of the contaminant?
Instantaneous      Instantaneous release of the contaminant.
Slow               Slow release of the contaminant.

(03)   TR               M .000 0000 1
What is the time since release of the contaminant (in months)?
Short              Short - Less than 1
Medium             Medium - Between 1 and 12
Long               Long - Greater than 12
(04)   DGW              M .000 0000 1
```

```
What is the depth to groundwater in meters?
Shallow          Shallow - Less than 1
Medium           Medium - Between 1 and 5
Deep             Deep - Greater than 5

(05)   HC               M .000 0000 1
What is the hydraulic conductivity of the soil in cm/sec ?
Low              Low - Less than 10-05
Medium           Medium - Between 10-05 and 10-03
High             High - Greater than 10-03

(06)   RIR              M .000 0000 1
What is the rainfall infiltration rate at the site in cm/day ?
Low              Low - Less than 0.05
Medium           Medium - Between 0.05 and 0.1
High             High - Greater than 0.1

(07)   ST               M .000 0000 1
What is the soil temperature on a celsius scale?
Cool             Cool - Less than 10
Medium           Medium - Between 10 and 20
Warm             Warm - Greater than 20

(08)   SSC              M .000 0000 1
What is the soil sorption  capacity (surface area) in m2/g?
Low              Low - Less than 0.1
Medium           Medium - Between 0.1 and 1
High             High - Greater than 1

(09)   LV               M .000 0000 1
What is the liquid viscosity of the contaminant in centiPoise?
Low              Low - Less than 2
Medium           Medium - Between 2 and 20
High             High - Greater than 20

(10)   VP               M .000 0000 1
What is the vapor pressure of the contaminant in mmHg?
Low              Low - Less than  10
Medium           Medium - Between 10 and 100
High             High - Greater than 100

(11)   WS               M .000 0000 1
What is the water solubility of the contaminant in mg/L?
Low              Low - Less than 100
Medium           Medium - Between 100 and 1000
High             High - Greater than 1000

(12)   LD               M .000 0000 1
What is the liquid density of the contaminant in g/cm3?
Low              Low - Less than 1

Medium           Medium - Between 1 and 2
High             High - Greater than 2
```

```
(13)   AC               M .000 0000 1
What is the soil air conductivity in cm/sec?
Low                Low - Less than 10-06
Medium             Medium - Between 10-06 and 10-04
High               High - Greater than 10-04

(14)   MC               M .000 0000 1
What is the soil moisture content in percentage?
Low                Low - Less than 10
Medium             Medium - Between  10 and 30
High               High - Greater than 30

(15)   SP               M .000 0000 1
What is the soil porosity in percentage?
Low                Low - Less than 20
Medium             Medium - Between 20 and 40
High               High - Greater than 40

(16)   Q1               L .000 0000 2
Would you like to read the information on the current
limitations and scope of the PHASE knowledge base?

(17)   Q2               L .000 0000 2
Please answer 'y' to read the guidelines in interpreting
the results of evaluation of phase by the system.
```

APPENDIX D

Computer Files for the Mobility Rule-base in STEP

STEP EXPERT SYSTEM
ACTIONS FILE FOR THE MOBILITY KNOWLEDGE-BASE (MOBILITY.IDA)

```
(001)  Liquid1           .00   00   1
Liquid mobility very likely.

(002)  Liquid2           .00   00   1
Liquid mobility less likely.

(003)  Liquid3           .00   00   1
Liquid mobility not likely.

(004)  Liquid4           .00   00   1
Liquid mobility uncertain.

(005)  Vapor1            .00   00   1
Vapor mobility very likely.

(006)  Vapor2            .00   00   1
Vapor mobility less likely.

(007)  Vapor3            .00   00   1
Vapor mobility not likely.

(008)  Vapor4            .00   00   1
Vapor mobility uncertain.

(009)  Dissolved1        .00   00   1
Mobility in dissolved water very likely.

(010)  Dissolved2        .00   00   1
Mobility in dissolved water less likely.

(011)  Dissolved3        .00   00   1
Mobility in dissolved water not likely.

(012)  Dissolved4        .00   00   1
Mobility in dissolved water uncertain.
```

STEP EXPERT SYSTEM
DECISION RULE INPUT FILE FOR MOBILITY KNOWLEDGE-BASE
(MOBILITY.IDR)

```
(01)    Liquid1            .0    0  Mobility very likely.
V   TR                Short
V   HC                High
V   SP                High
V   SSA               Low
V   ST                High
V   RF                Present
V   MC                Low
V   LV                Low
V   LD                High

(02)     Liquid2                 .0     0   Liquid phase mobility
somewhat likely.
A ! Liquid1           01
V   TR                Short      Medium
V   HC                Medium     High
V   SP                Medium     High
V   SSA               Medium     Low
V   ST                Medium     High
V   RF                Present
V   MC                Medium     Low
V   LV                Medium     Low
V   LD                Medium     High

(03)     Liquid3              .0     0   Liquid phase mobility not
likely.
A ! Liquid1           01
A ! Liquid2           02
V   TR                Long
V   HC                Low
V   SP                Low
V   SSA               High
V   ST                Low
V   RF                Absent
V   MC                High
V   LV                High
V   LD                Low

(04)     Liquid4                 .0     0   Liquid phase mobility
uncertain.
A ! Liquid1           01
A ! Liquid2           02
A ! Liquid3           03

(05)     Dissolved1         .0     0  Mobility in dissolved phase
very likely.
V   HC                High
V   MC                High
V   RIR               High
```

```
V   SP                 High
V   RF                 Present
V   DS                 Deep
V   WS                 High

(06)    Dissolved2         .0    0  Mobility is somewhat likely.
A ! Dissolved1         05
V   HC                 Medium     High
V   MC                 Medium     High
V   RIR                Medium     High
V   SP                 Medium     High
V   RF                 Present
V   DS                 Medium     Deep
V   WS                 Medium     High

(07)    Dissolved3         .0    0  Mobility is not likely.
A ! Dissolved1         05
A ! Dissolved2         06
V   HC                 Low
V   MC                 Low
V   RIR                Low
V   SP                 Low
V   RF                 Absent
V   DS                 Shallow
V   WS                 Low

(08)    Dissolved4         .0    0  Mobility is uncertain.
A ! Dissolved1         05
A ! Dissolved2         06
A ! Dissolved3         07

(09)     Vapor1                .0     0   Mobility of vapors very
likely.
V   AFP                High
V   TP                 High
V   WC                 Low
V   DS                 Shallow
V   VD                 High

(10)    Vapor2              .0     0  Mobility of vapors somewhat
likely.
A ! Vapor1             09
V   AFP                Medium     High
V   TP                 Medium     High
V   WC                 Medium     Low
V   DS                 Shallow    Medium
V   VD                 Medium     High

(11)     Vapor3                .0     0   Mobility of vapors not
likely.
A ! Vapor1             09
A ! Vapor2             10
V   AFP                Low
```

```
V   TP              Low
V   WC              High
V   DS              Deep
V   VD              Low

(12)    Vapor4              .0     0  Mobility of vapors uncertain.
A ! Vapor1          09
A ! Vapor2          10
A ! Vapor3          11
```

STEP EXPERT SYSTEM
DECISION VARIABLE FILE FOR MOBILITY KNOWLEDGE-BASE
(MOBILITY.IDV)

```
(01)   TR               M .000 0000 1
What is the time since release of the contaminant (in months)?
Short             Short - Less than 1
Medium            Medium - Between 1 and 12
Long              Long - Greater than 12

(02)   DS               M .000 0000 1
What  is  the  depth  of  contamination  below  the  surface  (in
meters)?
Shallow           Shallow - Less than 2
Medium            Medium - Between 2 and 10
Deep              Deep - Greater than 10

(03)   HC               M .000 0000 1
What is the hydraulic conductivity of the soil in cm/sec ?
Low               Low - Less than 10-05
Medium            Medium - Between 10-05 and 10-03
High              High - Greater than 10-03

(04)   RIR              M .000 0000 1
What is the rainfall infiltration rate at the site in cm/day ?
Low               Low - Less than 0.05
Medium            Medium - Between 0.05 and 0.1
High              High - Greater than 0.1

(05)   ST               M .000 0000 1
What is the soil temperature on a celsius scale?
Low               Low - Less than 10
Medium            Medium - Between 10 and 20
High              High - Greater than 20

(06)   LV               M .000 0000 1
What is the liquid viscosity of the contaminant in centiPoise?
Low               Low - Less than 2
Medium            Medium - Between 2 and 20
High              High - Greater than 20
```

```
(07)   VD                M .000 0000 1
What is the vapor density of the contaminant in g/m3?
Low               Low - Less than 50
Medium            Medium - Between 50 and 500
High              High - Greater than 500

(08)   WS                M .000 0000 1
What is the water solubility of the contaminant in mg/L?
Low               Low - Less than 100
Medium            Medium - Between 100 and 1000
High              High - Greater than 1000

(09)   LD                M .000 0000 1
What is the liquid density of the contaminant in g/cm3?
Low               Low - Less than 1
Medium            Medium - Between 1 and 2
High              High - Greater than 2

(10)   AFP               M .000 0000 1
What is the soil air filled porosity in percentage?
Low               Low - Less than 10
Medium            Medium - Between 10 and 30
High              High - Greater than 30

(11)   MC                M .000 0000 1
What is the soil moisture content in percentage?
Low               Low - Less than 10
Medium            Medium - Between 10 and 30
High              High - Greater than 30

(12)   SP                M .000 0000 1
What is the soil porosity in percentage?
Low               Low - Less than 10
Medium            Medium - Between 10 and 30
High              High - Greater than 30

(13)   WC                M .000 0000 1
What is the water content of the soil?
Low               Low - Less than 10
Medium            Medium - Between 10 and 30
High              High - Greater than 30

(14)   RF                M .000 0000 1
Are there any rock fractures present?
Present           Present
Absent            Absent

(15)   TP                M .000 0000 1
What is the total porosity of the soil?
Low               Low - Less than 10
Medium            Medium - Between 10 and 30
High              High - Greater than 30
```

```
(16)   SSA             M .000 0000 1
What is the soil surface area in m2/g?
Low               Low - Less than 0.1
Medium            Medium - Between 0.1 and 1
High              High - Greater than 1
```