COMPUTER METHODOLOGY FOR TRANSPORTATION AGENCIES TO SCREEN TECHNOLOGIES FOR HAZARDOUS WASTE REMEDIATION

by

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March 1993

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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 userfriendly 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 (5075% 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 re-circulation 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 percent 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 percent 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: cementbased, 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 percent 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 trademark of Borland International®, Scotts Valley, CA.

[2]EXCEL™ is a registered trademark 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.

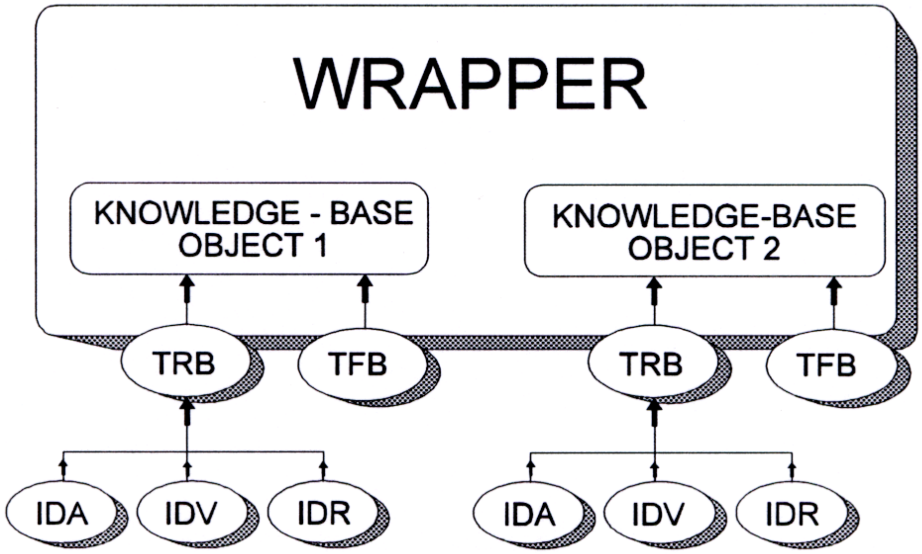

Figure 1. Typical Structure of an Application Using TRIPOD Classes

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

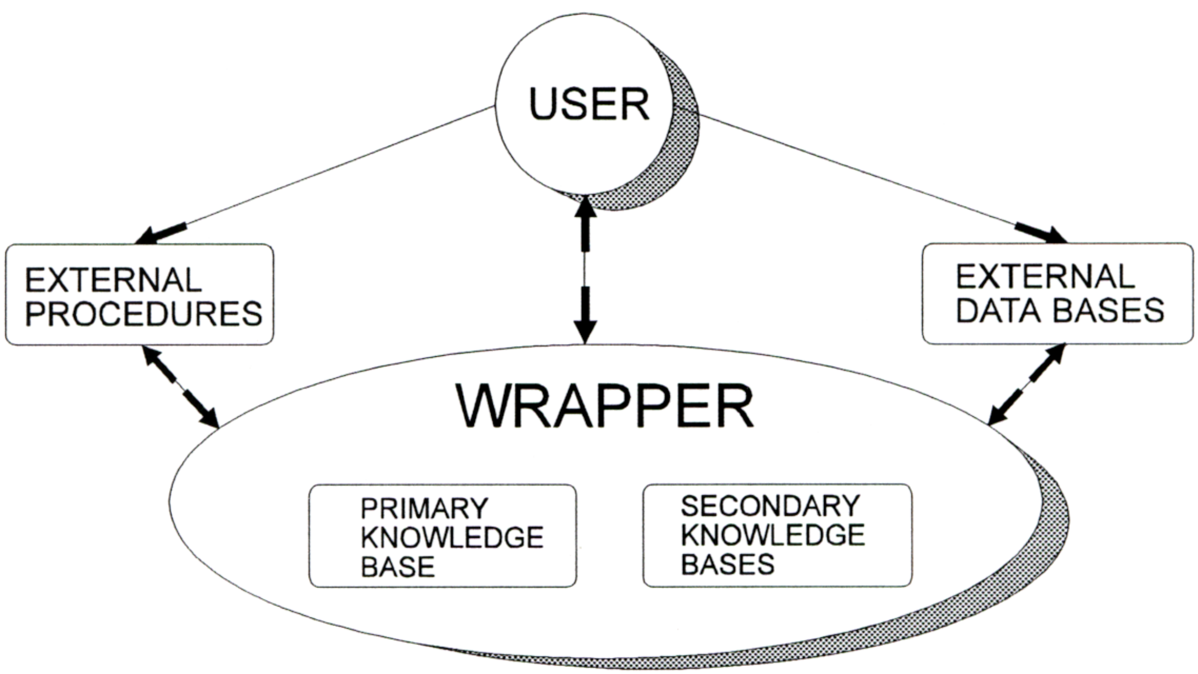

Figure 2. Implementation Strategy

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.

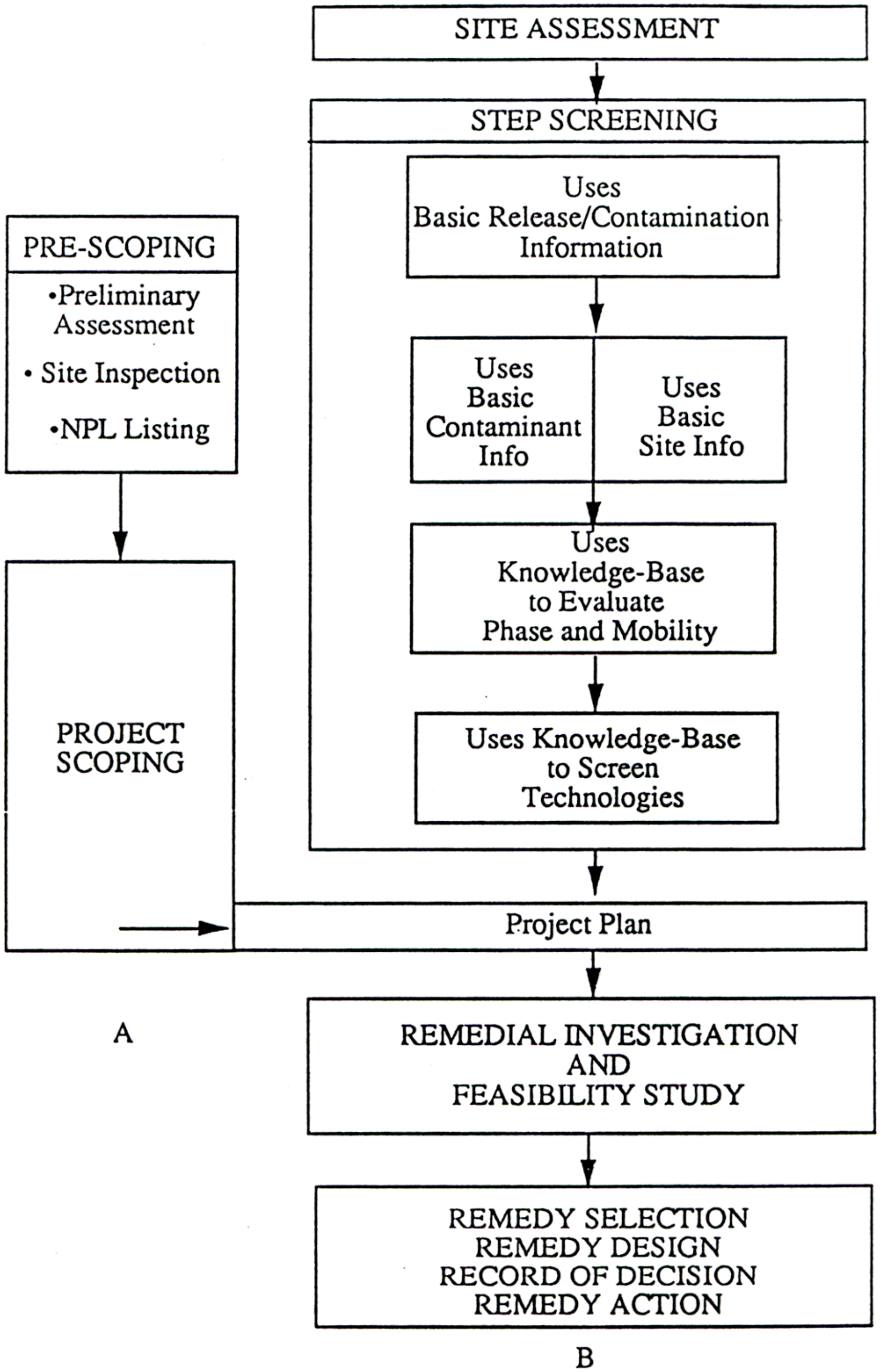

Figure 3. **The STEP Methodology in the Site Remediation Process (after U.S. EPA, 1988b)**

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 As presented in Figure 4, STEP utilizes information on 1) release and current extent of contamination, 2) soil characteristics, 3) characteristics, 4) phase of the contaminants, and 5) mobility of the treatment technologies. contaminant contaminant 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 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).

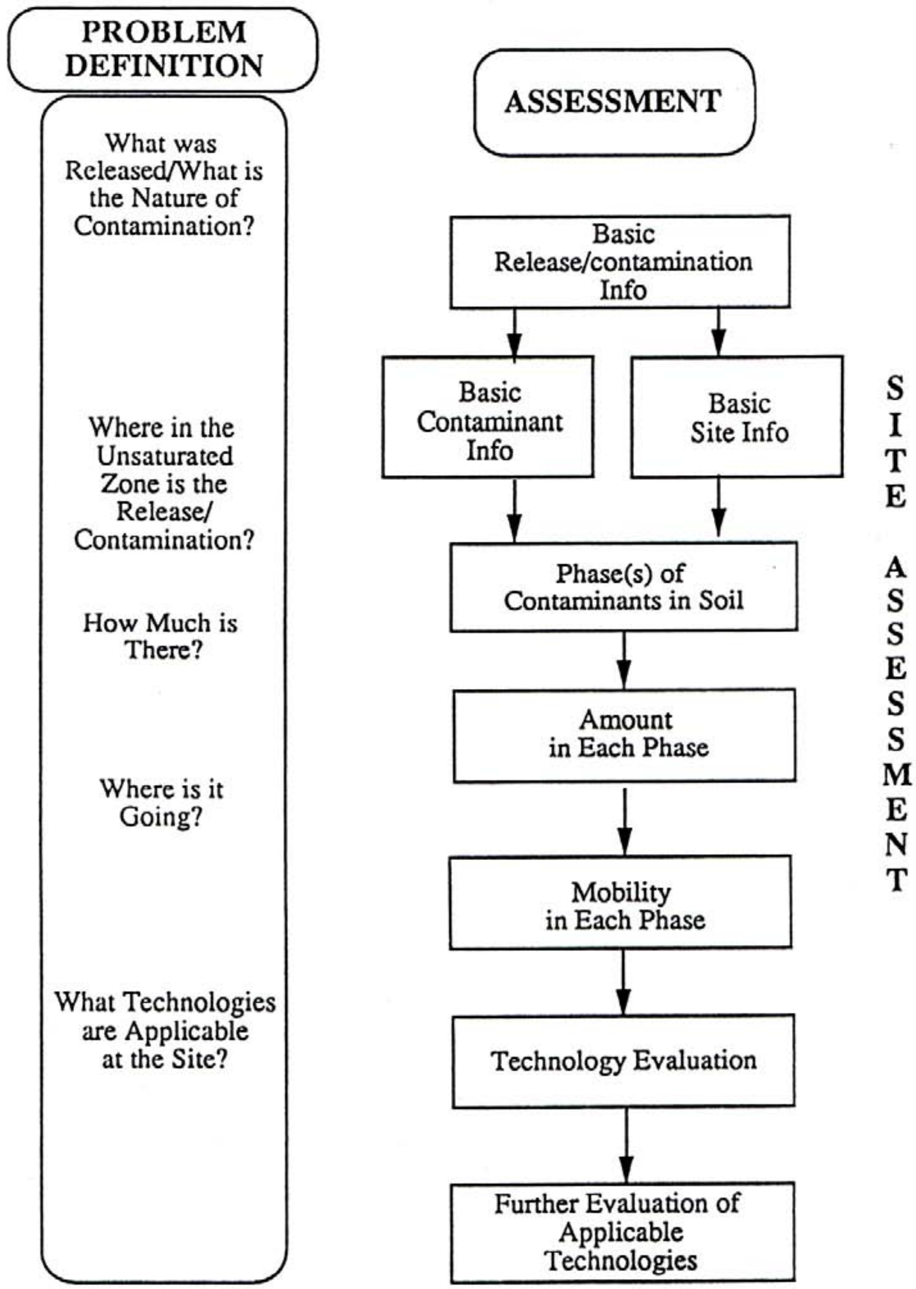

Figure 4. Site and Technology Assessment (after U.S. EPA, 1990a)

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.

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.

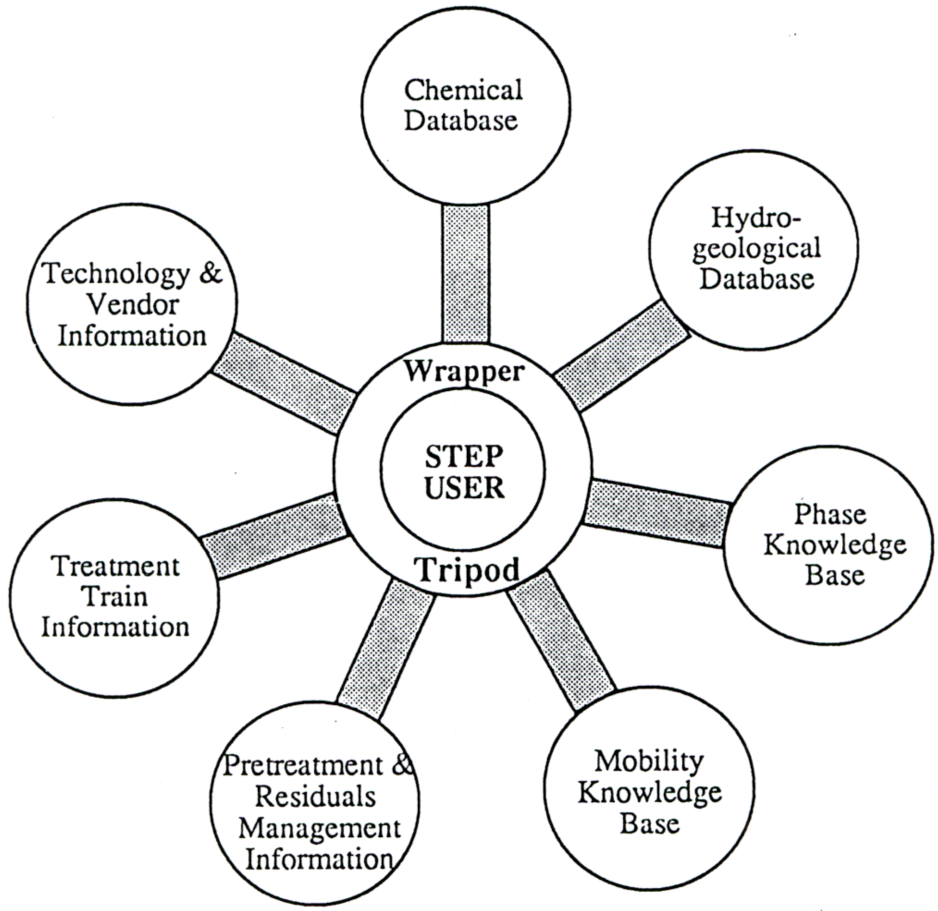

Figure 5. Components of the STEP Model

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, 19900. 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 knowledgebase. 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 posttreatment 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 pilotplant 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.

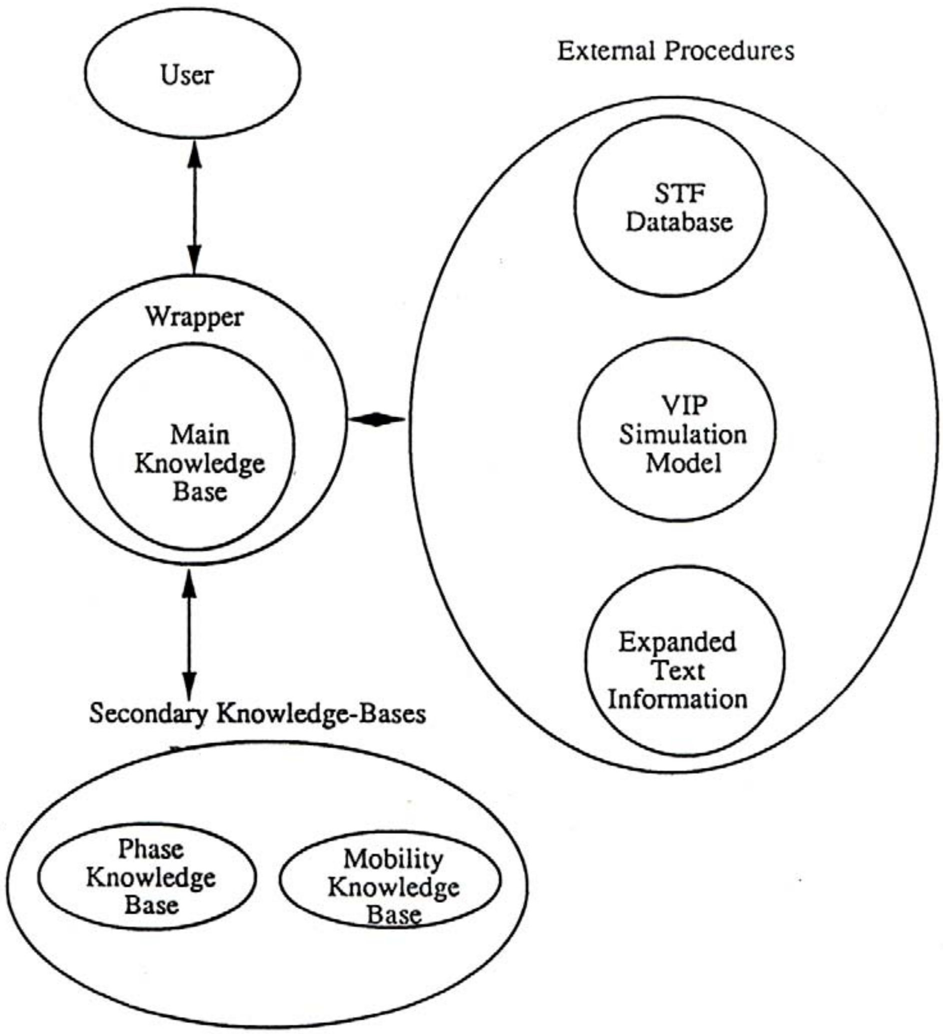

Figure 6. The Layout of the STEP Model

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 “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.

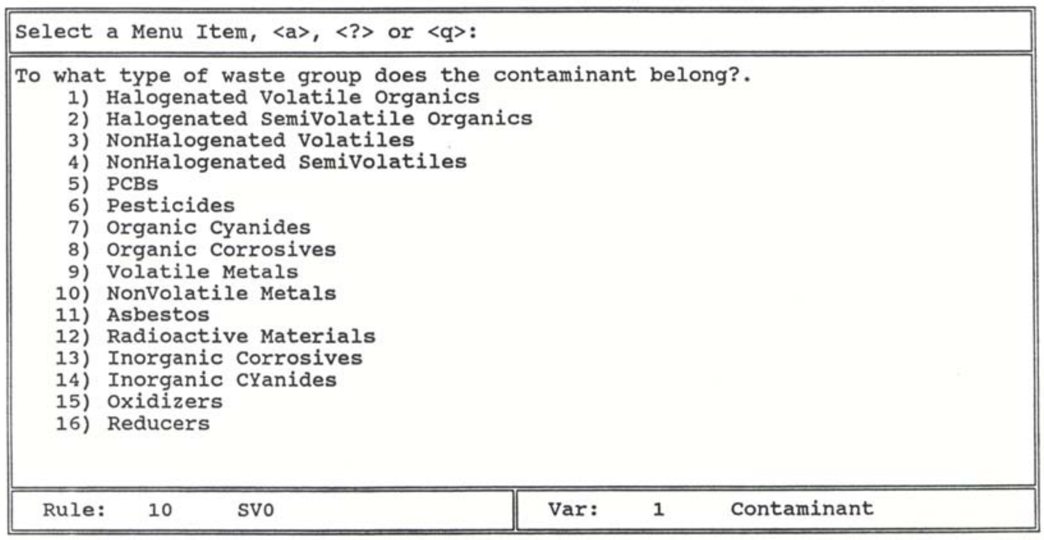

Figure 7. Screen Display Query for Chemical Group

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-volative 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.
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%	*****	*****

Table 2. Table Showing User-Model Interaction for the Case Study				
Step	**Question**	**Reply**	**STEP Response**	**Comments**
9	Identify the geologic conditions of the site	Homogeneous	*****	*****
10	What is the depth to groundwater?	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
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				
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 7P-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 nonexperts to do preliminary screening of appropriate technologies, and provide a training tool for in-house personnel.

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APPENDIX A

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APPENDIX B, C, D available on request