AFIT/GEE/CEC/92S-5

DEVELOPMENT OF A HEURISTIC KNOWLEDGE BASE FOR THE SELECTION OF APPLICABLE OR RELEVANT AND APPROPRIATE ENVIRONMENTAL REQUIREMENTS

THESIS

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THESIS

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Abstract

Applicable or Relevant and Appropriate Requirements (ARARs) are the basis used in establishing threshold limits for hazardous waste cleanups performed under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). ARARs selections must be applied consistently at numerous cleanup locations concurrently. The purpose of this research was to analyze activities required for the development of a heuristic knowledge base used for selection of ARARs. The problem domain for the research was limited to CERCLA cleanups of contaminated groundwater, through the use of a pump and treat strategy, using air stripping as the cleanup technology. The research examined literature concerning the importance of ARARs in the CERCLA restoration process and the knowledge acquisition and representation methods. The research then analyzed the activities required to acquire and represent the knowledge required for the selection of ARARs. A byproduct of the research was a proof-of-concept prototype expert system which was used to validate knowledge acquired and represented in the problem domain. Prototype validation included comparing the results of the expert system with ARARs identified in the Record of Decisions (RODs) for actual CERCLA cleanups. In three of four cases, the expert system successfully identified all ARARs germane to the cleanups.

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I. Introduction

Background

The cleanup of hazardous waste has become a major problem facing our nation today. Public interest concerning the health threats posed by hazardous waste began in the mid 1970s with the environmental disasters that occurred at Love Canal, New York and Times Beach, Missouri. As a result of the public concern generated by these incidents, the United States Congress passed the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) in 1980.

CERCLA, also known as the Superfund, gives the United States Environmental Protection Agency (USEPA) the authority and resources required to cleanup abandoned or inactive hazardous waste sites and respond to emergencies related to hazardous waste. A key component of CERCLA is 40 CFR Part 300: National Oil and Hazardous Substances Pollution Contingency Plan, also known as the National Contingency Plan (NCP), which provides specific direction concerning the remedial action process followed by the USEPA for the cleanup of hazardous waste sites (4:671).

The NCP divides the remedial action process into four phases. The process begins with the Preliminary Assessment/Site Inspection (PA/SI) phase. Next, the Remedial Investigation/Feasibility Study (RI/FS) phase is conducted. The findings of the RI/FS are given in a Record of Decision (ROD), which documents the direction to be followed during the remaining phases. The Remedial Design/ Remedial Action (RD/RA) phase is then executed. Finally, the Site Closeout (SC) phase concludes the Remedial Action Process. The cleanup of hazardous waste sites in the Air Force is performed through the Installation Restoration Program (IRP). The Air Force's IRP remedial action process mirrors the process outlined in the NCP (29:3-1).

A key activity of the RI/FS which is frequently continued during the RD/ RA phase is the identification of Applicable or Relevant and Appropriate Requirements (ARARs). The identification of ARARs requires an intimate knowledge of environmental regulations and their relationship with the chemical compounds that comprise the contaminant, the cleanup techniques used for the remedial action, and the specific location of the cleanup.

A knowledge based expert system (KBES) uses knowledge acquired from experts and applies it in a similar method as the experts to solve a problem. A KBES, which contains the expertise required to identify ARARs would be a valuable tool during the execution of the RI/FS process. However, the effort required to acquire and represent the knowledge for every possible scenario is very time consuming. Therefore, limiting the knowledge to a frequently encountered cleanup scenario improves the possibility of completing a task specific expert system in a timely manner.

Many CERCLA cleanup sites encounter aquifers contaminated with hazardous waste. A frequently used strategy for the cleanup of aquifers contaminated with hazardous waste is to pump and treat contaminated water, typically with air stripping as the treatment technology. According to the USEPA:

> Contaminated ground water is found at 74 percent of Superfund's 1,200 National Priority List (NPL) sites. Of the contaminated ground-water sites for which Records of Decision (RODs) have been signed (439 ground water RODs from FY82 to FY91), [p]ump-and-treat is specified in 70 percent . . . of the RODs. (43:1)

In a query of the Record Of Decision System (RODS), USEPA's full-text database of signed RODs, 52 percent of the signed RODs that use a pump-and-treat strategy use Air Stripping as the cleanup technology (47).

The pumping portion of the pump-and-treat strategy performs the removal of the contaminated ground water from the aquifer, and frequently the discharge of treated ground water by reinjection into the same aquifer. According to James and Rogoshewski, ground water pumping

> involves the active manipulation and management of groundwater in order to contain or remove a plume or to adjust groundwater levels in order to prevent the formation of a plume. The selection of the appropriate well type depends on the depth of the contamination and the hydrologic and geologic characteristics of the aquifer. Types of wells used in management of contaminated groundwater include wellpoints, suction wells, ejector wells, and deep wells. All these types of wells employ some form of injection and/or extraction wells. The function of the injection well is to

> direct the contaminants to the extraction wells. Pumping is most effective at sites where underlying aquifers have high intergranular hydraulic conductivities and where pollutant movement is occurring along fractured or jointed bedrock. In fractured bedrock, the fracture patterns must be traced in detail to ensure proper well placement. (13:12.36)

The other component of the pump and treat strategy involves the treatment of contaminated groundwater, through some form of treatment technology. As stated earlier, air stripping is frequently chosen as the treatment technology for the pump and treat strategy. According to the USEPA

> Air stripping is a means to transfer contaminants from aqueous solutions to air. Contaminants are not destroyed by airstripping but are physically separated from the aqueous solutions. Contaminant vapors are transferred into the airstream and, if necessary, can be treated by incineration, adsorption, or oxidation. Most frequently, contaminants are collected in carbon adsorption systems and then treated or destroyed in this concentrated form. The concentrated contaminants may be recovered, incinerated for waste heat recovery, or destroyed by other treatment technologies. Generally, air stripping is used as one in a series of unit operations and can reduce the overall cost for managing a particular site. Air stripping is applicable to volatile and semivolatile organic compounds. It is not applicable for treating metals and inorganic compounds. (39:1)

This research paper will analyze the activities required for the development of a KBES for the selection of ARARs. The problem domain for the research study was limited to ARARs for CERCLA cleanups of contaminated groundwater, through the use of a pump and treat strategy, using air stripping as the cleanup technology.

This chapter begins with a brief description of the general issue surrounding the research topic. Next, the specific problem surrounding the research topic is delineated. Based on the specific problem, research objectives are articulated. A detailed description of the scope and limitations of the study follows. A thesis overview concludes this chapter.

General Issue

CERCLA establishes guidance for performing the cleanup of aquifers contaminated with hazardous waste. The basis for establishing cleanup thresholds for restorations performed under CERCLA are ARARs (31:8723).

ARARs are best understood by dividing them into their component parts, "applicable" and "relevant and appropriate" requirements. Applicable requirements are "requirements promulgated under Federal and State law that specifically address the circumstances at a Superfund site."(42:xv) Relevant and appropriate requirements are "[r]equirements that, while not 'applicable' to a Superfund site, address situations sufficiently similar to a site that their use is well suited." (42:xv)

The USEPA differentiates between "applicable" and "relevant and appropriate" requirements as follows:

> The "applicability" determination is a legal one, while the determination of "relevant and appropriate" relies on professional judgement, considering environmental and technical factors at the site. (33:1)

Air Force Remedial Project Managers (RPMs) are "the primary contact for all response actions" (29:2-1) at Air Force Installations. RPMs face three impediments in identifying ARARs. First, RPMs have "technical rather than legal backgrounds" (6:2). Second, there is "insufficient time to adequately review the large body of Federal and State regulations" (6:2). Finally, "the criteria and policy for determining whether a regulation is applicable or relevant and appropriate are subject to both changes over time and 'political' negotiations and analysis" (7:1).

In an effort to overcome these impediments the USEPA has developed the Potential ARARs Selection Tool (PAST), a knowledge based expert system. PAST currently possesses two major limitations. First, the PAST system does not currently have the knowledge base to select "Relevant and Appropriate" requirements (7:2). Second, the knowledge has not been acquired and represented to identify ARARs for effluent discharged from the restoration process (21).

Specific Problem

Can heuristic or rule-of-thumb knowledge be formalized to assist Air Force and USEPA RPMs in selecting federally mandated ARARs for effluent discharges from pump and treat remediation methodologies, in particular air stripping, given a specific contaminant's chemical makeup and a particular cleanup site location?

Objectives

The research objectives of this study were:

1. Ascertain the effect ARARs have on the execution of the environmental restoration process.

2. Identify applicable requirements or relevant and appropriate requirements that impact effluent discharges from pump and treat aquifer restoration strategies, focusing principally on air stripping technologies.

3. Determine the status of knowledge acquisition and representation methods currently available for the development of knowledge-based expert systems.

4. Develop a heuristic knowledge base to assist RPMs with the identification of ARARs for pump and treat aquifer restoration methodologies.

5. Verify and validate that the KBES developed during this research is an appropriate problem solving tool for the specific problem domain addressed in this study.

Scope and Limitations of Research

The scope of the research was limited to the development of a heuristic knowledge base of ARARs for air stripping, including the liquid effluent waste stream. A necessary byproduct of this research was a proof-of-concept prototype expert system that was used to validate the knowledge acquired during the research. Two considerations drove the decision to limit the development to a proof-of-concept prototype expert system. First, this research was original from the viewpoint that it acquired knowledge that could be formalized to solve problems that could not previously be solved in this domain. Second, the time constraints imposed on the research effort made the development of a fully operational system infeasible. The ARARs contained in the knowledge base were limited to those that are federally mandated. The research was strictly limited to air stripping, the most frequently selected pump and treat groundwater restoration technology. Air stripping was selected due to its prevalence in the USEPA's Record of Decision Database (38:1). In addition, the contaminants considered by the research were limited to volatile and semi-volatile chemical liquids, since non-volatile chemicals cannot be treated by an air stripping technology. Because the goal of this research was to build upon the efforts already accomplished by the USEPA's PAST system, the knowledge was represented in a method compatible with their system.

Thesis Overview

Chapter I presents the concept of ARARs and provides background information on the problems associated with their identification, as well as a possible solution. This chapter also identifies the specific problem, research objectives, and scope and limitations of the study. Chapter II provides background information gleaned from literature on the effect ARARs have on the execution of the environmental restoration process, as well as the status of knowledge acquisition and knowledge representation methods currently used in the development of knowledge-based expert systems. Chapter III presents the specific methodology used to develop the heuristic knowledge base. Chapter IV presents the results of the research efforts and documents the findings of the validation of the knowledge base. Chapter V presents the conclusions inferred by the study, and makes recommendations for future research efforts.

II. Review of Literature

Overview

This chapter reviews the literature concerning ARARs and the development of heuristic knowledge bases. The chapter is divided into two main parts. The first part describes the impact of ARARs on the remediation process. The second part of this chapter examines the development of a heuristic knowledge-base.

ARARs are used as the basis for the development of cleanup thresholds for CERCLA Remedial Actions. The review begins with a general explanation of the concept of ARARs, what compliance with ARARs means, criticisms that have been asserted concerning ARARs, and some conflicts ARARs have with other environmental regulations. Next, the chapter outlines how ARARs are used during the CERCLA remediation process. The chapter then examines the impact ARARs have on the remediation of contaminated groundwater. The first part of this chapter concludes with a brief discussion of actions the USEPA has undertaken to facilitate the identification of ARARs.

A heuristic knowledge base contains rules, facts, and relationships which makeup the expertise of an expert sytem. The second part of this chapter describes the process followed in the development of heuristic knowledge bases. This portion of the chapter begins with an overview of expert systems and explains the part the knowledge-base plays in their operation. Next, the review examines the knowledge acquisition process, methods used to perform the process and problems associated with these methods. The second part of the chapter concludes with a review of knowledge representation methodologies currently in use and pitfalls in their execution.

The Impact of ARARs on the Remediation Process

The cleanup of contaminated groundwater is one of the greatest environmental challenges facing the United States today. ARARs are used as the basis for determining threshold limits for the cleanup of contaminated groundwater. This section begins with a brief explanation of the concept of ARARs and introduces some of the controversy surrounding them.

Background on ARARs. The Superfund Amendments and Reauthorization Act of 1986 amended Section 121(d) of CERCLA in the following way:

> For wastes left on site, remedial actions must comply with Federal and State environmental laws that are legally applicable or are relevant and appropriate under the circumstances of the release. (46:1)

The National Contingency Plan defines "applicable" and "relevant and appropriate" requirements as follows:

> Applicable requirements mean those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or State law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site. (33:1)

> Relevant and appropriate requirements mean those cleanup standards [that] . . . address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. (33:1)

Differentiating between "applicable" and "relevant and appropriate" requirements is an important factor in understanding the ARARs concept. The United States Environmental Protection Agency (USEPA) differentiates between "applicable" and "relevant and appropriate" requirements as follows: "The 'applicability' determination is a legal one, while the determination of 'relevant and appropriate' relies on professional judgement, considering environmental and technical factors at the site" (33:1). The process followed in the selection of ARARs is described in Appendix A.

Complying with ARARs is significantly different from complying with environmental requirements under other circumstances. Under CERCLA, the USEPA requires that on-site remediation activities "comply with the substantive requirements but need not comply with administrative and procedural requirements" (35:1-1), this guideline is known as the "on-site" rule (25). The USEPA defines on-site as "the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action" (35:1-1). For the cleanup of a contaminated aquifer, the "areal extent of contamination" would include the contaminant plume upon which cleanup activities are focused (25). Furthermore, the "suitable areas in very close proximity" would encompass all areas needed to conduct the remedial action, including areas needed to conduct the remedial action. For example, this would include areas for contractor storage and staging, and observation wells (25). Administrative requirements are "those mechanisms that facilitate the implementation of the substantive requirements of a statute or a regulation (e.g. requirements related to the approval of, or consultation with administrative bodies, documentation, permit issuance, reporting, recordkeeping, and enforcement)."(46:3) Substantive requirements are "those requirements that pertain directly to actions or conditions in the environment." (46:3) The on-site rule allows the parties executing the cleanup to ignore permitting requirements for activities performed entirely on- site. Through CERCLA, the USEPA requires off-site activities to comply with ARARs as follows:

> Actions involving the transfer of hazardous substances or pollutants or contaminants off site must comply with applicable Federal and State requirements and are not exempt from any formal administrative permitting requirements. Off-site actions are not governed by the concept of relevant and appropriate. (35:1-1)

The USEPA has identified three types of ARARs which can impact a cleanup under CERCLA: chemical-specific, location-specific and action-specific. Chemical-specific ARARs are "health or risk based numerical values or methodologies used to determine acceptable concentrations of chemicals that may be found in or discharged to the environment" (46:3). Location- specific ARARs "restrict actions or contaminant concentrations in certain environmentally sensitive areas" (46:3). Action-specific ARARs are typically "technology- or activity-based requirements or limitations on actions or conditions involving specific substances" (46:3).

Some controversy surrounds the use of ARARs to establish cleanup standards. For example, Meyninger and Marlowe criticize establishing threshold limits for a cleanup under CERCLA based on ARARs in the following way:

> Such limits have serious shortcomings because they divide the environment into discrete media, such as air or water. This limits standard setting to one particular environmental pathway, and, often to a single route of exposure, with all other media assumed to be clean. (18:65)

Meyninger and Marlowe advocate the use of a risk assessment model that "estimates real-world risk more efficiently than current methods of adopting single medium limits because it takes into account cumulative exposures and risks from multiple sources" (18: 67).

Conflicts with the Resource Conservation and Recovery Act (RCRA). CERCLA works to cleanup "reckless hazardous waste disposal practices of the past" (16:161). RCRA "addresses the management of existing and future hazardous waste activities" (16:161). Through RCRA's Hazardous and Solid Waste Amendments (HSWA), a Corrective Action Program similar to CERCLA's Response Program has been implemented to cleanup old Solid Waste Management Units (SWMUs) (16:162). A SWMU is "any discernible unit at which solid wastes have been placed at any time regardless of whether the unit was intended for the management of solid or hazardous waste" (16:163).

In a comparison of these two programs, Martino and Kaszynski found that many federal facilities listed on CERCLA's National Priority List (NPL) for cleanup, are also categorized as SWMUs and subject to RCRA's Corrective Action Program (16:164). For these cleanup sites, RCRA's corrective action rules could potentially become the primary ARAR.

RCRA's corrective action program requires cleanups to comply with permitting requirements, while CERCLA only requires ARARs to comply with substantive requirements for on-site activities (16:175). Martino and Kaszynski believe that RCRA's Corrective Action Program "limits flexibility within the permitting process and could lead to delays in the implementation of corrective action remedies" (16:175) under CERCLA.

Effect of ARARs on the CERCLA Remediation Process. The remediation process followed by cleanups performed as part of the Air Force IRP mirrors the process developed under CERCLA (29:3-1). The cleanup of hazardous waste under CERCLA follows a process divided into four distinct phases: Preliminary Assessment/Site Inspection (PA/SI), Remedial Investigation/Feasibility Study (RI/FS), Remedial Design/Remedial Action (RD/RA), and Site Closeout (SC). This section will describe how ARARs impact the process, focusing in particular on the RI/FS and RD/RA phases.

Impact of ARARs on the RI/FS. The purpose of the RI/FS phase is to characterize "the nature and extent of risks posed by uncontrolled hazardous waste sites" and to evaluate "potential remedial options" (41:1-3). During the RI/FS phase "ARAR identification is progressive, with requirements identified and refined as a better understanding is gained of site conditions, site contaminants, and remedial action alternatives" (40:3). The RI/FS can be divided into three activities: scoping, the Remedial Investigation (RI), and the Feasibility Study (FS).

The scoping activity, which is based on information obtained during the PA/SI, identifies an overall "management strategy" (41:1-6) for the RI/FS. A major task undertaken during the scoping activity is the identification of potential ARARs impacting the site. According to the USEPA, identifying potential ARARs during the scoping phase serves three purposes: "Identifying remedial goals and alternatives; establishing communications with support agencies" (40:3); and facilitating "better planning of field activities" (40:3).

The RI follows the scoping activity and involves two major tasks: site characterization and treatability studies (41:1-7). The identification of chemical- and location-specific ARARs is accomplished as part of the site characterization task (41:1-7). According to the USEPA:

> During the RI, as a better understanding is gained of site conditions and contaminants, identification of chemical- and location-specific ARARs continues to: (1) Better plan future activities, including identifying the scale of any required treatability studies, and (2) Identify remedial action alternatives. (50:3)

Treatability studies are undertaken to "gather information to assess the feasibility of a technology" (41:1-8). In an effort to streamline the RI/FS, Johnston and Wynn recommend performing treatability studies as early as possible during the RI, so that results can be used to evaluate whether proposed alternatives meet potential ARARs (14:737).

The FS, performed concurrently with the RI, serves as "the mechanism for the development, screening, and detailed evaluation of alternative remedial actions" (41:1-6). During the FS, action specific ARARs are identified for the remedial action alternatives, and an analysis is performed to compare how the various alternatives meet their potential ARARs (40:1-7). In performing the Remedy Selection activity under the FS, the NCP requires the

> selection of remedies that are cost-effective and that effectively mitigate and minimize threats to public health and welfare and the environment. In selecting the appropriate extent of remedy, the lead agency considers cost, technology, reliability,administrative and other concerns, and their relevant effects on public health and welfare and the environment. Federal ARARs are used as the basis for determining cleanup levels. (31:8723)

The USEPA has developed a remedy selection strategy which considers nine criteria in the selection of the most appropriate remedial action for a cleanup. The nine criteria, displayed in figure 1, are placed into three categories: threshold, balancing, and modifying criteria (31:8724). The threshold criteria, which include compliance with ARARs, focus on "statutory requirements that each alternative must satisfy in order to be eligible for selection."(37:5-1) In other words, compliance with ARARs must be satisfied for a potential remedy to be considered feasible. Balancing criteria are "the technical criteria that are considered during the detailed analysis."(37:5-1) The modifying criteria are "evaluated following com-

Nine Criteria for Remedy Selection

Threshold Criteria:

* Overall Protection of human health and the environment
* Compliance with ARARs (or waiver)

Balancing Criteria:

* Long-term effectiveness and performance
* Reduction of mobility, toxicity, or volume through treatment
* Short-term effectiveness
* Implementability
* Cost effectiveness

Modifying Criteria:

* State acceptance
* Community acceptance

Figure 1. Nine Criteria for CERCLA Remedy Selection

ment on the RI/FS report and the proposed plan and will be addressed once a final decision is being made and the ROD is being prepared.

Impact of ARARs on RD/RA. Upon completion of the RI/FS phase, a Record of Decision (ROD) is written, which "presents the selected remedy and provides the rationale for its selection" (32:1). Based on the findings of the ROD, a Remedial Design is undertaken to develop the plans and specifications required to carry out the Remedial Action. ARARs are an important factor to be considered during the Remedial Design. The USEPA requires the following clause in their plans and specifications statement of work given to the Architect/Engineer (A/E) firm performing the design:

> The A/E shall ensure that the design package submitted is in accordance with CERCLA procedures on compliance with other environmental laws. . . . All applicable or relevant and appropriate requirements identified in the [Record Of Decision/Enforcement Decision Document] ROD/EDD shall be analyzed and incorporated into the design by the A/E. The A/E shall identify the controlling parameters as required by such standards. (49:2-14)

The USEPA also requires its project managers to review the plans and specifications submitted by the A/E firm for the following items:

- Compliance with all applicable or relevant and appropriate environmental and public health requirements identified in the ROD/EDD.
- Utilization of currently accepted environmental control measures and technology.
- Consistency with ROD/EDD, and environmental and public impacts. (49:2-19)

During the Remedial Action, the contractor is bound by the contract to comply with all requirements included in the plans and specifications, which includes compliance with ARARs contained in the ROD. The USEPA is currently in the process of developing procedures for measuring the attainment of ARARs in a series of publications called Methods for Evaluating the Attainment of Cleanup Standards. These documents outline "sampling and analysis methods" (44:xvi) for measuring the attainment of ARARs during the RA phase. According to the USEPA:

> Statistical methods are emphasized because there is a practical need to make decisions regarding whether a site has met a cleanup standard in spite of uncertainty. The uncertainty arises because Superfund managers are faced with being able to sample and analyze only a small portion of the [media] at the site yet having to make a decision regarding the entire site. Statistical methods are designed to permit this extrapolation from the results of a few samples to a statement regarding the entire site.(44:xvi)

Impact of ARARs on Groundwater Remediation. Four strategies are typically used to control contaminated groundwater:

- Divert "clean," "upstream" groundwater around the contamination source.
- Lower the groundwater table beneath the contamination source to minimize leachate generation.
- Control the source followed by treatment of the resulting plume contamination.
- Contain the contamination plume. (17:61)

These strategies are "implemented with any combination of the following remedial technologies: groundwater pumping . . ., subsurface drains, barriers, and in-situ treatment" (17:61). The most frequent remediation technique currently in use for groundwater cleanup is pumping and treating (27:1465). In October 1990, Travis and Doty found that "68% of Superfund Records of Decision (RODs) select groundwater pumping and treating as the final remedy to achieve aquifer restoration" (27:1465).

For most groundwater remediations, the primary ARAR is the Safe Drinking Water Act's (SDWA's) Maximum Contaminant Levels (MCLs) for groundwater that is currently being used for drinking or may be used for drinking (33:4). When MCLs are the primary ARAR, Goodrich et al. propose the establishment of threshold limits for the cleanup based on the "levels and mixtures of contaminants the drinking water treatment technology can accept and still produce drinking water meeting the MCLs" (5:61).

Criticisms of the Use of ARARs for Pump and Treat Remediation. Pumping and treating water from contaminated aquifers has been criticized as being ineffective as a remediation method (27:1465). *Steimle found that:*

> Although pump-and-treat remediation has been selected to clean up most contaminated ground-water sites, there are significant drawbacks to this technology. It has been found to be a very long-term process, which may require decades or more at many sites. Large volumes of water must be treated over long periods of time, requiring substantial operation and maintenance expense. In addition, subsurface contaminant sources often are not effectively identified, particularly dense non-aqueous phase liquids (DNAPLs). Subsurface heterogeneity and the complexity of contaminant mixtures create a need to develop innovative methods to provide more effective and less expensive alternatives to pump-and- treat. (43:1)

Travis and Doty cite "past experience" (27:1465) with groundwater transport models, and previous attempts to use pump and treat techniques for groundwater remediation (27:1465) as evidence of its ineffectiveness. One explanation for the ineffectiveness of pump and treat techniques is that "contaminants in groundwater partition between the water and organic matter in soils. As the groundwater is pumped, the chemicals are held back (retarded) by their adherence to soil particles" (27:1465).

Travis and Doty recommend discontinuing "the use of Applicable or Relevant and Appropriate Requirements (ARARs) as cleanup goals for aquifer restoration" (27:1466). Travis and Doty argue that since pump and treat techniques are ineffective, ARARs as cleanup goals are misleading the public, because they are unachievable (27:1466).

Current Systems for Identifying ARARs. Kovalick, Town, and Deardorf conducted a survey of 530 members of the USEPA's regional hazardous and solid waste staff in an effort to determine the technical needs of those involved in the USEPA's hazardous and solid waste programs (15:1480). Technical information on treatment standards was among the top ten needs identified by the USEPA's CERCLA staff (15:1482) and the "CERCLA audience" which includes EPA contractors and the regulated community (15:1485).

One way the USEPA has tried to satisfy the need for technical information on treatment standards is through the publication of the CERCLA Compliance With Other Laws Manual and the Compendium of CERCLA ARARs Fact Sheets and Directives:

> The purpose of the CERCLA Compliance With Other Laws Manual is to assist the Remedial Project Managers (RPMs) in identifying and complying with all Applicable or Relevant and Appropriate Requirements (ARARs) for remedial actions taken at Superfund Sites. (35:1-1)
>
> The [Compendium of CERCLA ARARs Fact Sheets and Directives] were developed by EPA's Office of Solid Waste and Emergency Response. EPA prepared the fact sheets to assist those involved in the conduct of reponse

> actions in complying with Section 121 (d), "Degree of Cleanup," of CERLA as ammended by SARA and 40 CFR Part 300, Subpart E, Section 300.400(g) "identification of applicable or relevant and appropriate requirements" of the NCP. (36:1)

Another initiative undertaken by the USEPA, in conjunction with the Department of Energy (DOE) and the U.S. Army Construction Engineering Research Laboratory (USACERL), is a major enhancement of the U.S. Army Corps of Engineers' Computer-aided Environmental Data System (CELDS) (1). This enhancement, known as the ARARs-Assist Database, will contain

> abstracts of all Federal Statutes, plus the full texts of these environmental requirements: Federal and State statutes and regulations, Federal executive orders, U.S. international treaties, Federal interagency agreements, and Indian tribal laws. Other features of the library to serve all environmental inquiries, not only those related to CERCLA actions, will be the EPA Catalog of Superfund Publications, ARARs policy documents, and ARARs tutorial; environmental review/NEPA guidance; lists of contacts in Federal and State agencies and Indian tribal organizations; and, information about accessing other useful Federal data systems. (1)

The ARARs-Assist Database, provides an on-line system, which is easily updated and provides "full-text, full-search" features (1). A major drawback of the ARARs-Assist Database, is the lack of a search strategy to assist the user in identifying potential ARARs, and the "applicable" and "relevant and appropriate" analysis.

The USEPA is also developing the Potential ARARs Selection Tool (PAST), a knowledge based expert system, that follows the same decision logic found in the CERCLA Compliance With Other Laws Manual (6:1). The decision to develop PAST was based on results from a survey of the "automated decision support system needs" of 200 hazardous waste decision makers (6:2). Reasons for developing PAST included:

(1) "technical rather than legal backgrounds" (6:2) of decision makers,

(2) "insufficient time to adequately review the large body of Federal and State regulations" (6:2), and

(3) "the criteria and the policy for determining whether a regulation is applicable or relevant and appropriate are subject to changes over time and 'political' negotiations and analysis" (7:1).

PAST allows the user to identify potential chemical-, location-, and action-specific ARARs, and assists with the "applicable" determination of potential ARARs. Also, the knowledge-base and user-interface developed under PAST provide the basic structure for automating the entire ARARs selection process.

PAST currently possesses two major limitations. First, the knowledge base does not contain the rules required to select "Relevant and Appropriate" requirements (7:2). Second, the knowledge has not been acquired and represented to identify ARARs for effluent discharges from the restoration process (21). These limitations can be mitigated by expanding the knowledge base used by PAST.

Development of Heuristic Knowledge Bases

A good heuristic knowledge base is the key component of an expert system. An expert system is "a computer program that emulates the behavior of human experts, who are solving real-world problems associated with a particular domain of knowledge" (22:15). An expert system contains three components:

(1) A knowledge base that contains "the knowledge or expertise of the domain which is the designated area of expertise for the system"(44:1-7).

(2) An inference engine, which "contains the specific procedures and algorithms for using the rules and facts in the knowledge base to solve a problem"(44:1-7).

(3) The user interface, which "permits the user and system to communicate"(44:1-7).

Pigford and Baur describe the development of an expert system as follows:

> (1) extracting from the expert(s) the knowledge and methods used to solve the problem, and (2) the reforming of the knowledge/methods into an organized form for later use. The process of extraction and reformation are known as knowledge acquisition and representation, respectively, and are complex and time consuming processes. The sum of the two processes is known as knowledge engineering. (22:15-16)

The following paragraphs explain the knowledge acquisition and representation processes, describe the most common methods of performing them, and problems associated with these methods.

Knowledge Acquisition. Knowledge acquisition can be defined as:

> The accumulation, transfer and transformation of problem solving expertise from some knowledge source to a computer program for constructing or expanding the knowledge base. Potential sources of knowledge include human experts, textbooks, databases, special research reports, and the user's own experience. (28:802)

According to Simmons and Chappel, the "knowledge acquisition task can consume 50 percent to 80 percent of the total effort of implementing a[n] [expert] system"(26:27).

The two most common methods of acquiring knowledge from experts are interviews and protocol analysis (3:1422). A typical procedure for interviewing experts follows:

> The interview is conducted by a knowledge engineer who poses questions or problems to the expert. The expert in turn, is expected to provide answers or solutions that hopefully reveal some of the facts, rules and heuristics relevant to the domain in question. (3:1422)

Protocol analysis entails "the observation of a domain expert by a knowledge engineer as the expert solves a problem within his domain" (3:1422).

The knowledge engineer must be aware of several pitfalls in the knowledge acquisition process. First, "the expert cannot articulate reasons for his behavior in the form of standard rules"(26:27). Expressing knowledge is unnatural for many people, and the knowledge may not have been taught verbally (3:1422-3). Another problem is the time constraint put on the expert, who "typically does not have the time available for extensive interviews, especially because his expertise is in short supply" (26:27). Finally, the experts "behavior is observed, interpreted, and transformed into a formalized version by the knowledge engineer"(3:1423). Simmons and Chappel suggest videotaping and careful notetaking during interview sessions to efficiently use the time spent with the expert (26:27).

Knowledge Representation: Knowledge representation is defined as "the method used to encode and store facts and relationships in a knowledge base"(9:262). The following are some typical methods of knowledge representation:

Production Rules. The most common method of representing knowledge is production rules (22:39). Rules are structured with a premise that leads to a conclusion, in an "if-then" format (26:42). Production rules, also known as If-Then rules, are generally structured as follows:

IF $c_1, c_2, \ldots, c_n$
THEN $a_1, a_2, \ldots, a_n$

Where,

c_i is a condition or a situation; and
a_i is an action or a conclusion. (8:75)

For example, a rule for determining when to use your home's air conditioner might be written to say:

IF	Temperature	> 85 degrees
AND	Humidity	> 80 percent
THEN	Turn on air conditioner.	

Semantic Networks. Pigford and Baur explain the concept of semantic networks as follows:

> This method is based on a network structure and is usually viewed conceptually by graphic means. A semantic net is described by points (nodes) connected by directed links (arcs and arrows) that show hierarchical tree relations between nodes. Nodes represent objects, concepts or events. Arcs can be defined in a variety of ways that are dependant on the type of knowledge they connect. (22:41)

In a common form of semantic network, the directed links are labeled with "has" or "is-a" conditions (8:75) The relationship between the directed links and the points "establish an inheritence property in the network." (8:75) An example of a semantic network is shown in figure 2.

Frames. A frame is a "way of organizing knowledge into a collection or bundle where the knowledge contained in the frame is common to the concept, object, or situation"(22:44). According to Fikes and Kehler, in this method of knowledge representation, knowledge is decomposed into highly modular pieces called frames. For example, the knowledge may consist of concepts and situations, attributes of concepts, and relationships between concepts,

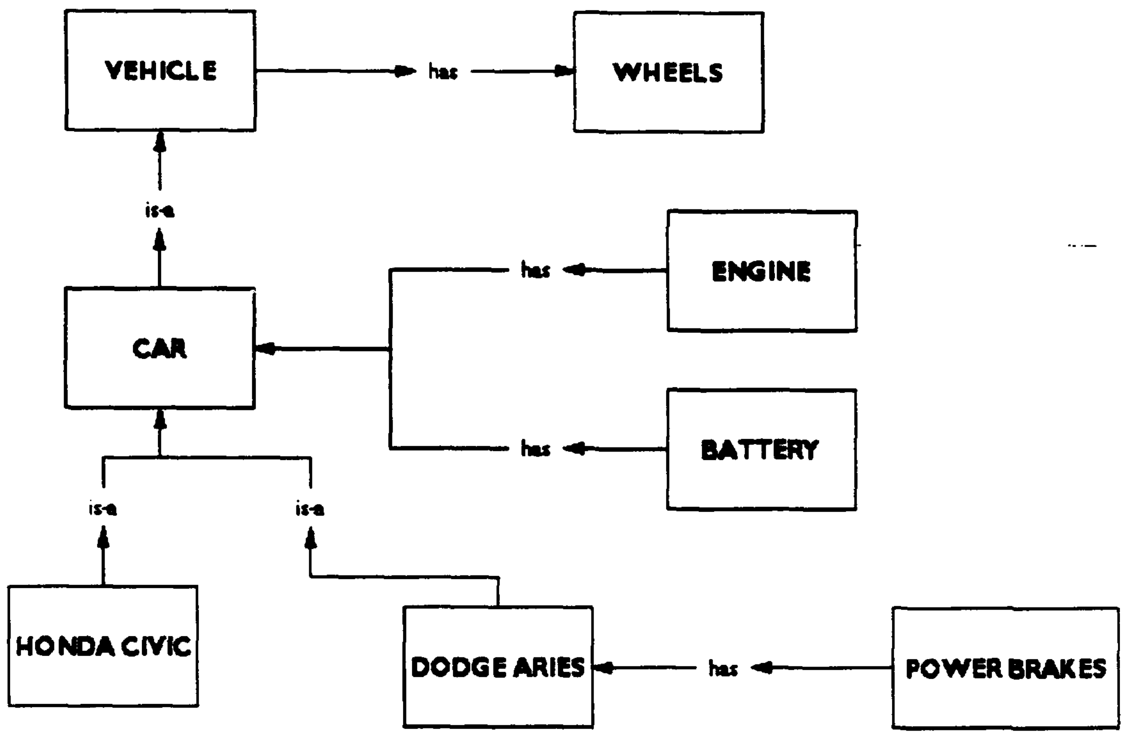

Figure 2: Example of a Semantic Network (8:76)

and procedures to handle relationships as well as values of attributes. In such a case, each concept could be represented as a seperate frame. (8:75)

Figure 3 displays examples of frames. According to Gupta and Prasad, "the frame representation scheme is better suited, as compared to production rules, to problems involving deeper knowledge."(8:75)

Object-Attribute-Value Triplets. The object-attribute-value model of knowledge representation can be explained in the following way:

> In this scheme, objects may be physical entities such as a door or a transistor, or they may be conceptual entities such as a logic gate, a bank loan, or a sales episode. Attributes are general characteristics or properties associated with objects. Size, shape, and color are typical attributes for physical objects. Interest rate is an attribute for a bank loan, and setting might be an attribute for a sales episode. The final member of the triplet is the value of an attribute. The value specifies the specific nature of an attribute in a

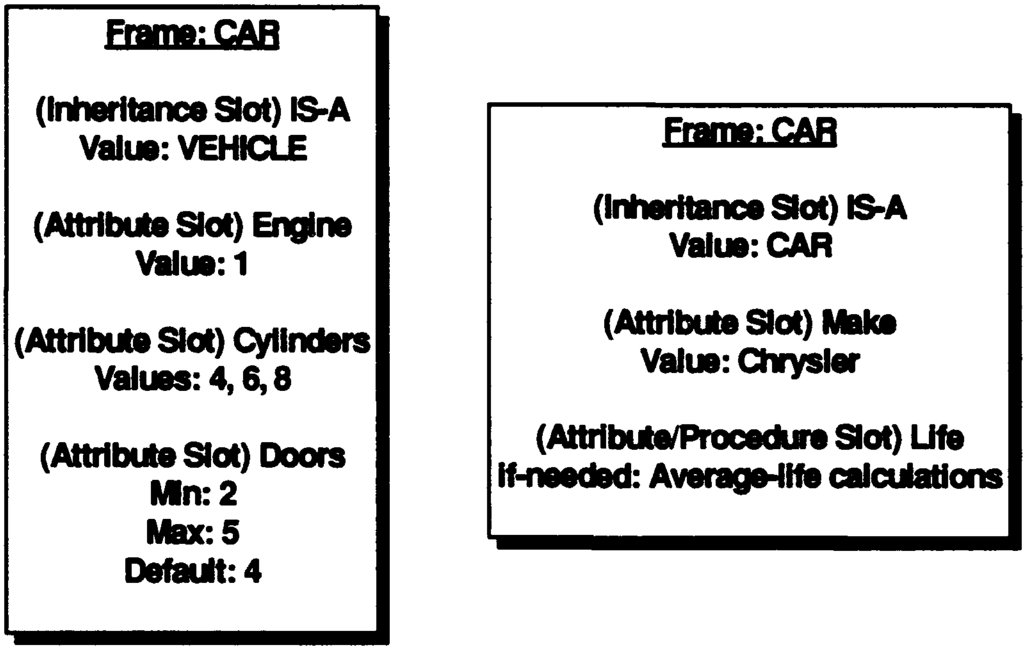

Figure 3: Example of a Frame(8:76)

> particular situation. An apple's color may be red, for example, or the interest rate for a bank loan may be 12 percent. (9:38)

An example of an O-A-V triplet is shown in figure 4.

Predicate Logic. Predicate logic is used to assess the "truth of assertions about objects, concepts, or events by using the techniques of propositional logic (calculus)" (22:46).

The biggest pitfall with knowledge representation is the "profound difference between the machinery of the brain, as compared to existing computers"(26:28). Simmons and Chappel suggest combining the various models of knowledge representation into a knowledge representation strategy to mitigate this problem (26:28). Frames should be used "in formulating typical situations and exposing the assumptions associated with them"(26:28). Semantic nets "can be

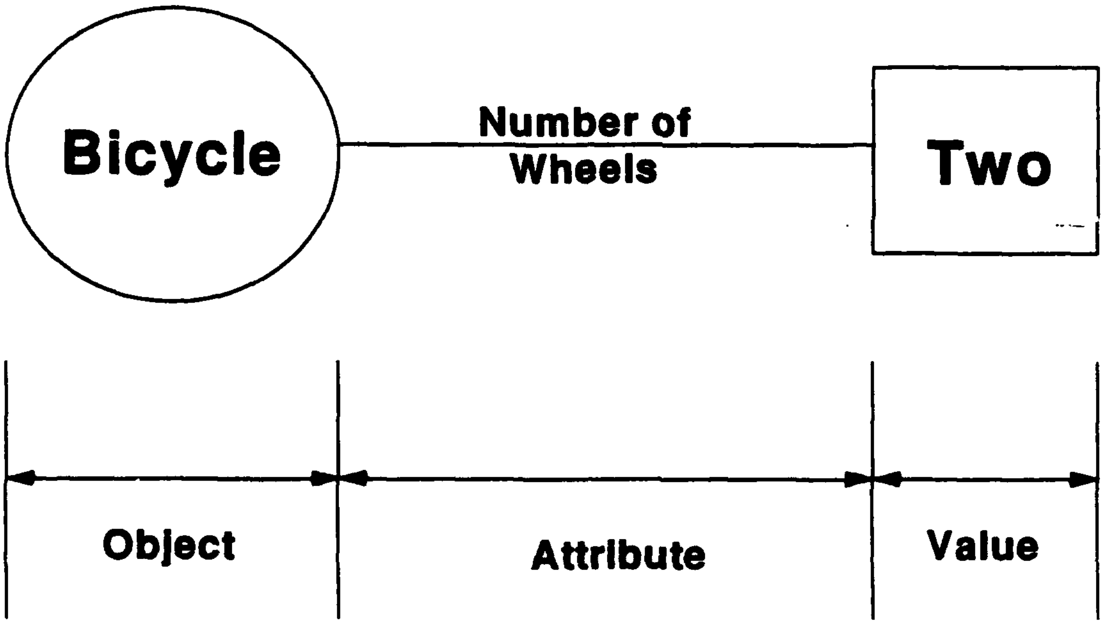

Figure 4: Example of an Object-Attribute-Value Triplet (6:39)

used to show the specific nature of relationships between elements of the knowl edge"(26:28). Production rules can be used to model "simple decision process- es"(26:28).

Conclusions

Identifying ARARs is one of the most important activities performed during the RI/FS phase of the environmental restoration process. Proper identification of ARARs requires expertise concerning the interaction of the chemical make-up of the contaminant, the treatment technologies employed and the cleanup site loca- tion. Expertise which has been effectively captured in a knowledge-based expert system can simplify this laborious task.

The literature reviewed in this chapter illustrates some of the complexity of the ARARs concept. A review of ARARs is presented which discusses how they are complied with, the various types of ARARs, the controversy surrounding them, and conflicts they have with other environmental regulations. An understanding of this information is vital to the effective identification of ARARs. Literature is also presented which describes how ARARs are managed during the environmental restoration process. The literature shows how ARARs evolve in their specificity as the restoration process progresses.

Literature examining the impact of ARARs on groundwater remediation is also presented. The Maximum Contaminant Levels promulgated under the Safe Drinking Water Act are the prominent ARARs. Criticisms of the pump and treat method of remediating aquifers and the use of ARARs for this method are also presented.

The efforts undertaken by the USEPA to clarify the ARARs identification process are also presented. A promising product currently under development is PAST, a knowledge-based expert system. PAST has automated the task of identifying applicable ARARs but falls short of identifying relevant and appropriate ARARs or ARARs associated with effluent discharges from the treatment technology. Incorporating these shortfalls requires expertise in the form of heuristics.

The literature also investigates the process that must be followed to acquire and represent heuristic knowledge in an expert system. The literature explains methodologies followed to acquire knowledge from experts and some of the problems associated with the task. Finally, the literature explains the methodologies that may be used to represent knowledge, and how these methodologies can be combined to improve their effectiveness.

III. Methodology

Introduction

The purpose of this chapter is to explain the methodology that was used to solve the specific problem of this study. Developing a heuristic knowledge base to assist Air Force and USEPA RPMs with the identification of ARARs for pump and treat aquifer restoration methodologies requires several major steps. The first step was to determine if available data demonstrates that a heuristic solution process is appropriate for this domain. The next step was to conduct a literature review on ARARs and knowledge-base development. Heuristic knowledge was then acquired and represented in a knowledge base. The final step was to develop a proof-of-concept prototype expert system that was verified, validated and evaluated by experts in the problem domain.

Problem Area and Domain Selection

The first step in this study was to determine if the study's specific problem is appropriate for expert system application. Pigford and Baur, suggest three questions that should be considered in determining the suitability of expert systems for a specific problem area:

1. Is expert system development possible for the problem solution?
2. Is expert system development justified for the problem solution?
3. Is expert system development appropriate for the problem solution? (22:91)

In determining if expert system development is possible for the problem solution, the first factor considered was the availability of recognized experts in the domain area (9:199, 22:92, 23:27). In selecting ARARs for pump and treat aquifer restoration, recognized experts were available within Headquarters Air Force Materiel Command's (HQ AFMC's) environmental law staff. The characteristics of the problem was another factor considered in determining if an expert system is possible (22:93). An expert in the selection of ARARs for pump and treat aquifer restoration should be able to determine which regulations are applicable, as well as those that are relevant and appropriate to a given situation. AFMC's environmental law staff meet this requirement. Therefore, expert system development is possible, because recognized experts in the problem domain were available, and could solve problems posed to them.

In determining if expert system development is justified for the problem solution, developers need to consider "how the expert system will be used or implemented."(22:93) True expertise in the selection of ARARs is limited to a few individuals, with high demands placed on their time. Effectively capturing expertise in an expert system can free-up some of the time these experts spend advising on ARARs issues. Another consideration is the payoff that the expert system will bring to the problem area (9:200-1, 22:93, 22:27). Due to the enormity of the nation's environmental restoration program, an expert system that selects ARARs can distribute this expertise to several locations simultaneously. An expert system that selects ARARs for a remediation project will also reduce the time spent by scientists and engineers tasked with developing and reviewing the RI/FS and RD phases of the project. Therefore, because a shortage of expertise exists, the expertise is needed at several locations simultaneously, and development will expedite performance of ARARs selection, the expert system is justified.

Finally, the appropriateness of a problem for expert system development depends on expert heuristics and symbolic reasoning (22:94, 23:27-8). According to Prerau "the domain should be characterized by the use of expert knowledge, judgement and experience" (23:27). In the selection of ARARs, heuristics are required to determine which regulations are relevant and appropriate. Symbolic reasoning is required for ARAR selection since the solution is based on four factors: the chemical characteristics of the contaminant, the technologies employed in the cleanup, the specific location of the cleanup, and effluent discharged from the cleanup process. Therefore, because heuristics and symbolic reasoning are required, an expert system for ARARs selection is appropriate.

Literature Review

A review of the current literature pertaining to the study's specific problem was undertaken. This review consisted of two parts. Part one ascertained the effect ARARs have on the environmental restoration process. Part two considered the knowledge acquisition and representation methods currently used in the development of knowledge based expert systems.

Effect of ARARs on Environmental Restoration. A literature review was accomplished to ascertain the effect ARARs have on the execution of the environmental restoration process. This literature focused on the effect ARARs have on contaminated aquifer restoration using pump and treat cleanup technologies. A comprehensive search was undertaken of literature contained in the Superfund Publication Catalog to determine the official USEPA policy toward ARARs. This effort was complemented by a search of environmental journal articles contained in the Applied Science and Technology Index to get the practitioner's viewpoint on ARARs. Journal articles were limited to those published after 1986, since Superfund Amendments and Reauthoriztion Act (SARA) of 1986 which mandated major policy changes concerning ARARs.

Development of Heuristic Knowledge Bases. The literature review also considered the status of knowledge acquisition and knowledge representation methods currently used in the development of knowledge-based expert systems. This review examined current methodologies used to acquire heuristic knowledge from experts. The review also explored techniques used to represent the heuristic knowledge in an expert system. The information was obtained through journal articles and government publications.

Knowledge Acquisition

The knowledge acquisition process involved two steps. First, a basic understanding of ARARs affecting pump and treat remediation technologies were attained through a review of official documents on ARARs. Next, interviews were conducted with experts on the selection of ARARs for pump and treat cleanup remediation technologies.

Exploratory Research. The first step in the knowledge acquisition process was to "gain a basic understanding of the expert's area of domain and an understanding of the problem(s) to be solved."(15:98) In order to accomplish this, ARARs that impact effluent discharges from pump and treat aquifer restoration methodologies were identified based on information contained in the CERCLA

Compliance With Other Laws Manuals, the Compendium of CERCLA ARARs Fact Sheets and Directives, and the Code of Federal Regulations.

Data Analysis Plan. During the review of official documents on ARARs, a decision was made concerning whether or not to include the data being reviewed. Data was separated into three categories: definitely include, definitely do not include, or questionable data. Data categorized as "definitely include" are regulations that are obviously applicable to the problem domain. Data categorized as "definitely do not include" are regulations that are obviously not applicable, and not relevant and appropriate to the problem domain. Finally, data categorized as "questionable" are those regulations that require expertise for interpretation with regard to their being "applicable" or "relevant and appropriate."

Inclusion of an environmental requirement in the knowledge base was based on its applicability or relevance and appropriateness to four criteria. The *four criteria included:*

(1) How does the requirement affect pump and treat remediation technologies?

(2) Does the requirement have implications concerning the cleanup site?

(3) How do the potential chemical contaminants that can be treated using pump and treat remediation technologies affect the requirement?

(4) How do the potential effluents from the pump and treat remediation process affect the requirement?

Interviews. Once a basic understanding of the problem domain was attained, non-scheduled structured interviews were used to solicit heuristic knowledge from experts. Nonscheduled-structured interviews guide the focus of the interview, but not the response (11). Questions asked during the interviews were derived from the "questionable" areas identified during the review of the official documentation concerning ARARs. Experts were asked "what if" questions on how they would approach these "questionable" areas. Detailed notes and audio taping of the interviews were used whenever possible to document data acquisition, and maximize the benefit of time spent with the experts. Heuristic knowledge attained from these interviews was used to augment and validate the information attained through the review of official documents.

Expert Selection. Experts selected for the interviews included lawyers, RPMs, and environmental management program managers. Lawyers are tasked with advising on the selection of ARARs during the RI/FS and RD phases of an environmental restoration project. Environmental program managers working in base-level environmental management must ensure compliance with environmental requirements at base-level. RPMs are tasked with reviewing these selections at the USEPA. "Experts" were limited to individuals who were directly involved in identifying ARARs for a ROD, or reviewing their validity during Remedial Design, for cleanups similar to those found in the problem domain. Other criteria for determining if an individual possessed expertise included their responsibility for establishing policy and guidance on ARARs, and approval authority of RODs in the problem domain.

Knowledge Representation

Information obtained through the literature and interviews was assembled into a heuristic knowledge base that is intended to assist RPMs with the identification of ARARs for pump and treat aquifer restoration methodologies. The knowledge base was organized into four categories of ARARs information: water, air, RCRA, and location-specific.

Because the goal of the research was to build upon the efforts already accomplished by the USEPA's PAST system, the knowledge was represented in a method compatible with this system. The PAST system uses a combination of rules and objects for knowledge representation (7:4). Knowledge representation through rules and objects is used in the following manner for the PAST system:

> The object structure of the system defines the problem domain space. System rules provide the linkage between the site characteristics and potential ARARs. As such, rules embody the system's decision criteria. (7:5-6)

Proof-Of-Concept Prototype Expert System Development

The content of the knowledge base was then translated into rules for a proof-of-concept prototype expert system. The USEPA describes a proof-of-concept prototype as follows:

> The proof-of-concept prototype is a very small working model of the expert system developed to assess preliminary feasibility of the problem domain. It is developed by following a narrow line of reasoning for a specific topic to its conclusion. . . . This prototype shows inherent strengths and weaknesses of further development. It will answer the question of whether or not another technology or approach is feasible. It also allows the knowledge engineer to assess the framework, scope, interface and issues borne out during knowledge acquisition and the design process. (44:4-19)

The proof-of-concept prototype expert system has been developed using the Kappa-PC expert system shell developed by Intellicorp Inc. This shell was used in the development of the USEPA's PAST system. The user interface used for the system was Toolbook, developed by Assymetrix Corporation. Again, this user interface was chosen because it was used to develop the PAST system.

Verification and Validation

Verification is "the process of ensuring the accuracy of the acquired knowledge that gives credibility to the expert system for its knowledge" (22:101). The Proof-Of-Concept Prototype Expert System was verified during development to ensure that rules are consistent. In particular, rules were verified to eliminate redundancy and conflicts, as well as subsumed or circular rules (19:70-2). The verification process also involved checking the rules for completeness (19:72-3).

Validation checks "the accuracy of inference chains that may be used on the knowledge base." (22:101) The proof-of-concept prototype expert system was validated through consultations with the experts. The output of the Proof-Of-Concept Prototype Expert System was evaluated against RODs for actual cleanups which use a pump and treat strategy and air stripping as the treatment technology to determine if the inference strategy and ARARs selected for the scenario match actual ARARs contained in the ROD. Comments made by the experts concerning errors and discrepancies in the knowledge base have been documented and incorporated into results of the research effort.

Summary

Chapter III describes the methods that were used to develop a heuristic knowledge base that assists RPMs with the identification of ARARs for pump and treat aquifer restoration methodologies. The chapter began with an analysis of the problem domain to determine its suitability for expert system development. Next the chapter describes the literature review pertaining to the study's problem domain. The chapter then describes the methodologies followed for the development of the problem domain including knowledge acquisition and representation, expert system development, and knowledge validation and verification.

IV. Results and Findings

Overview

This chapter documents the process followed in solving the specific problem of the study. The chapter begins by explaining the development of the heuristic knolwedge base for the problem domain, focusing specifically on the knowledge acquisition and representation proecesses. The process followed in the development of the proof-of-concept prototype expert system is then presented. The chapter then documents the results of the validation and verification process and concludes with an evaluation of the study objectives.

Heuristic Knowledge Base Development

The development of the heuristic knowledge base required the application of a systematic approach to knowledge acquisition and representation. Figure 5 describes the process followed during the development of the heuristic knowledge base. This section begins with an examination of the methods used for acquiring the knowledge required to represent the problem domain. Next, a review is provided of the techniques used in representing knowledge in the problem domain.

Knowledge Acquisition. The first phase in the development of the heuristic knowledge base was knowledge acquisition. Knowledge acquisition is the "transfer and transformation of problem-solving expertise from some knowledge source to a program."(10.:129) The knowledge acquisition phase involved three major activities: familiarization with the problem domain, selection of experts, and interviewing the selected experts.

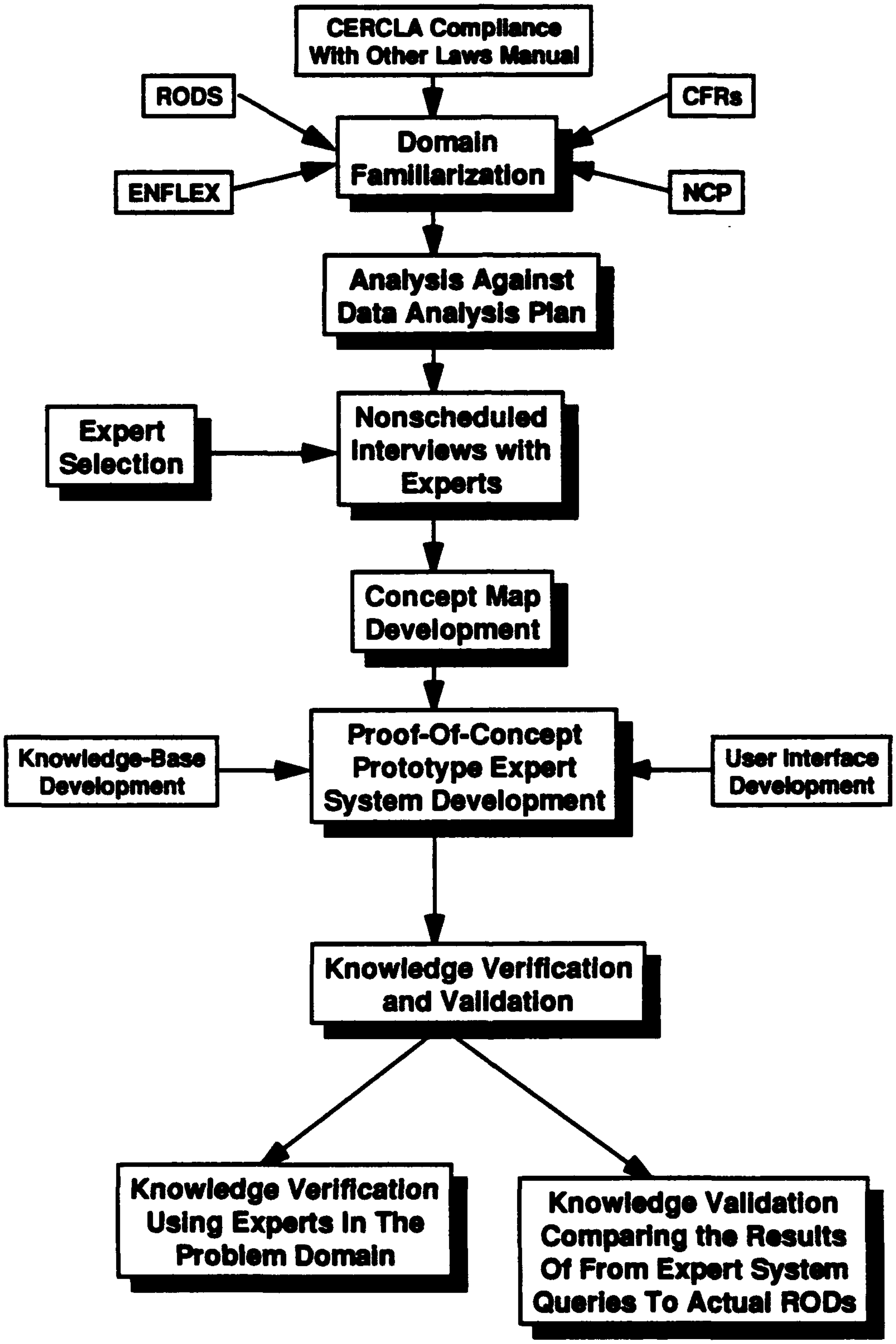

Figure 5: Flowchart of the Development of the Heuristic Knowledge Base

Familiarization with the Problem Domain. The first activity in the knowledge acquisition phase was to become familiar with the problem domain. According to Pigford and Baur ,

> It is often difficult for an expert to express thoughts pertinent to [the] subject domain. Because the expert has a deep knowledge about the subject, as he or she talks, assumptions are made about the qualifications of the listener. If the listener is unprepared for the subject, what the expert says is likely to be meaningless, causing frustration during the communication process and possibly resulting in a waste of time as each tries to understand the other. (22:98)

Familiarization with the ARARs problem domain involved the review of many different sources of information. Published sources of information included USEPA guidance documents as well as Federal statutes and regulations. Electronic sources of information included the USEPA's RODS data base, and ENFLEX a CD-ROM data base of environmental laws.

Attaining an understanding of the ARARs selection process began with a thorough review of the USEPA's CERCLA Compliance With Other Laws Manual. This two volume manual explains the process that must be followed to select ARARs for a CERCLA cleanup. The CERCLA Compliance With Other Laws Manual also reviews major Federal environmental regulations, and explains circumstances where these regulations are ARARs for a cleanup.

Familiarization with the problem domain also included a review of the Compendium of CERCLA ARARs Fact Sheets and Directives. These documents update and expand the information originally contained in the CERCLA Compliance With Other Laws Manual.

Portions of the Code of Federal Regulations (CFR) dealing with environmental regulations were also reviewed. These documents provided the specific details for requirements that are included in the knowledge base as either applicable requirements or relevant and appropriate requirements.

Another document reviewed during the familiarization process was the NCP which outlines and describes the policies and procedures that must be followed when a hazardous waste site cleanup is performed under CERCLA. Information contained in the Preamble to the Final Rule of the NCP was extremely useful in explaining the background as well as the USEPA's position regarding several ARAR issues.

ENFLEX, a CD-ROM database of Federal environmental laws and regulations, was keyword searched to find areas where regulations could be considered applicable or relevant and appropriate. For example, the CERCLA Compliance With Other Laws Manual when discussing National Emissions Standards for Hazardous Air Pollutants (NESHAPs), says that

> NESHAPs are not generally applicable to Superfund remedial activities because CERCLA sites do not usually contain one of the specific source categories regulated. Moreover, NESHAPs as a whole are generally not relevant and appropriate because the standards of control are intended for the specific type of source regulated and not all sources of that pollutant. . . . However, part of a NESHAP may be relevant and appropriate to a CERCLA site. (35:2-9)

In determining if a portion of a NESHAP is relevant and appropriate, a keyword search was performed in ENFLEX using NESHAPs and air stripping. NESHAP was chosen as a keyword because it was the program in question. Air Stripping became a keyword because it was the treatment technology employed in the domain. ENFLEX found two records as a result of the keyword search. Questions concerning these records were posed to an expert to determine if they were relevant and appropriate ARARs, and the expert verified that they were in fact relevant and appropriate requirements.

Another electronic source of information used during familiarization was the Superfund Record of Decision System (RODS). RODS is a full-text database of all RODs signed for CERCLA cleanup sites, and currently contains RODs signed through Fiscal Year 1990. A keyword search of RODS was performed to attain the ARARs for all RODs that involved contaminated groundwater, employing a pump and treat cleanup strategy, and using air stripping as the cleanup technology. Figure 6 displays the results of this query.

Based on the results of the query, it became evident that the problem technology chosen for ARARs selection was among the most used cleanup methods for CERCLA cleanup. Reports were generated of the abstract and ARARs portions of RODs for records identified for the query. These reports provided infor-

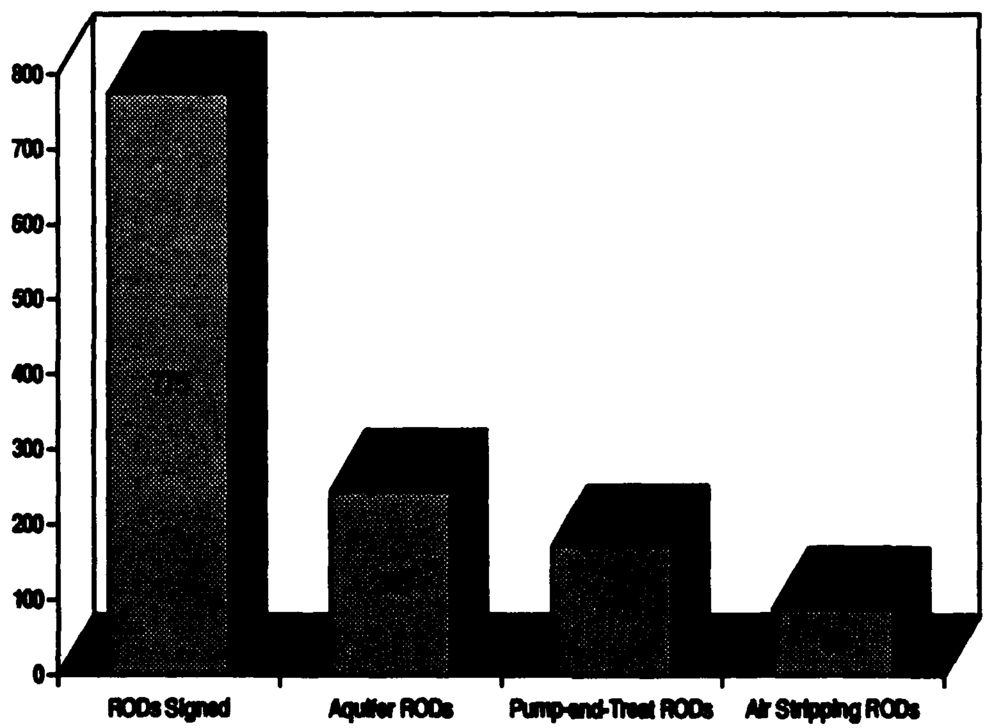

Figure 6: RODS Query of Problem Domain (40)

mation on the type of ARARs previously identified for the problem domain.

Expert Selection. The next activity in the knowledge acquisition phase was to select experts familiar with the problem domain. An expert is "an individual who is widely recognized as being able to solve a particular type of problem that most other people cannot solve nearly as effectively or efficiently." (9:31) Expertise in the problem domain was solicited from: MAJCOM environmental lawyers, current and former USEPA RPMs, and base-level environmental management program managers. Table 1 lists the experts who were interviewed as part of the research.

Expertise in environmental law was solicited from Mr. Tom Rudolph and Major Laurence Soybel of Air Force Materiel Command's Environmental Law Division (AFMC/JAV). Mr. Rudolph specializes in RCRA and CERCLA matters, and provided the expertise on the overall ARARs process, RCRA ARARs, Toxic Substance Control Act (TSCA) ARARs, and Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) ARARs. Major Soybel specializes in natural resources laws and regulation, and provided expertise on ARARs for the Endangered Species Act and Fish and Wildlife Coordination Act, as well as Water ARARs. Acquiring expert knowledge from environmental lawyers was critical to understanding the jurisdictional basis upon which the environmental laws were created. The environmental lawyers were able to show us when environmental laws were considered applicable requirements or relevant and appropriate requirements, and explain the reasoning behind each determination.

Expertise was also solicited from former and current USEPA RPMs. Dr. Will Rowe and Mr. Tim Underwood of the MITRE Corporation, are former USEPA RPMs. Dr. Rowe helped with understanding some difficult RCRA ARARs issues, and provided some excellent examples of where these issues are

Table 1: Experts Interviewed During Knowledge Aquisition Phase

Area	Expert	Position	Qualifications
ARARs Process	Mr. Tom Rudolph	Environmental Counsel -- HQ AFMC/JAV	CERCLA Law Specialist
RCRA	Mr. Tom Rudolph	Environmental Counsel -- HQ AFMC/JAV	RCRA Law Specialist
	Dr Will Rowe	Consultant -- The MITRE Corporation	Former USEPA Superfund RPM
Water	Maj Laurence Soybel	Environmental Counsel -- HQ AFMC/JAV	Holds LLM Degree in Environmental Law
	Mr Tim Underwood	Consultant -- The MITRE Corporation	Consultant -- The MITRE Corporation
	Mr. Turpin Ballard	USEPA Region V Superfund RPM	USEPA RPM
	Mrs Sandy Henry	Water Program Mgr -- 2750 ABW/EM	Resp for Compliance w/water laws at WPAFB
Air	Mr Ed Hess	Air Program Manager -- 2750 ABW/EM	Resp for Comp w/air laws at WPAFB
Resource Protection	Maj Laurence Soybel	Environmental Counsel -- HQ AFMC/JAV	Endangered Species Act Specialist
	Dr Jan Ferguson	Cultural Resources Pgm Mgr -- 2750 ABW/EM	Manages historic preservation program at WPAFB
Toxics and Pesticides	Mr. Tom Rudolph	Environmental Counsel -- HQ AFMC/JAV	Hazardous Waste Law Specialist.

applied. Mr. Underwood provided some practical expertise on Clean Water Act and Safe Drinking Water Act ARARs. Mr. Turpin Ballard, an RPM with USEPA Region V, the USEPA RPM responsible for CERCLA cleanup activities at Wright-Patterson AFB, provided additional expertise on ARARs affecting clean-ups employing an air stripping technology for aquifer restoration. The knowledge solicited from these former or current RPMs, provided an excellent insight into the practical application of the ARARs selection process in the field.

Another excellent source of expertise on environmental regulations were program managers working in the Resource Protection Branch of the Wright-Patterson AFB Environmental Management Office (2750 ABW/EME). Mr. Ed Hess, the Air Program Manager provided expertise for Clean Air Act ARARs in the problem domain. Dr. Jan Ferguson, the Historic Preservation Program Manager, provided expertise on ARARs from the National Historic Preservation Act and National Historic Landmarks Act. Mrs. Sandy Henry, provided expertise on the Clean Water Act's Section 404 permitting process. These program managers are responsible for managing basewide environmental programs for specific media, including applying for environmental permits, and working with regulators on compliance issues. The expertise they provided was invaluable in providing specific knowledge on determining if potential ARARs were applicable or relevant and appropriate.

<u>The Interview Process.</u> The final activity in the knowledge acquisition process was to interview the experts. According to Hayes-Roth, Waterman and Lenat

> Domain experts act as informants who tell the knowledge engineers about their knowledge or expertise. The domain expert does so without necessarily having a carefully conceived teaching strategy in mind. Nor does the domain expert reformulate the previous statements spontaneously. The knowledge engineer is an "acquirer" who restates what has been understood of the problem and confirm it using test cases and other experts. (10:141)

The interview activity involved several tasks including developing questions, preparing the interview environment, scheduling and finally carrying out the interviews.

Questions used during the interviews evolved out of the familiarization activity. Potential questions were identified based on the data analysis plan described in Chapter III. Algorithmic knowledge on the ARARs process was identified through EPA documents. While some heuristic knowledge was gleaned from the familiarization activity, most of the heuristic knowledge employed could only be acquired from domain experts. Questions posed to the experts focused on two major areas of heuristic knowledge. First, based on the CERCLA Compliance With Other Laws Manuals, questions were developed to clarify the process used in determining when and how particular portions of environmental legislation are applicable or relevant and appropriate to the problem domain. Second, based on previously signed RODs, the CERCLA Compliance With Other Laws Manuals, and the Compendium of CERCLA ARARs Fact Sheets and Directives, questions were formulated to determine when and how a specific regulatory citation is applicable or relevant and appropriate.

Successful interviews depended on creating the right environment. Interviews were carried out in the domain experts' work areas whenever practical. The domain experts' work areas contained reference materials needed to make many of the determinations required from questions posed to them. Notes and audio taping were used during the interviews to document data acquisition, and maximize the benefit of time spent with the experts. The notes documented the general direction the interviews were taking. Audio tapes were referred back to when items were missed or unclear in the notes. Finally, care was taken not to overwhelm the experts or monopolize their time. Interview sessions lasted between two and three hours.

Interview sessions were scheduled based on the media where the knowledge was to be acquired from. The first interview session dealt with the ARARs selection process, and dealt with the problem domain in very general terms. Next, an interview session was held to determine how ARARs are selected for the Resource Conservation and Recovery Act (RCRA). An interview session was also held on water ARARs. Water ARARs focused on the Clean Water Act, Safe Drinking Water Act, and Ground Water Protection Policies. Another session was held on resource protection ARARs and ARARs for toxics and pesticides. Resource protection ARARs focused on National Historic Preservation Act, Archeological and Historic Preservation Act, Endangered Species Act, Wildlife and Scenic Rivers Act, Fish and Wildlife Coordination Act, Coastal Zone Management Act, and the Wilderness Act. Toxics and Pesticides ARARs focused on the Toxic Substances Control Act and the Federal Insecticide, Fungicide, and Rodenticide Act. Finally, an interview session was held on Air ARARs focusing on the Clean Air Act.

Knowledge Representation. The next phase in the development of the heuristic knowledge base was knowledge representation. Knowledge representation "deals with the structures used to represent the knowledge provided by the domain expert or experts." (8:75) The method used to represent knowledge acquired in the problem domain was concept mapping. However portions of the concept maps were represented using Object-Attribute-Value (O-A-V) techniques.

Concept mapping was the method chosen for the knowledge representation phase in the development of the heuristic knowledge base. Concept maps, also known as semantic networks, are

> intended to represent meaningful relationships between concepts in the form of propositions. Propositions are two or more concept labels linked by words in a semantic unit. In its simplest form, a concept map would be just two concepts connected by a linking word to form a proposition. (20:15)

The knowledge representation scheme used for this research problem domain used linking actions or statements rather than words.

Knowledge representation using concept maps has three major advantages that made it desirable for the knowledge domain. First, concept maps are very flexible (9:36). As knowledge is acquired and represented, new propositions can either be added or existing propositions revised simply by "rewiring" the existing map. Second, subordinate branches on the map inherit the properties of the branches preceding them on the map (9:36). The inheritance feature of concept mapping is easily applied to object-oriented expert system shells like KAPPA-PC, which pass inherited traits along their tree structure. Finally, because concept maps provide an organized, graphical representation of concepts in the problem domain

> They allow teachers and learners to exchange views on why a particular propositional linkage is good or valid, or to recognize missing linkages between concepts that suggest a need for new learning. . . . Misconceptions are usually signalled by a linkage between two concepts that leads to a clearly false proposition or by a linkage that misses the key idea relating two or more concepts. (20:19-20)

Concept mapping in the problem domain was an iterative process. The initial structure of the concept map was developed based on information attained during the familiarization phase with the problem domain. Nodes on the map that appeared to be unclear, were investigated through interviews with the experts for clarification. The experts were also able to provide information on branches that could be deleted. After the interviews, revisions were made to the maps and other problem areas were identified. This iterative process continued until knowledge in the problem domain was clearly represented.

An example of the concept maps generated is shown in figure 7. This map represents the air ARARs generated based on the problem domain. As demonstrated in this figure, much of the information is contained in a compact format, yet it readily shows the logical flow of knowledge in the domain. This method of knowledge representation allows users to sort easily through information and arrive at data germane to particular circumstances or concerns at a given CERCLA site. Concept maps can grow very large in a short period of time, yet still be easy to work with. Concept maps developed as part of this research to represent knowledge in the problem domain are contained in appendix B.

Object-Attribute-Value (O-A-V) triplets were also used for the knowledge representation phase in the development of the heuristic knowledge base. According to Harmon and King

> In this scheme, objects may be physical entities . . ., or they may be conceptual entities . . . Attributes are general characteristics or properties associated with objects. . . . The final member of the triplet is the value of an attribute. The value specifies the specific nature of an attribute in a particular situation. (9:38)

O-A-V triplets are easily applied to an object-oriented expert system shell.

An example of O-A-V triplets is shown in figure 8, and is part of the air ARARs concept map shown in figure 7. Attributes noted in the branch are inherited by the lower portions of the branch. In figure 8, the value of the citations are true only if you have both "hazardous air pollutants" and "vinyl chloride and TCE." Other citatations in figure 8 only become active if "hazardous air pollut-

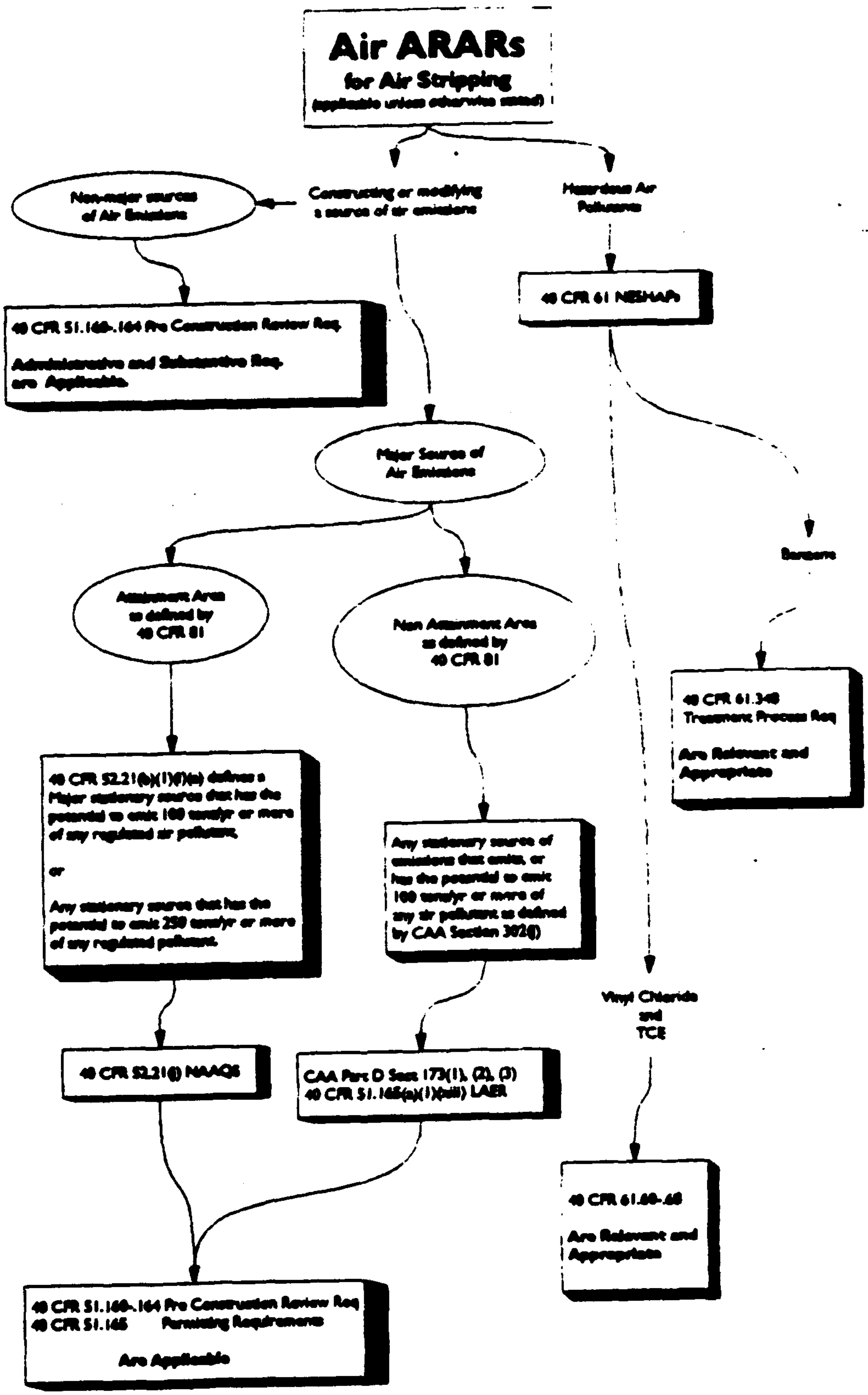

Figure 7: Sample Concept Map, Portraying Air ARARs in the Problem Domain

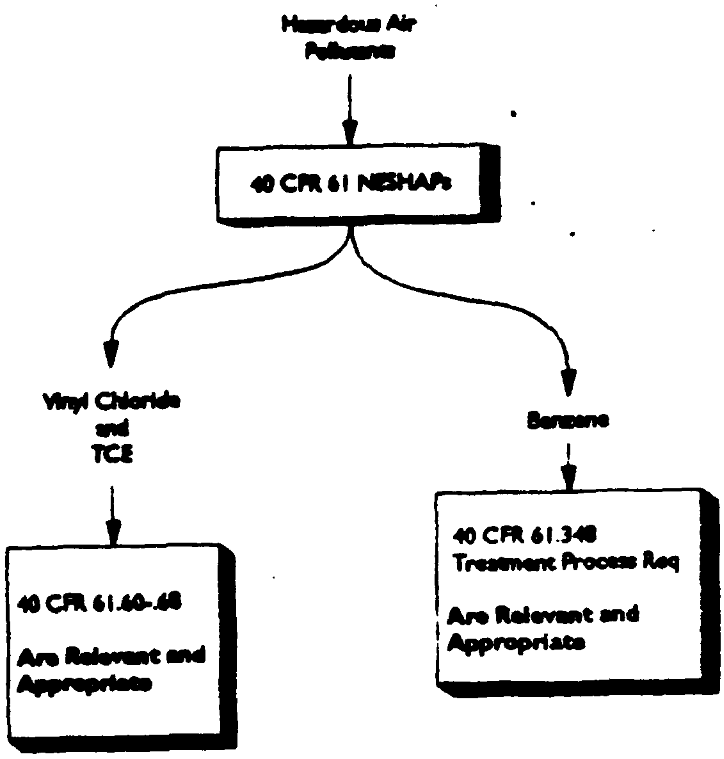

Figure 8: Example of O-A-V Triplet from Problem Domain

ants" and "benzene." Because of the inheritance feature of O-A-V triplets, both the attribute on the lower part of the branch and the one on the upper branch must be included in the "If" portion of the "If-Then" control structure for rules, not just the attributes of the last branch.

Proof-Of-Concept Prototype Expert System Development

A byproduct of the research was a proof-of-concept prototype expert system. As discussed in chapter II, expert systems contain three major components: the knowledge base, the inference engine, and the user interface.

The proof-of-concept prototype expert system uses KAPPA-PC, an object-oriented expert system shell developed by Intellicorp for the knowledge base and inference engine. Because KAPPA-PC is object oriented and contained a powerful rule base, knowledge represented on the concept maps was easily translated to an electronic format. Data is inherited down KAPPA-PC's object tree as queries progress in the user interface.

The system's user interface was developed using Assymetrix Toolbook, version 1.53. Toolbook is very prevalent as a user interface for several Microsoft Windows 3.X applications including Excel, Word for Windows and KAPPA-PC. Dynamic Data Exchange (DDE), a feature of Windows 3.X allows Toolbook to communicate with other Windows applications. Commands executed in Toolbook are programmed using a computer language known as Openscript. Openscript is very similar to the macro languages used by many of the popular spreadsheet applications, and contains a limited "If-Then" control structure that allows a preliminary screening and control of query selections, before sending a block of data to KAPPA-PC.

The proof-of-concept prototype expert system development phase involved two major activities: development of the user interface and the computerized knowledge base.

User Interface Development. Development of the user interface began with a review of the concept maps to determine what information was required to create the rules required for the problem domain. The user interface was used to pass user queried data to the knowledge base in KAPPA-PC, where it interacted with the rules.

The user interface as it existed in PAST had to be reviewed to determine what information was transferred to PAST's knowledge base that relates to the problem domain. Next, an assessment was made concerning what additional information needed to be transferred for the problem domain.

Based on the assessment of information needs, additional queries were developed in Toolbook. First, the PAST user interface was examined to decide where information needed to be added to the existing system. For example, additional requirements were identified for location ARARs, including information dealing with a site within the 100 year flood plain. Figure 9 shows the location-specific characteristics screen at it existed in PAST. Figure 10 shows how a button was added for the 100 year flood plain to the location-specific characteristics screen. Next, new screens were designed and implemented for information that was completely new and not closely related to anything previously done in PAST. For instance, figure 11 shows a screen that was developed for the user to identify characteristics of the liquid effluents.

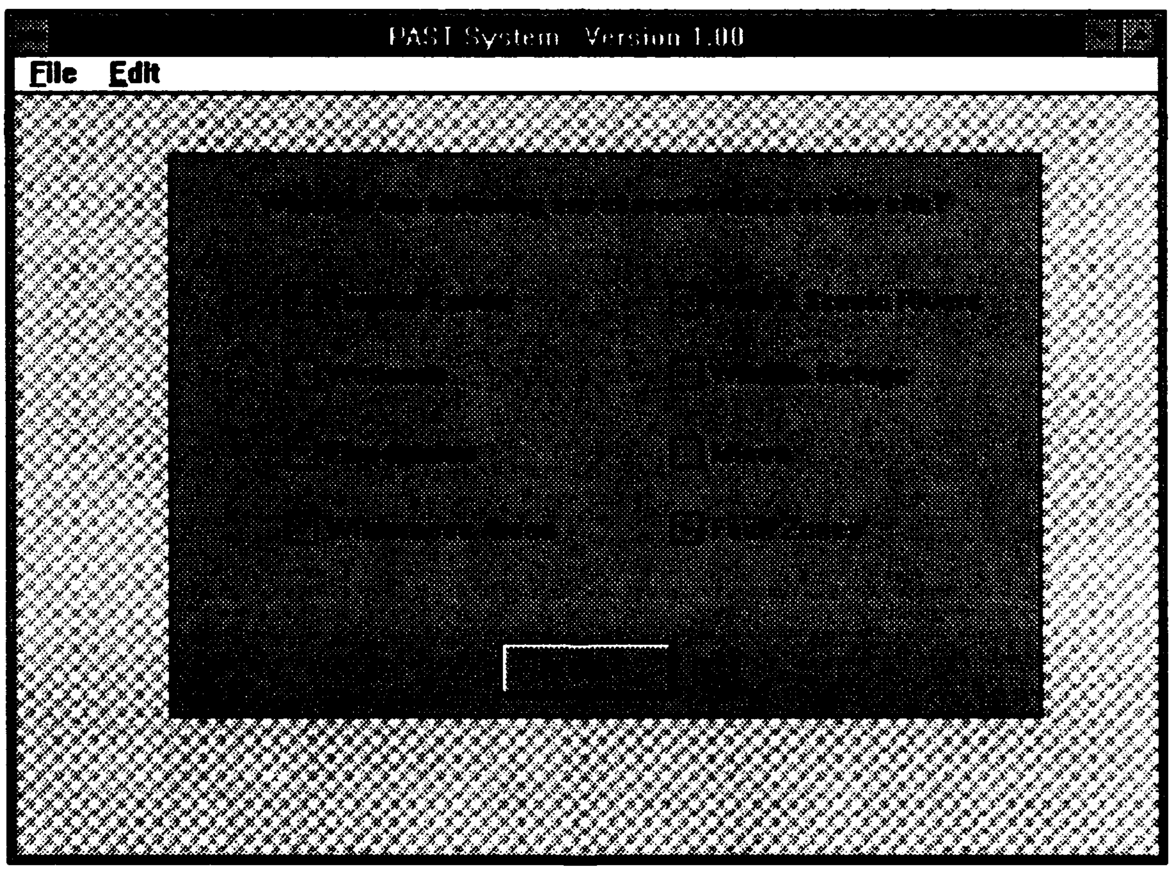

Figure 9: Location-Specific Criteria in PAST

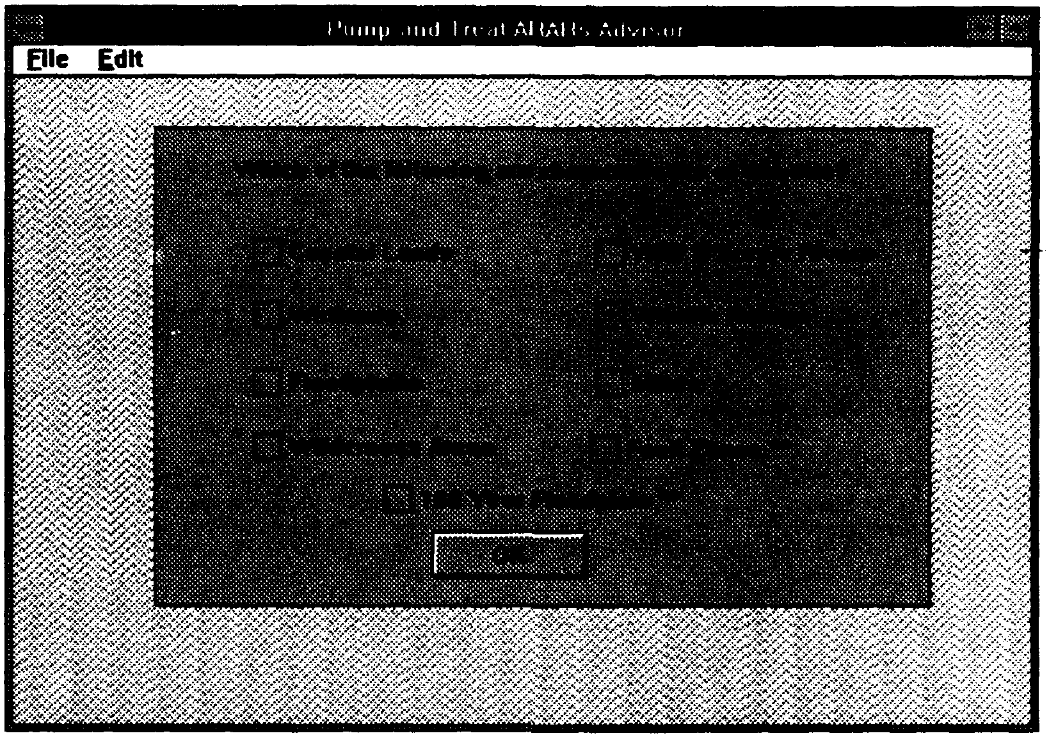

Figure 10: Location-Specific Criteria in Pump-And-Treat ARARs Advisor

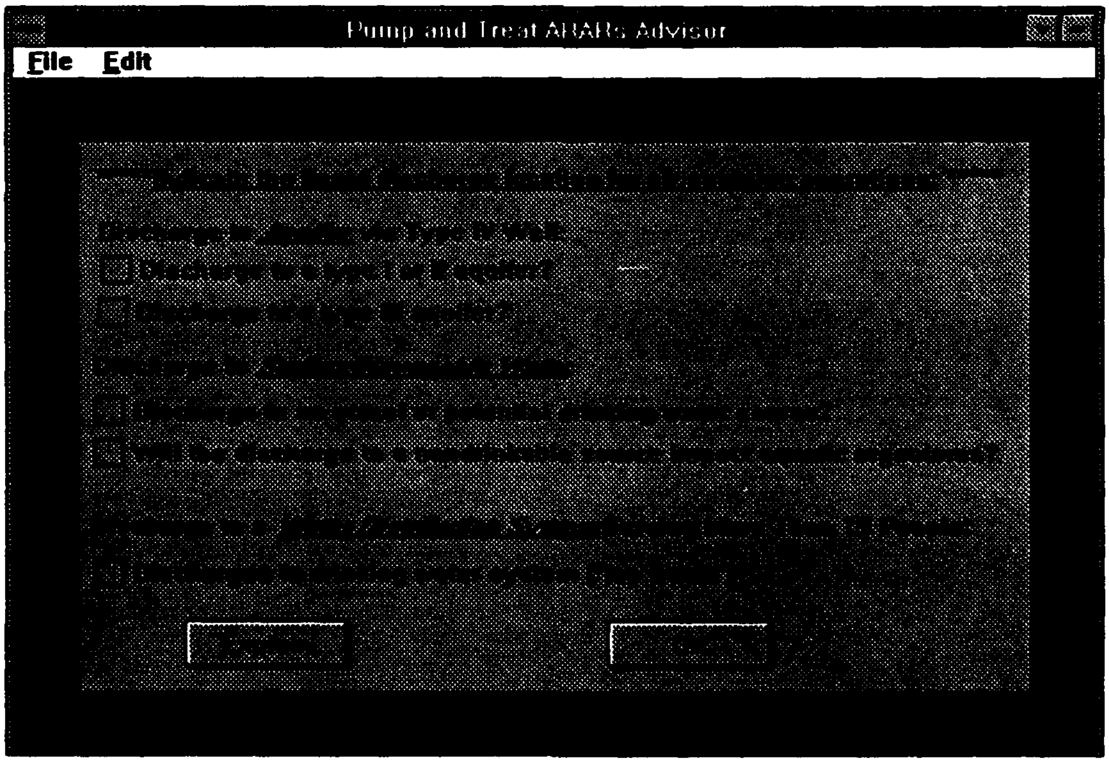

Figure 11: Screen Showing Characteristics of Liquid Effluent.

Knowledge Base Development. Knowledge base development began with an analysis of the concept map to determine what information is needed to decide if a requirement is applicable or relevant and appropriate. Based on this analysis a preliminary "If-Then" control structure was developed for potential rules. This control structure was developed in plain english rather than KAL, which is the computer language used by KAPPA-PC.

The next activity was to review PAST's KAL rules from an english language viewpoint and compare them to the rules generated by the concept map. First, a systematic search of PAST's knowledge base was undertaken to determine if rules existed that match the control structure developed in plain english. If a match is found, the rule was deemed to be satisfactory, and the search returned to the concept map to look at another leaf.

Next, a search was undertaken to determine where the "If" portion of PAST's KAL "If-Then" control structure matches the concept map rules, however the "Then" portion required additions or deletions of citations. If a match was found, additions or deletions were made to PAST's KAL rule and the search returned to another leaf of the concept map.

A search was also undertaken to determine if portions of a KAL rule met most of the "If" portion of the english language control structure, as well as the "Then" portion of the KAL control structure where additions or deletions needed to be made. Again, when a match was found, additions were made to the "If" portion of the rules and changes were made to the "Then" portion as required, and the search returned to another leaf of the concept map.

Finally, when no or minimal similarities existed between PAST's KAL rules and the english language control structure, rules were constructed from scratch. The search then returned to another leaf of the concept map. This methodology reduced the possibility of developing conflicting rules, since the project involved additions to an existing knowledge base.

The final activity involved creating new objects on the object-oriented tree structure. First, missing citations were added to the federal regulations portion of the tree, along with the pertinent attributes concerning this object. Pertinent attributes included the title of the citation, as well as the name of the environmental statute. For example, the following information was added concerning a Clean Air Act ARAR:

OBJECT	=	CFR_40_52:Act
ATTRIBUTES	=	CFR_40_52:ACT CFR_40_52:PART
VALUES	=	Clean Air Act Air Programs-Approval and Promulga tion of Implementation Plans

Objects were also amended or created to contain additional information identified by the user interface relative to site characteristics and liquid effluent discharges. The format used for objects and their attributes was:

OBJECT_NAME:SLOT_NAME

Where the OBJECT_NAME represents the "object," and the SLOT_NAME represents the "attribute." Examples of site characteristic "object-attributes" included:

SITE_CHARACTERISTICS:ONsite_treatment
SITE_CHARACTERISTICS:ONsite_discharge

The SITE_CHARACTERISTICS object already existed, the ONsite_treatement, and ONsite_discharge slots were added so an "on-site" determination can be made for determining if a requirement is "applicable" or "relevant and appropriate." The slots can possess a logical true or false value. If an ONSite slot is false then the attribute proves to be off-site, and the requirement can only be "applicable," rather than either "applicable" or "relevant and appropiate." An example of a new object added to the system was the Liquid_Discharge object:

Liquid_Discharge:potable_water_supply
Liquid_Discharge:drinkable_surface_water
Liquid_Discharge:impacts_aquatic
Liquid_Discharge:Aquifer_class_III
Liquid_Discharge:Aquifer_class_I_and_II

A "true" value for any of the slots of the Liquid_Discharge object make that attribute germane to the characteristics found at the site. Finally, branches were added to the tree for relevant and appropriate requirement citations germane to the site domain, as determined by the system's rules. Figure 12 is a schematic diagram showing how this research amended the tree stucture existing in PAST

Table 2 summarizes the changes this research has made to PAST's knowledge base. The ammended knowledge base is contained in the unsubmitted second volume of this research (24). The knowledge base consists of classes, rules, functions, and methods. Classes are objects used to represent information contained within the problem domain (11:1-2). These classes included location, chemical and action-specific characteristics of a cleanup and the specific regulatory citations for potential ARARs. The rules are used to "represent if-then reasoning, which may or may not relate to individual objects." (11:2-7) Functions are used to control the actions of the knowledge base. Methods "specify how an object behaves." (11:2-12)

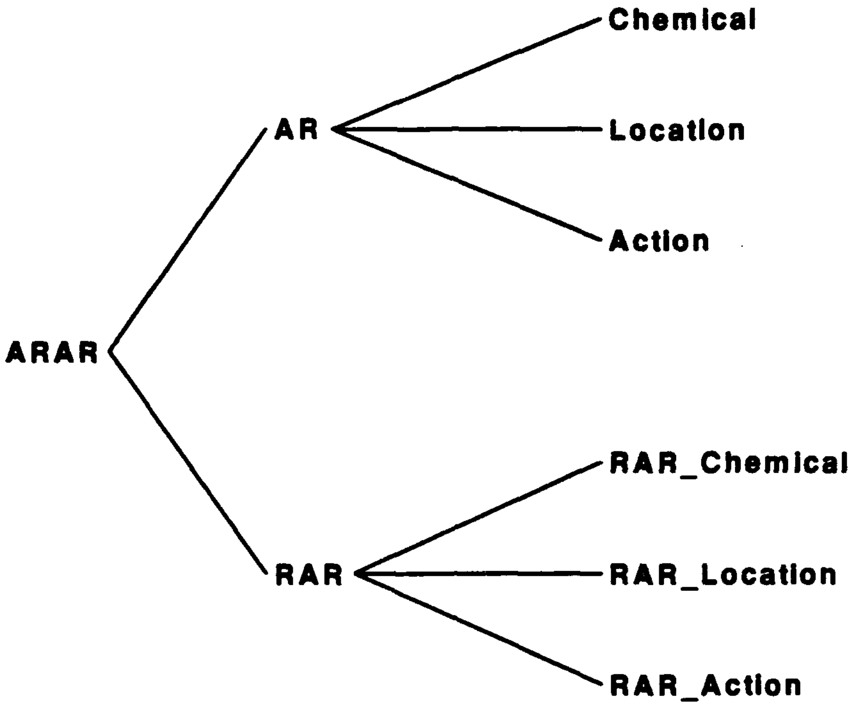

Figure 12: Knowledge Base Tree-Structure As Amended By This Research

Table 2: Summary of Changes Made to the Existing Knowledge Base

	Original Knowledge Base	Added	Modified	Deleted	New Knowledge Base
Classes	533	70	-	-	603
Rules	143	26	8	4	165
Functions	19	1	3	-	20
Methods	50	-	3	-	50

Knowledge Base Verification and Validation

Verification and validation was the final phase in the iterative process of refining the knowledge acquisition process and represented in the heuristic knowledge base development. This phase verified the accuracy of information, and validated the inferences needed to activate the rules represented by the branch.

Verification is "the process of ensuring the accuracy of the acquired knowledge that gives credibility to the expert system for its knowledge." (22:101) The concept maps were verified during knowledge base development to ensure the consistency of the branches. In particular, the concept map branches were verified to eliminate redundancy or conflicts, as well as subsumed or circular relationships (19:70-2). The verification process also involved checking the concept maps for completeness (19:72-3).

Validation checks "the accuracy of inference chains that may be used on the knowledge base." (22:101) The concept maps were validated through consultations with experts. Experts used during this phase included Mr.Tim Underwood of the MITRE Corporation, a former USEPA RPM; and Lt Col Bernard Schafer of the HQ USAF Environmental Law and Litigation Division (AFLSA/JACE), an environmental lawyer. The concept maps were evaluated to determine if inference strategies and ARARs selected for the problem domain met the experts' expectations.

As part of the validation and verification phase, the experts were given the most recent version of the concept maps. The experts reviewed the individual leafs of the concept maps and analyzed them for misrepresented knowledge and omissions. Comments made by the experts were recorded, the concept maps were corrected, and new maps were produced for the next iteration of verification and validation by the next expert.

The proof-of-concept prototype expert system was also demonstrated for the experts, in order to solicit feedback concerning the computerized representation of the knowledge base. Lt Col Schafer had two questions concerning the proof-of-concept prototype expert system:

- How easy is it to update the knowledge base?
- Who will do these updates?

The computerized knowledge base should be updated based on changes made to the concept maps. Updating the concept maps is a fundamental first activity in the update process. Concept maps allow the knowledge engineer to easily identify and begin developing new rules. Performing this activity may be time consuming, since it requires the knowledge engineer to perform additional knowledge acquisition and representation. The next activity is to computerize the changes made to the concept maps. Updating changes to existing rules can be done relatively easily. Developing new rules can become more complex, especially if more information needs to be queried through the user interface.

The updates to the knowledge base should be accomplished by the USEPA. The USEPA is responsible for promulgating regulations which support environmental protection legislation. Because of their intimate knowledge of the regulations and with PAST, the USEPA's Risk Reduction Engineering Laboratory would be most qualified to make the changes to the knowledge base.

The proof-of-concept prototype expert system was validated using RODs for actual cleanups. As stated earlier, a keyword search of the RODS database yielded 89 RODs that used a pump-and-treat strategy and air stripping technology for their cleanups. From RODS, reports were generated which contained the abstracts and ARARs portions of these 89 RODs. These reports were then screened to find RODs that contained enough information to consult the proof-of-concept expert system. Factors that were required for a successful consultation included specific details on the cleanup location, identification of contaminants, a detailed description of the cleanup approach, and a detailed listing of the ARARs identified for the ROD. Four RODs where selected for use in validating the proof-of-concept prototype expert system. Table 3 summarizes the information used during the consultation.

The proof-of-concept prototype expert system successfully identified all of the ARARs for three of the four consultations. On the fourth consultation for the Lone Pine

Table 3: Summary of RODs Used for Validation

	Trial Number 1	Trial Number 2	Trial Number 3	Trial Number 4
Site Name	FAA Technical Ctr	Croyden TCE Spill	Kearsarge Metallurgical Corp.	Lone Pine Land Fill
Location	Pamona, NJ	Bristol Township, PA	Conway, NH	Freehold, NJ
ROD Date	900928	900629	900928	900928
NTIS Report No.	EPA/ROD/R02-90/1	EPA/ROD/R03-90/0	EPA/ROD/R01-90/0	EPA/ROD/R02-90/1
Location Characteristics	None	Floodplain, Fish and Wildlife.	100 Year Floodplain, Wetlands, Fish and Wildlife	Wetlands, Floodplain, Fish and Wildlife, Historic Place.
Primary Contaminants of Concern	Toluene, PCBs, Chromium	TCE, 1,1-DCE	TCE, Chromium	Benzene, PCE, TCE, Phenols, Toluene, Xylene, Arsenic, Lead and Chromium.
Remedial Action Selected	Pump-and-Treat w/ Air Stripping & Emission Controls; and reinjection to aquifer.	Pump-and-Treat w/Air Stripping and Carbon Adsorption, on-site discharge to surface water. Vapor Phase Carbon Adsorption Treatment of Air Stripper Exhaust.	Pump-and-Treat with Metal Precipitation, Air Stripping (for VOCs) and Carbon Column Treatment (to control air emission from Air Stripper). Discharge to a POTW.	Pump-and-Treat with Air Stripping, Metal Filtration/Precipitation & Carbon Adsorption. Reinjection of Treated Ground Water back into Aquifer.

Landfill, the proof-of-concept prototype expert system, did not identify ARARs for 40 CFR 50, National Ambient Air Quality Standards, and 49 USC 1801 - 1813, Hazardous Materials Transportation Act. These two citations where not represented as classes in the knowledge base.

Three other observations can be made from the consultation using actual RODs. First, as expected, state requirements preempted Federal requirements in many instances. Second, the proof-of-concept prototype expert system appeared to identify additional ARARs not included in the RODs. These ARARs may have been negotiated out of the ROD by the parties to the ROD, or they may have been overlooked by the developers of the ROD. Finally, the proof-of-concept prototype expert system was more specific than the RODs in listing ARARs for the cleanup. Where a ROD may have only listed the Clean Water Act as an ARAR, the proof-of-concept prototype expert system specifically lists the specific subsection of the regulation, and identifies it as applicable or relevant and appropriate. Table 4 shows a comparison of the results of Federal ARAR selection contained in the Croyden TCE spill ROD, and the query of the prototype expert system. Two interesting observations can be made concerning these results. First, the ROD indicated that vinyl chloride NESHAPs were applicable. First, the CERCLA Compliance With Other Laws Manual indicates that NESHAPs regulate specific source categories. Air stripping used as a CERCLA remediation technology, is not included as a specific source category regulated by NESHAPs. However, stripping performed at a manufacturing plant is a specific source category regulated by NESHAPs, and a Superfund Cleanup using Air Stripping could be considered sufficiently similar. Therefore, NESHAPs for vinyl chloride is considered relevant and appropriate, instead of applicable (35:2-9). Second, the ROD indicated that MCLs, are applicable ARARs for liquid effluent discharged to surface waters. However, during the knowledge acquisition portion of this research, the experts indicated NPDES Pretreatment Standards are the

Table 4: Comparison of Federal ARARs Selection for Actual ROD and Prototype Expert System

ARAR Type	ARAR Citations Contained in the ROD	ARAR Citatations Identified by the Proof-of-Concept Prototype Expert System
Location-Specfic ARARs	40 CFR 6.302 Fish and Wildlife Coordination Act -- Floodplain and Fish and Wildlife Protection	40 CFR 6.302 Fish and Wildlife Coordination Act -- Floodplain and Fish and Wildlife Protection 40 CFR 6.302(A) Fish and Wildlife Coordination Act -- Procedures for Floodplain Mgt and Wetlands Prot. 40 CFR 264 RCRA- Facility Stds for Owners and Operators of TS&D Facilities.
Chemical-Specfic ARARs	40 CFR 141.61 Safe Drinking Water Act - Maximum Contaminant Levels (Applicable) 40 CFR 61(F) Clean Air Act -- NESHAPs for Vinyl Chloride (Applicable)	40 CFR 61(F) Clean Air Act -- NESHAPs for Vinyl Chloride (Relevant and Appropriate) 40 CFR 761.40,.45 TSCA- Marking of PCBs (Applicable) 40 CFR 264.175(I) RCRA- Use and Mgt of Containers 40 CFR 264.317 RCRA- Special Req for Haz Wastes F20, F21, F23, F26, and F28 40 CFR 264.343(O) RCRA- Incinerator Performance Stds. 40 CFR 265,266,268.42,269.42(A) RCRA- Treatment Standards
Action-Specific ARARs	40 CFR 122.44 Clean Water Act - NPDES Ambient Water Quality Stds. 40 CFR 122.44(A) Clean Water Act - NPDES Effluent Limits 40 CFR 125.100,.104,122.41(I), 136.1-.4 Clean Water Act- Effluent Discharge Monitoring Requirements.	40 CFR 122.44 Clean Water Act - NPDES Ambient Water Quality Stds. 40 CFR 122.44(A) Clean Water Act - NPDES Effluent Limits 40 CFR 125.100,.104,122.41(I), 136.1-.4 Clean Water Act- Effluent Discharge Monitoring Requirements. 40 CFR 51.160-164 Clean Air Act- Preconstruction Review Requirements. 40 CFR 264(E) RCRA- Manifest System 40 CFR 264(G) RCRA- Closure and Post-Closure Requirements 40 CFR 264(H) RCRA- Financial Requirements 40 CFR 264.1030 RCRA- Air Emission Standards for Process Vents 40 CFR 268 RCRA- Land Disposal Restrictions

applicable cleanup standard for liquid effluent discharges to surface waters. Furthermore, MCLs are only applicable ARARs when the liquid effluent is discharged to a potable water distribution system. MCLs are relevant and appropriate ARARs in other circumstances.

Evaluation of Study Objectives

The research objectives accomplished by this study were:

1. Ascertain the effect ARARs have on the execution of the environmental restoration process. This objective was accomplished during the literature review documented in Chapter II. The results of this literature review showed that ARARs are used as a method for establishing cleanup threshold limits under CERCLA. Compliance with ARARs is one of nine criteria used during the detailed analysis of alternatives that must be performed as part of the RI/FS. Statutory requirements mandate that all feasible alternatives must comply with ARARs. Therefore, compliance with ARARs is a "go/no go" criteria during alternative screening.

2. Identify applicable requirements and relevant and appropriate requirements that impact effluent discharges from pump and treat aquifer restoration strategies, focusing principally on air stripping technologies. The process followed in achieving this objective is documented earlier in this chapter. Successful knowledge acquisition of the expertise required to identify ARARs required a multidisciplinary approach incorporating the knowledge of experts in remediation project management, environmental engineering, science and law. The research expanded PAST's knowledge base in the areas of ARARs for liquid effluent discharges and relevant and appropriate requirements for air stripping technologies.

3. Determine the status of knowledge acquisition and representation methods currently available for the development of knowledge-based expert systems. The results of the investigation required to accomplish this objective are documented in the review of literature contained in Chapter II. Results of the investigation suggests that a combination of familiarization with relevant literature in the problem domain and nonscheduled structured interviews with problem domain experts is the most appropriate method of knowledge acquisition. The results of the investigation also showed that knowledge representation using a combination of concept maps and O-A-V triplets would reduce problems associated with the "profound difference between the machinery of the brain, as compared to existing computers"(25:28).

4. Develop a heuristic knowledge base to help RPMs with the identification of ARARs for pump and treat aquifer restoration methodologies. The methodologies used in accomplishing this objective are documented in the knowledge representation portion of this chapter. Concept mapping was used for the development and representation of the heuristic knowledge base for the problem domain. Concept mapping proved to be an effective intermediate method of transferring human expertise to a computerized format. Contained within the concept maps were O-A-V triplets, another method of knowledge representation. With O-A-V triplets, attribute values are inherited down the branch in a manner similar to knowledge representation on an object oriented expert system shell.

5. Verify and validate that the KBES developed during this research is an appropriate problem solving tool for the specific problem domain addressed in this study. The verification and validation process used for this research was documented earlier in this Chapter. Knowledge acquired and represented in the heuristic knowledge base was verified by experts in the problem domain. Experts in the

problem domain were able to determine the accuracy of knowledge representation in the heuristic knowledge base. Validation of the knowledge base was accomplished by comparing the results of queries of the prototype expert system to those selected in the RODs for actual Superfund cleanups. By comparing the results of the prototype expert system to ARARs for actual RODs, the accuracy of the heuristic knowledge base was quantified.

Summary

This chapter presented the process followed in solving the specific problem of the study. The chapter begins with a description of the methods and techniques used in acquiring and representing knowledge in the problem domain. The chapter also presents the process followed in adapting the represented knowledge to a proof-of-concept prototype expert system. Results of the validation and verification process are also presented. An evaluation of the study objectives concludes the chapter.

V. Conclusions and Recommendations

Overview

This chapter provides a summary of the research, reviewing the major tasks performed and recapping the evaluation of the research objectives. Next, general conclusions are inferred from the research, focusing on how the research affects expert system development in the problem domain, and expert system development overall. Finally, recommendations for future research efforts in the problem domain are presented.

Summary of Research

The primary purpose of the research was to develop a heuristic knowledge base for the selection of ARARs for a CERCLA cleanup using air stripping as the cleanup technology. Performing this task required the development of a strategy for knowledge acquisition and representation.

Chapter I provided background information surrounding the research topic, and specifically stated the general issue upon which the research problem was based. The specific research problem was articulated in Chapter I, along with the research objectives that were carried out to resolve the research problem. Finally, Chapter I contained the scope of the research along with limitations placed on it.

A review of literature pertaining to the research problem is presented in Chapter II. The chapter began with an analysis of issues surrounding ARARs, including definitions, scope, selection, and impact on groundwater remediation.

Chapter II also investigated the techniques used for the development of heuristic knowledge bases including knowledge acquisition and knowledge representation methods.

The methodology used to solve the research problem was outlined in Chapter III. A step-by-step explanation of the major tasks, including problem area and domain selection, literature review, knowledge acquisition and representation, proof-of-concept expert system development, and knowledge verification and validation is presented.

Chapter IV documents the results and findings of the research. The process and results of the knowledge acquisition and representation phases are reported, as well as the procedures used to transfer the knowledge to a computerized format. The procedures and outcomes of the knowledge verification and validation phase of the research are also described. Finally, an evaluation of the research study objectives is presented. The evaluation of research objectives found that:

1. ARARs are used as the basis for establishing cleanup threshold limits under CERCLA. Statutory requirements mandate that all feasible alternatives must comply with ARARs. Therefore, compliance with ARARs is a "go/no go" criteria during alternative screening.

2. Successful knowledge acquisition of the expertise required to identify ARARs dictated a multimedia and multidisciplinary approach incorporating knowledge gleaned from written sources with the expertise of professionals in environmental engineering, science and law. This research also expanded the existing knowledge contained in PAST's knowledge base.

3. The combination of familiarization with relevant literature in the problem domain and nonscheduled structured interviews with problem domain experts was the most appropriate method of knowledge acquisition for ARARs selection. The results of the investigation also showed that knowledge representation using concept maps would alleviate many of the problems associated with the representing human expertise in an expert system (24:28).

4. Concept mapping was used for the development and representation of the heuristic knowledge base for the problem domain. Concept mapping proved to be an effective method of transferring human expertise to a computerized format. Concept map attributes are inherited down the branch similar to the knowledge representation on an object oriented expert system shell.

5. The verification and validation process used for this research included consultations with experts and testing of the proof-of-concept expert system. Experts in the problem domain were able to validate the accuracy of knowledge representation in the heuristic knowledge base. Validation of the knowledge base through a comparison of the results of queries of the prototype expert system to those selected in the RODs for actual Superfund cleanups quantified the accuracy of the heuristic knowledge base.

Research Conclusions

A number of conclusions can be drawn from this research study. The most apparent is that given a limited domain, the study demonstrated that knowledge on both applicable requirements and relevant and appropriate requirements can be acquired and represented.

The knowledge acquisition portion of the research study revealed that a multimedia multidisciplinary approach is required for the selection of ARARs. Knowledge acquisition must begin with a familiarization of the official documentation on ARARs. Written information must be combined with a combination of legal, project management, engineering and scientific expertise to understand fully which ARARs are required for a CERCLA cleanup.

During the knowledge acquisition and representation phases, expert system developers must consider the type of expert system shell that will be used. The type of expert system shell will guide the method of knowledge representation. For this research problem, an object-oriented expert system shell was used. Therefore, concept mapping proved to be the appropriate method of knowledge representation, which in-turn directed the knowledge acquisition method. The main objective in knowledge acquisition was acquiring knowledge that could be assembled into a control structure for expert system rules. Other methods of knowledge acquisition and representation may be more appropriate for different expert system shells.

The study also showed that graphical knowledge representation is a useful intermediate step in the computerization of knowledge on an object-oriented expert system shell. Concept mapping, which allows subordinate leafs on a branch to inherit the values of upper leafs in the concept map hierarchy, easily transferred knowledge to object-oriented shells like KAPPA-PC, which have an object-attribute feature.

The research study also demonstrated a methodical approach to acquiring and representing new knowledge for an existing expert system. The systematic method of representing knowledge on concept maps and then examining the existing rule base to see where the new knowledge can be placed proved to be very effective.

The process followed during the knowledge acquisition phase of the research could easily be extended and applied to the manual selection of ARARs for any CERCLA remediation. The ARARs selection process requires an initial familiarization with written documentation concerning potential ARARs for a given set of circumstances. The next step is to query experts on specific elements of environmental legislation, to obtain the heuristic knowledge required to determine if a requirement is applicable or relevant and appropriate.

Preliminary research on the problem suggested that the ARARs selection process must be performed accurately and consistently. ARARs selection is an important portion of the IRP remedial action process, however it is often misunderstood by the practitioners. Capturing ARARs expertise in an expert system can help to alleviate this knowledge gap, while selecting ARARs accurately and consistently. This in-turn will allow RPMs to screen multiple alternative cleanup technologies more efficiently. This may eventually result in more expeditious ROD development and approval.

Finally, expert systems can be a valuable tool for Air Force Environmental Management. The development and use of expert systems allows an organization to free-up its expertise for more challenging projects that cannot be automated, or that require more creative thought. ARARs selection is just one aspect of environmental management, and expert systems could successfully be applied to other areas of the IRP program, as well as environmental compliance, environmental planning or pollution prevention.

Recommendations for Further Research

Much research remains to be accomplished if the ARARs selection process is to become fully automated. There are at least four areas where future research could be performed.

First, research should be focused on increasing the depth of the existing expert system. The proof-of-concept expert system developed as a part of this research is limited to Federal applicable or relevant and appropriate requirements. However, the ARARs selection process requires RPMs to consider state ARARs, To-Be-Considered requirements, and ARAR waivers, before the process is completed. Expertise in these areas needs to be captured and included in the existing system.

Next, research could concentrate on increasing the breadth of the existing proof-of-concept expert system. The existing system selects ARARs for CERCLA remediation of contaminated aquifers using a pump and treat strategy with air stripping as the contaminant removal technology. Future research could focus on acquiring and representing knowledge for additional technologies.

An interface could also be developed to tie the proof-of-concept expert system to an on-line database like ARARs-Assist, or a CD-ROM database like ENFLEX. Through this research, the expert system would become a user interface, which provides the strategy required to efficiently and effectively search the database. The primary advantage of having an expert system shell tied to a database is the ability to view the full text of an environmental requirement. Furthermore, changes required because of new or amended laws and rules, could be made to the database, with only minor changes to the expert system.

The concept of "sufficiently similar" continually appeared during the selection of relevant and appropriate requirements. Determining if a cleanup technology or contaminant is sufficiently similar requires a comparison of site circumstances with factors relating to the environmental requirement. A fuzzy logic model, using a set of generic responses and weighting factors would allow the user to make this determination without having to possess the special expertise on the environmental legislation in question.

Appendix A: The ARARs Selection Process

Introduction

The CERCLA Compliance With Other Laws Manual outlines the following five-step decision framework for ARARs selection:

(1) Identify potential ARARs.

(2) Analyze the potential ARARs to determine whether they are actually applicable to the particular conditions at the site.

(3) If the requirements are not applicable, . . . analyze potential ARARs the to determine whether they are relevant and appropriate to the particular conditionsat the site.

(4) In developing the site risk assessment, which is used to determine protectiveness, criteria, guidance, advisories, and proposed standards may be used in addition to ARARs. These to-be-considered criteria, guidance, advisories, and proposed standards are not promulgated requirements (and are not potential ARARs), but are an important component of the protectiveness determination required by the statutes.

(5) Determine whether circumstances are present that might justify a waiver of any otherwise applicable or relevant and appropriate requirements. (34:1-55)

Figure 13 shows how these steps are incorporated into a process for selecting ARARs. The following sections discuss in detail the decisions that are required when executing the five-step decision framework.

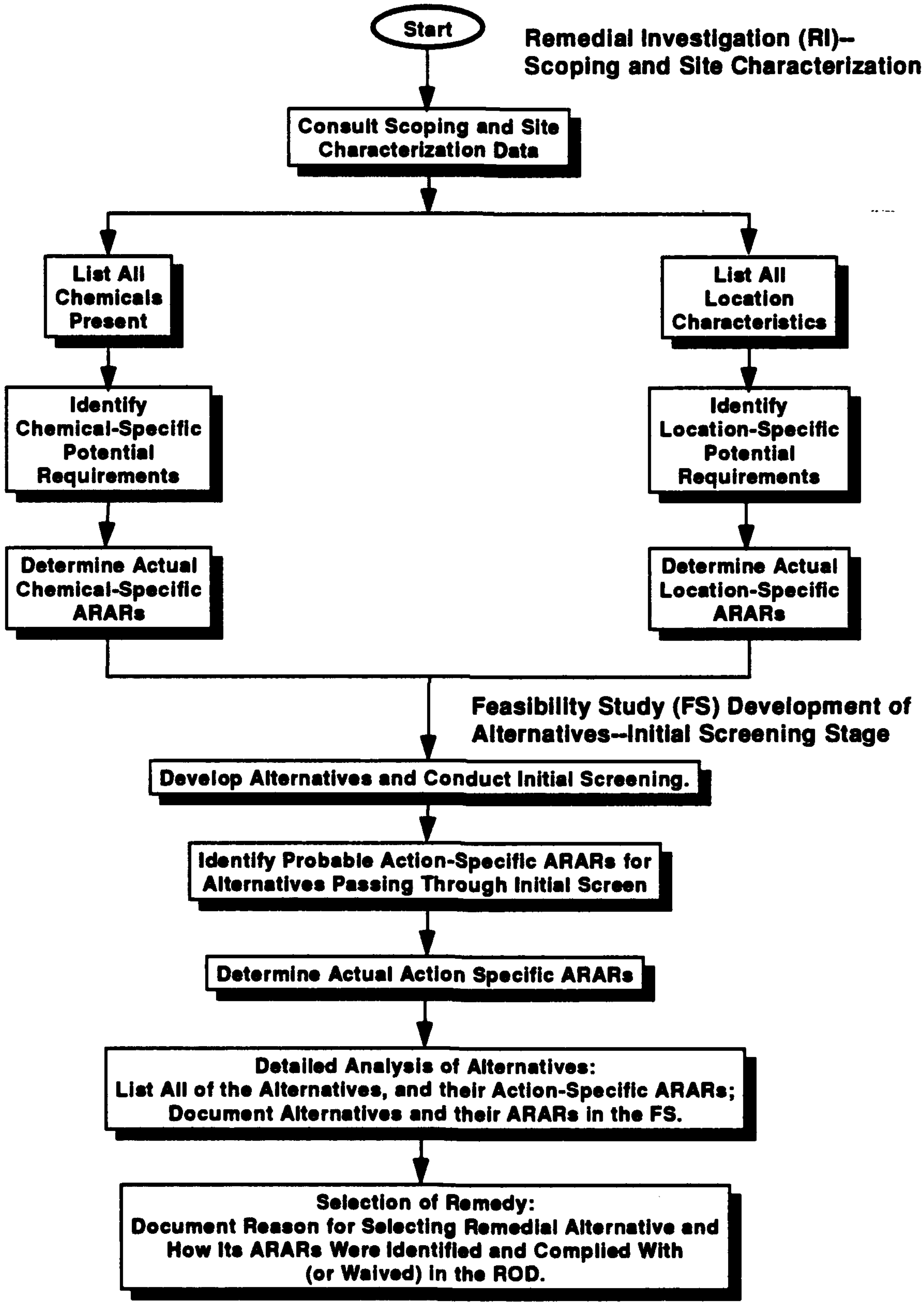

Figure 13: Procedure for Identifying ARARs (34:1-57)

Potential ARARs Identification

As shown in figure 13, the ARARs identification process begins after

> the scoping and site characterization phase of the Remedial Investigation, when sufficient information has been developed so that initial judgements can be made about the chemicals present at the site and any special characteristics of the site location that must be taken into account. (34:1-56)

At this point potential chemical and action-specific ARARs can be identified. The Preamble to the NCP Final Rule provides a comprehensive list of potential Federal ARARs (31:8765-7). The CERCLA Compliance With Other Laws Manual has organized these potential ARARs into matrices for chemical, location, and action-specific ARARs, which lists the potential ARARs and prerequisites for consideration as ARARs. Potential ARARs are identified by cross referencing the data attained during the scoping and site-characterization phases of the Remedial Investigation with the chemical and location-specific ARARs matrices.

Potential action-specific ARARs typically cannot be identified until the development of alternative Remedial Actions is accomplished as part of the Feasibility Study (34:1-59). The same process is followed when identifying action-specific ARARs as was followed with chemical- and location-specific ARARs, except the action-specific ARARs matrix is used.

Applicable ARARs Determination

The CERCLA Compliance With Other Laws Manual indicates that

> The basic criterion for an applicable requirement is that it directly and fully addresses or regulates the hazardous substance, pollutant, contaminant, action being taken, or other circumstances at a site. (34:1-60)

The NCP points out that decisionmakers generally have "little discretion in determining whether the circumstances at a site match those specified in a requirement." (31:8743)

Determining if an ARAR is applicable to the circumstances at a site requires decisionmakers to make an "objective comparison of the jurisdictional prerequisites of the requirements to the circumstances at the site"(2:2) to determine if a direct correspondence exists. The jurisdictional prerequisites include:

(1) [W]ho is subject to the statute or regulation;

(2) [W]hat types of substances or activities fall under the authority of the statute or regulation;

(3) [W]hat is the time period of for which the statute or regulation is in effect; and,

(4) [W]hat type of activities does the statute or regulation require, limit, or prohibit. (2:2)

Figure 14 displays the decisionmaking procedures required for making the applicable determination for potential ARARs.

Relevant and Appropriate ARARs Determination

If a potential ARAR is proven not to be applicable, the decisionmaker must then go through additional procedures to determine if the potential ARAR is relevant and appropriate. According to the CERCLA Compliance With Other Laws Manual, the following considerations must be applied to the requirement when making the relevant and appropriate determination:

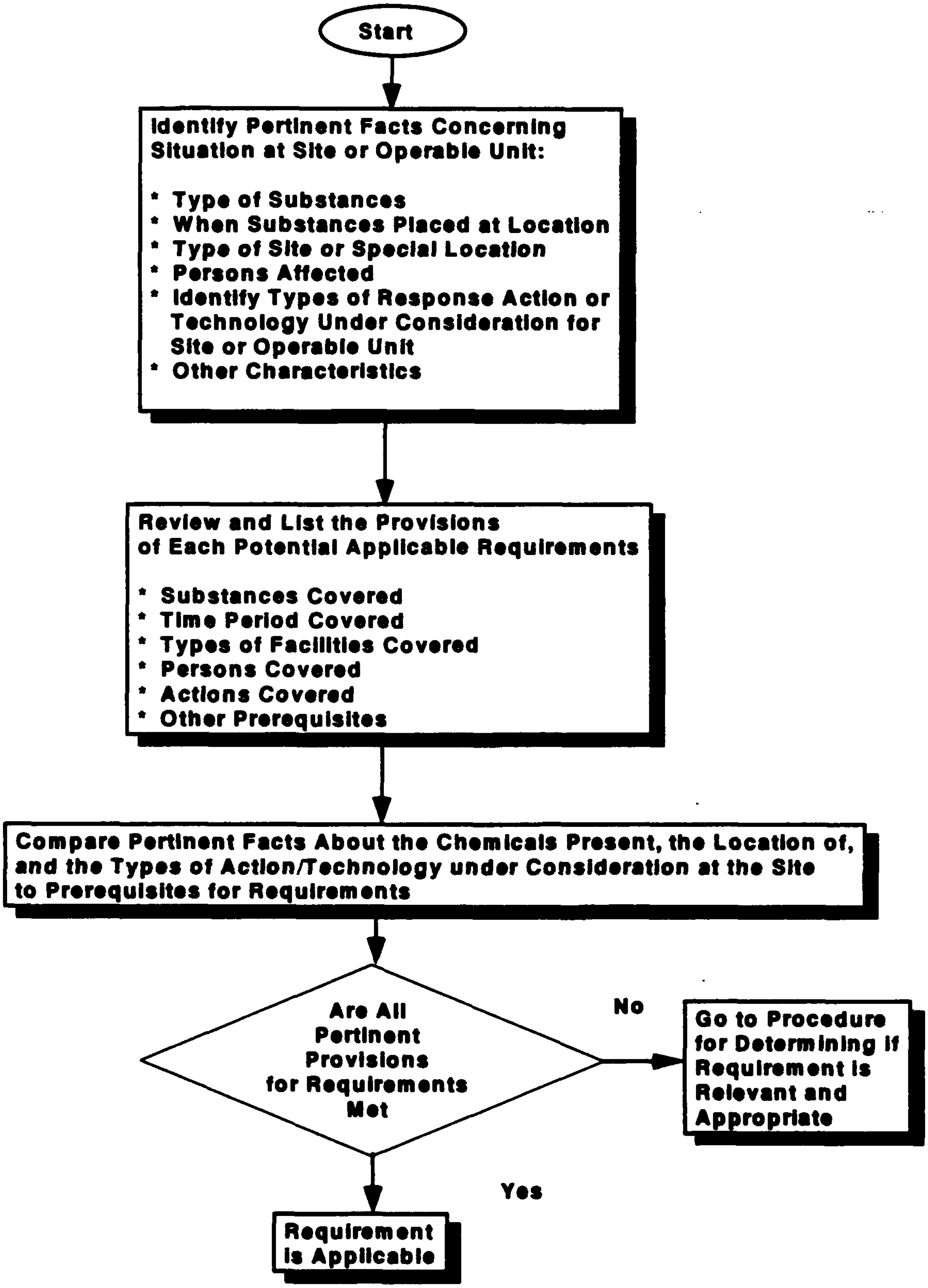

Figure 14: General Procedure for Determining If Requirement is Applicable (34:1-62)

(1) [The requirement] regulates or addresses problems or situations sufficiently similar to those encountered at the CERCLA site (i.e. relevance), and

(2) [The requirement] is appropriate to the circumstances of the release or threatened release, such that its use is well suited to the particular site. (34:1-65)

The NCP, in 40 CFR 300.400(g)2 identifies eight factors which must be used in making the relevant and appropriate determination:

- The purpose of the requirement and the purpose of the CERCLA action;
- The medium regulated or affected by the requirement and the medium contaminated or affected at the CERCLA site;
- The substances regulated by the requirement and the substances found at the CERCLA site;
- The actions or activities regulated by the requirement and the remedial action contemplated at the CERCLA site;
- Any variances, waivers, or exemptions of the requirement and their availability for the circumstances at the site.
- The type of place regulated and the type of place affected by the release or CERCLA action;
- The type and size of structure or facility regulated and the type and size of structure or facility affected by the release or contemplated by the CERCLA action;
- Any consideration of use or potential use of affected resources in the requirement and the use or potential use of the affected resource at the CERCLA site.(31:8842)

The decisionmaking procedures used for determining if a requirement is relevant and appropriate are displayed in figure 15. The <u>CERCLA Compliance With Other Laws Manual</u> suggests a two step process in determining if a requirement is relevant and appropriate

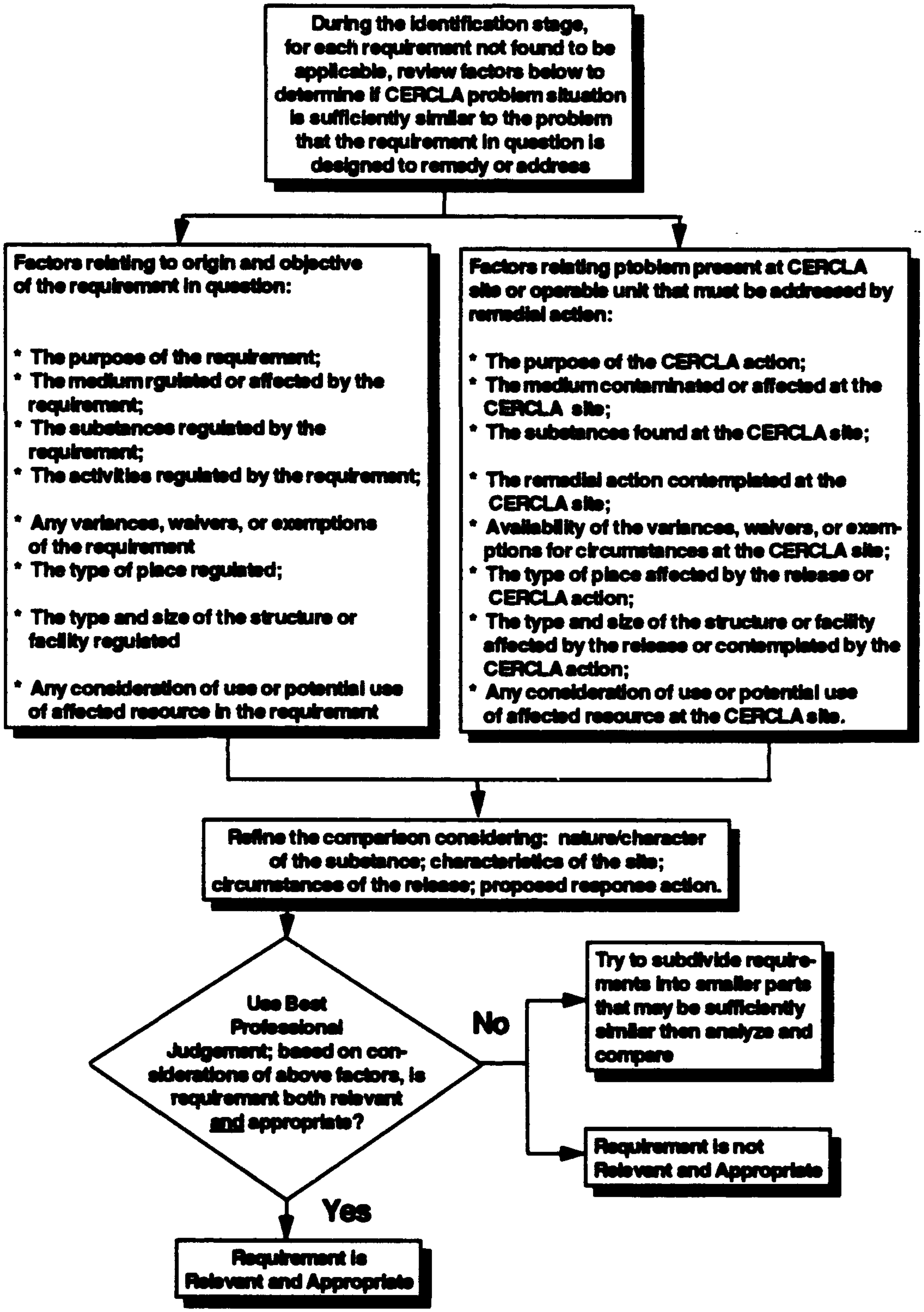

Figure 15: General Procedure for Determining if Requirement is Relevant and Appropriate (34:1-66)

> First, the determination focuses on whether a requirement is relevant base on a comparison between action, location, or chemicals covered by the requirement and related conditions of the site, the release, or the potential remedy. This step should be a screen which will determine the relevance of the potentially relevant and appropriate requirement under consideration. (34:1-65)
>
> The second step is to determine whether the requirement is appropriate by further refining the comparison, focusing on the nature/characteristics of the substances, the characteristics of the site, the circumstances of the release, and the proposed remedial action. (34:1-65)

According to the NCP, a "requirement must be both relevant, in that the problem addressed by a requirement is similar to that at the site, and appropriate, or well suited to the circumstances of the release and the site, to be considered a relevant and appropriate requirement." (31:8742)

The decisionmaking procedures shown in figure 14 state that if the initial relevant and appropriate determination for a potential ARAR is unsuccessful, the decisionmaker should "subdivide requirements into smaller parts that may be sufficiently similar the analyze and compare." (34:1-66) The NCP explains that finding "some parts of a regulation relevant and appropriate, and others not, allows EPA to draw on those standards that contribute to and are suited for the remedy and the site, even though all components of a regulation are not appropriate."(31:8743)

Identification of To-Be-Considered Requirements

The NCP "provided that advisories, criteria or guidance to-be-considered (TBC) that do not meet the definition of ARAR may be necessary to determine what is protective or may be useful in developing Superfund remedies." (31:8744) There are three types of TBCs identified by the NCP:

- health effects information with a high degree of credibility,

- technical information on how to perform or evaluate site investiga tions or remedial actions, and

- policy (31:8744).

Figure 16 illustrates the decision making procedures used in making the TBC determination. According to the CERCLA Compliance With Other Laws Manual the "basic criterion is whether use of the material to be considered is necessary to protect public health or the environment at a CERCLA site."(34:1-76)

Although identifying TBCs is not mandatory (31:8745), the EPA believes that TBCs can be useful in making the protectiveness determination for a CERCLA site because

> ARARs do not exist for every chemical or circumstance likely to be found at a Superfund site, . . . it may be necessary when determining cleanup requirements or designing a remedy to consult reliable information that would not otherwise be considered to be a potential ARAR.(31:8745)

Determination of ARARs Waivers

SARA provides six circumstances where an ARAR may be waived (29:1675). Since the Air Force is the Federal Lead Agency for cleanups performed under the IRP, ARAR waivers are an option that RPMs should be aware of (25). Waivers provided under CERCLA Section 121(d)(4) include:

(A) the remedial action selected is only part of a total remedial action that will attain such level or standard of control when completed;

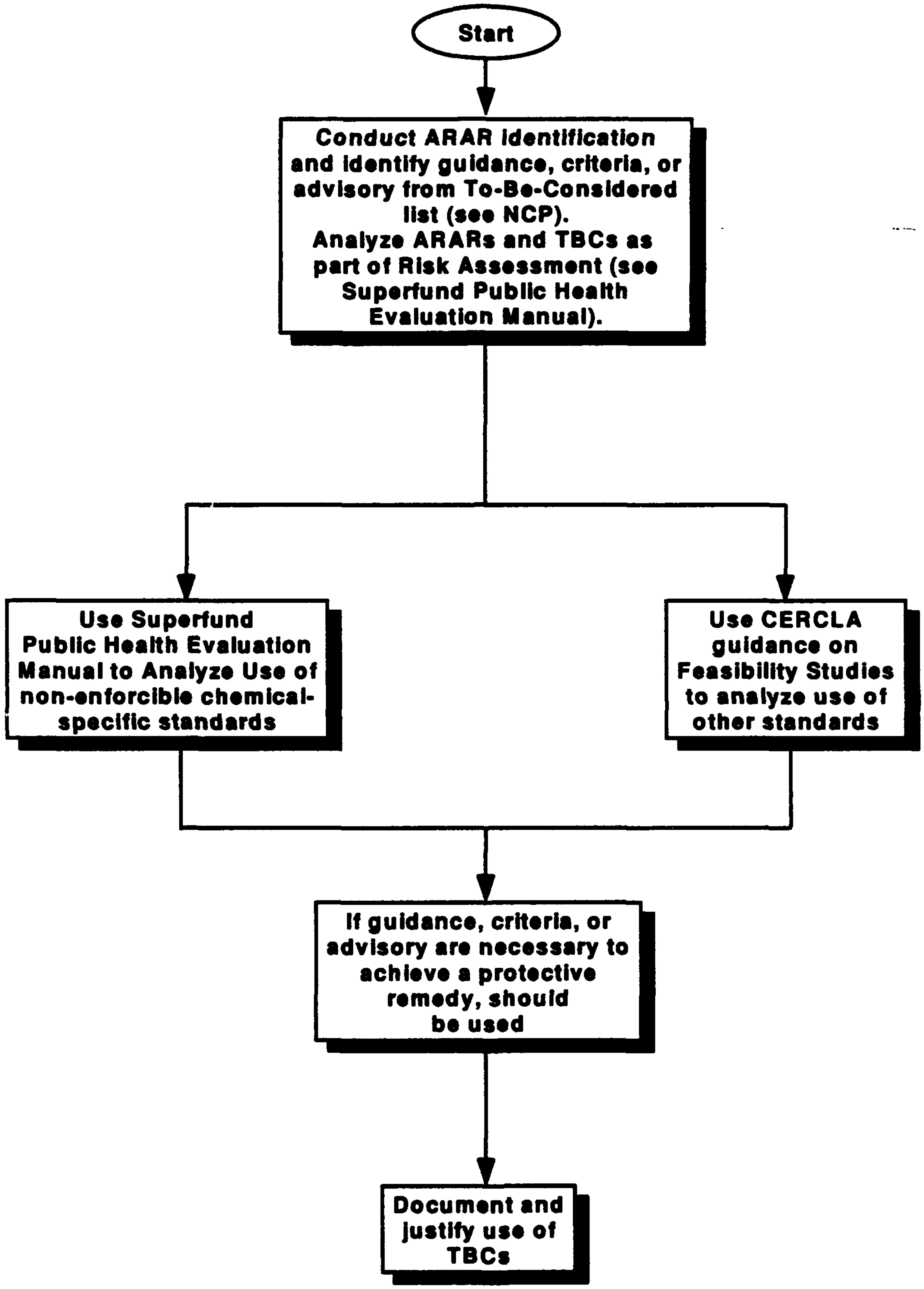

Figure 16: General Procedure for Determining if Guidance or Criteria Should be Considered (34:1-77)

(B) compliance with such requirement at that facility will result in greater risk to human health and the environment than alternative options;

(C) compliance with such requirements is technically impracticable from an engineering perspective;

(D) the remedial action selected will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, criteria, or limitation, through the use of another method or approach;

(E) with respect to a State standard, requirement, criteria, or limitation, the State has not consistently applied (or demonstrated the intention to consistently apply) the standard, requirement, criteria, or limita tion in similar circumstances at other remedial actions within the State; or

(F) in the case of a remedial action to be undertaken solely under section 104 using the Fund, selection of a remedial action that attain such level or standard of control will not provide a balance between the need for protection of public health and welfare and the environment at the facility under consideration, and the availability of amounts from the Fund to respond to other sites which present or may present a threat to public health or welfare or the environment, taking into consideration the relative immediacy of such threats.(30:1675-1676)

Waivers can only be applied to activities which take place on-site (30:8747). Waivers must be invoked "for each ARAR that will not be attained; the waivers apply only to attainment of ARARs and not to any other CERCLA statutory requirements for remedial actions, such as protection of human health and environ ment."(38:8747)

Appendix B: Concept Maps

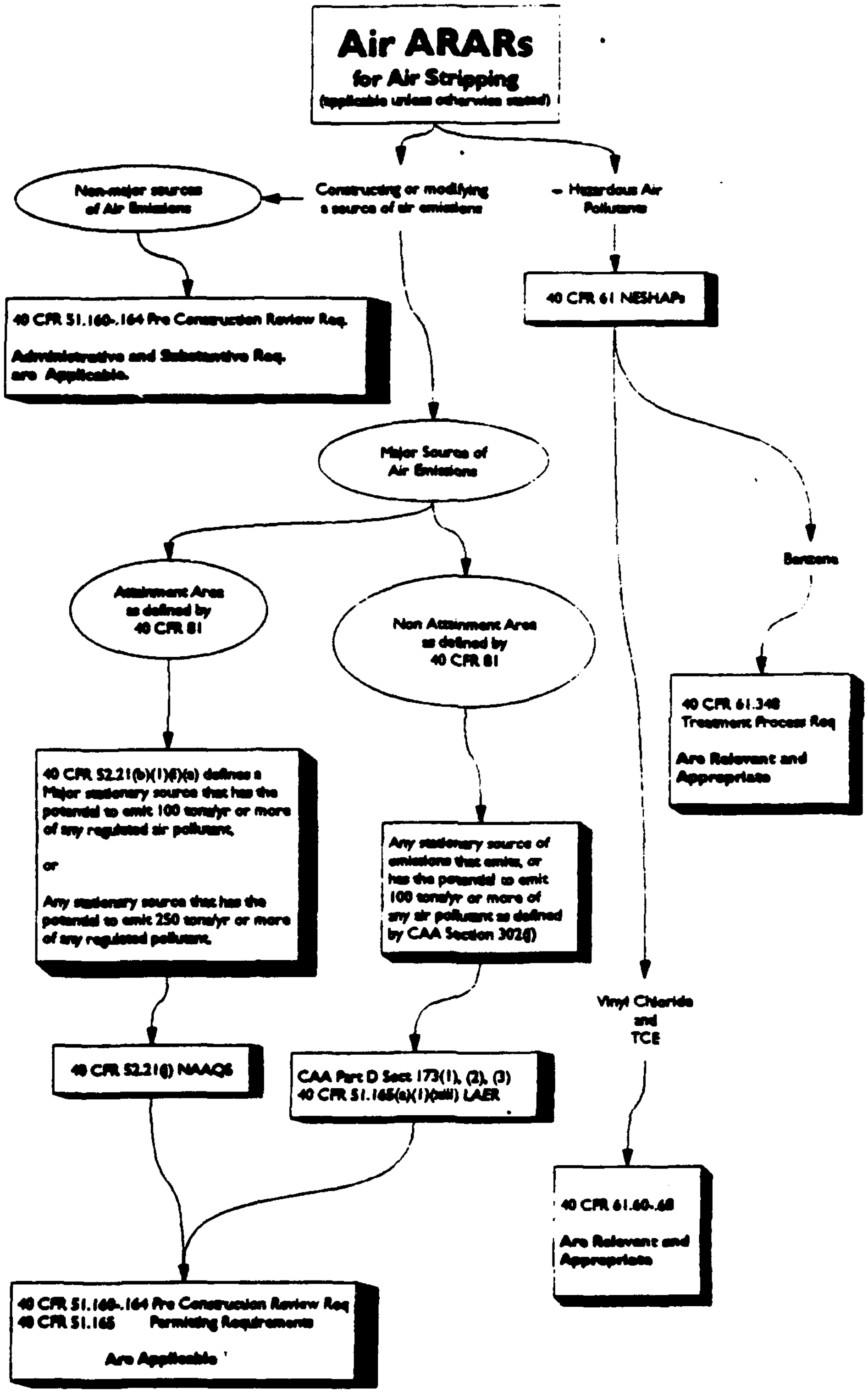

Figure 17: Concept Map - Air ARARs for Air Stripping

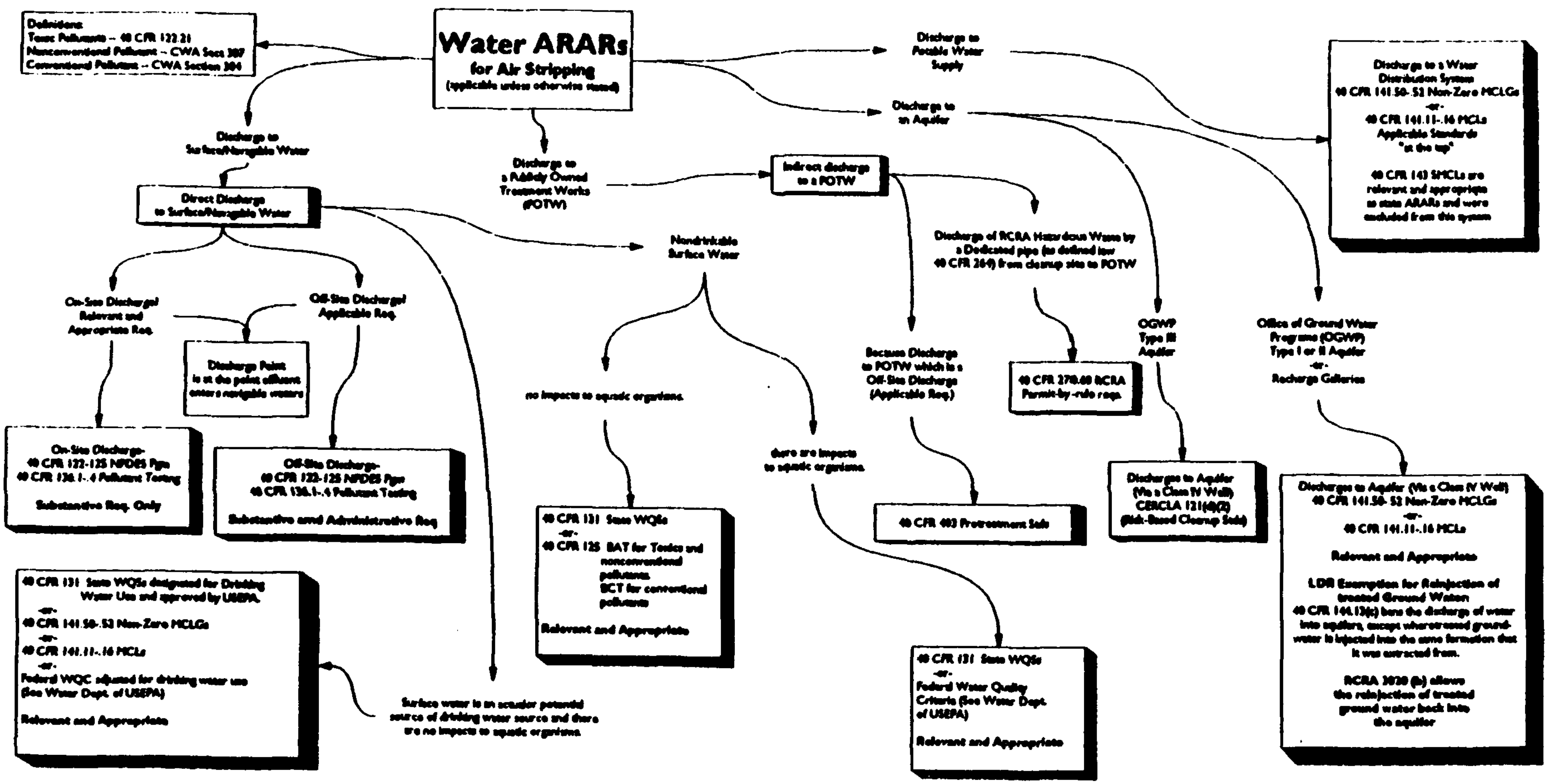

Figure 18: Concept Map - Water ARARs for Air Stripping

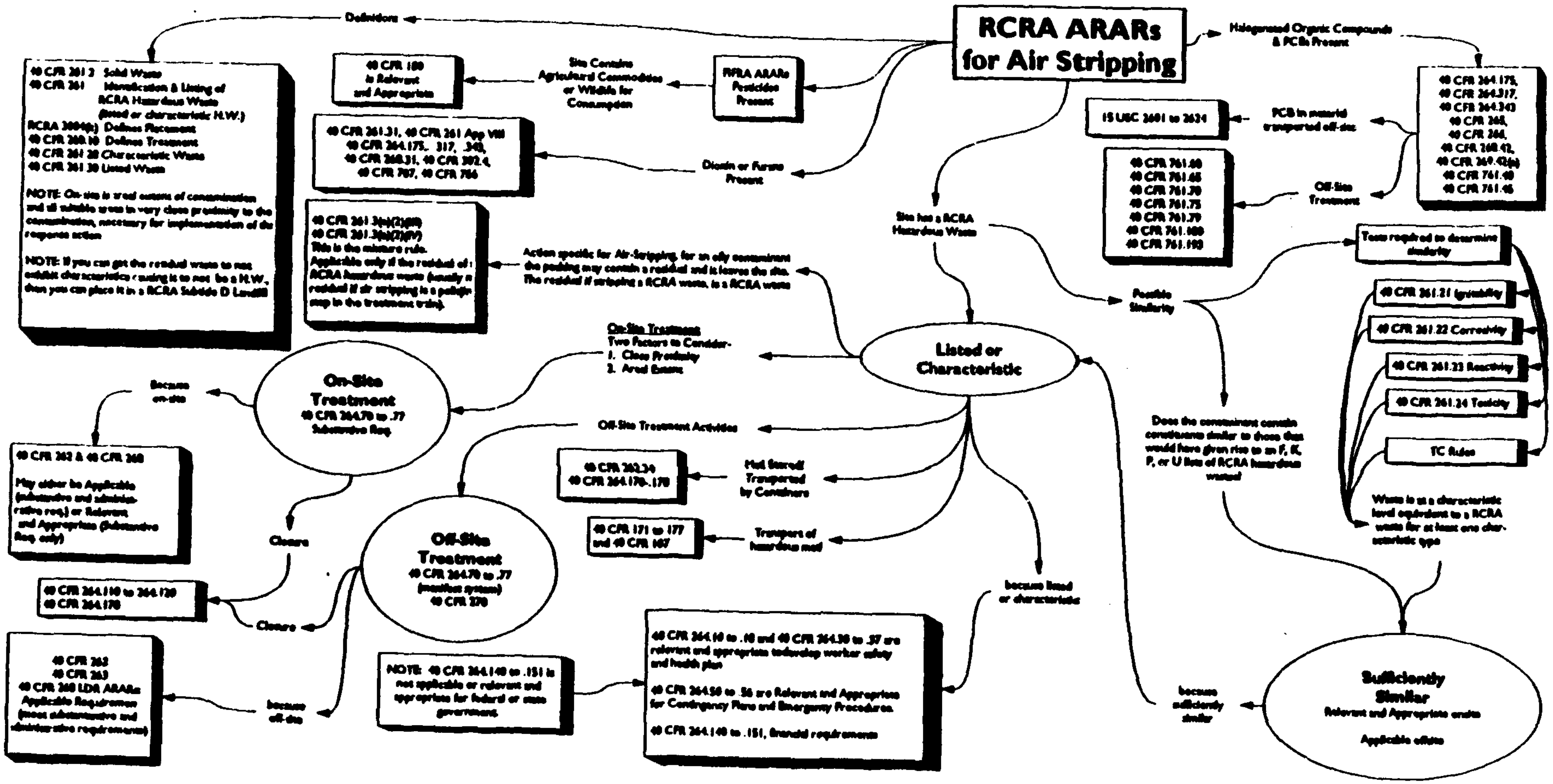

Figure 19: Concept Map - RCRA ARARs for Air Stripping

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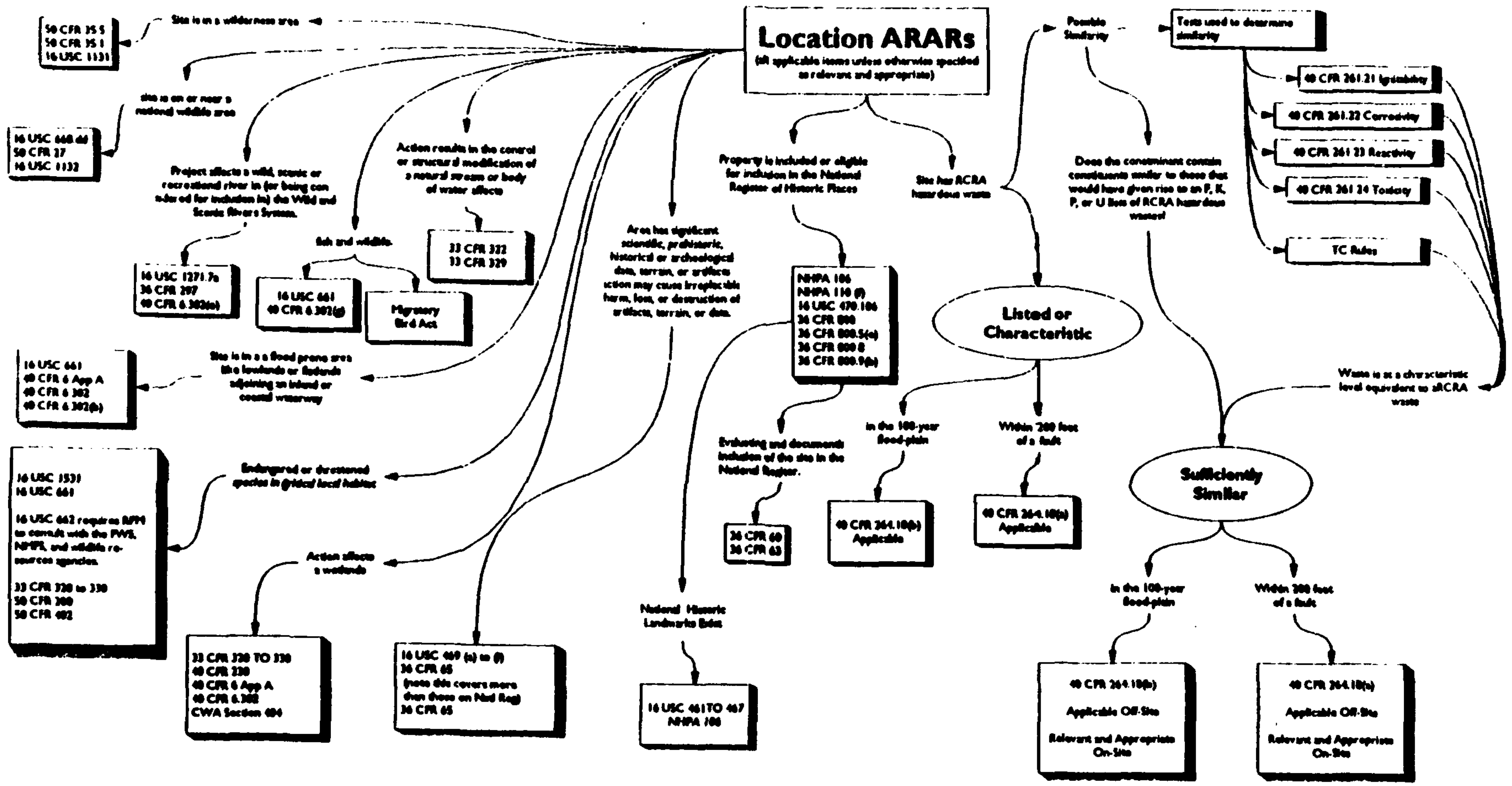

Figure 20: Concept Map - Location ARARs for Air Stripping

Bibliography

1. Cohen, Rhea, "ARARs-Assist, the On-Line Environmental Requirements Library," Report to ARARs-Assist Users Group. US EPA, Washington DC, May 1992.

2. Cohen, Rhea, "Introduction to ARARs:Applicable or Relevant and Appropriate Requirements." Unpublished Report, US EPA Office of Emergency and Remedial Response, Washington DC, May 1992.

3. Cooke, Nancy M. and James E. McDonald. "A Formal Methodology for Acquiring and Representing Expert Knowledge," Proceedings of the IEEE,74: 1422-30 (October 1986).

4. Davis, McKenzie L. and David A. Cornwell. Introduction to Environmental Engineering. New York: McGraw-Hill Publishing Company, 1990.

5. Goodrich, James A. et al. "Is Remediated Groundwater Meeting SDWA Requirements?" Journal of the American Water Works Association, 83: 55-62 (March 1991).

6. Greathouse, Daniel and Jay Clements. "PAST - The Potential ARARs Selection Tool" Report to US EPA. US EPA/RREL, Cincinnati OH, October 1991.

7. Greathouse, Daniel and Jay Clements. "PAST System (Version 0.46/0.47) Functional Description" Report to US EPA. US EPA/RREL, Cincinnati OH, October 1991.

8. Gupta, Aman and Bandreddi E. Prassad, Principles of Expert Systems. New York: IEEE Press, 1988.

9. Harmon, Paul and David King. Expert Systems: Artificial Intelligence in Business. New York: John Wiley and Sons Inc., 1985.

10. Hayes-Roth, Frederick, Donald A. Waterman, and Douglas B. Lenat. Building Expert Systems. Reading MA: Addison-Wesley Publishing Co., 1983.

11. Huguley, John T., Jr. Lecture in COMM 630, Research Methods. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, 10 February 1992.

12. IntelliCorp Inc. KAPPA User's Guide: Kappa Version 1.2. Publication Number: KAP1.2-UG-MSW2-1, Mtn. View CA:Intellicorp Inc, 1991.

13. James, S. and P. Rogoshewski. Handbook of Hazardous Waste Treatment and Disposal. New York: McGraw-Hill Book Company, 1989.

14. Johnston, Gary L. and Lynda H. Wynn. "A Management Systems Review of the Superfund RI/FS: Opportunities for Streamlining," Journal of the Air and Waste Management Association, 40: 733-7 (May 1990).

15. Kovalick, Walter W. Jr., Jerri P. Town, and Mary B. Deardoff. "Assessment of Need for Technical Information in EPA's Hazardous and Solid Waste Programs," Journal of the Air and Waste Management Association, 40: 1478-1485 (November 1990).

16. Martino, Louis and Gary Kaszynki. "A Comparison of the CERCLA Response Program and the RCRA Corrective Action Program," Hazardous Waste and Hazardous Materials, 8: 161-184 (February 1991).

17. Martino, Louis and Gary Kaszynski. "The Regulatory Status of Groundwater Intercept and Treatment Systems," Federal Facilities Environmental Journal, 2: 59-74 (Spring 1991).

18. Meyninger, Rita and Christopher Marlowe. "The Model Cleanup," Civil Engineering, 59: 64-67 (May 1989).

19. Nguyen, Tin A. et al. "Knowledge Base Verification," The AI Magazine, 8: 69-73 (Summer 1987).

20. Novak, Joseph D. and D. Bob Gowin, Learning How to Learn. New York: Cambridge University Press, 1990.

21. Patterson, Craig, Knowledge Engineer. Personal Interview. Computer Science Corporation, Cincinnati OH, 14 Jan 1992.

22. Pigford, D.V. and David Baur. Expert Systems for Business: Concepts and Applications. Boston MA: Boyd and Fraser Publishing Company, 1990.

23. Prerau, David S. "Selection of an Appropriate Domain for an Expert System," The AI Magazine, 6: 26-30 (Summer 1985).

24. Puetz, Capt Gerald B. and Capt Scott J. Borg, Development of a Heuristic Knowledge Base for the Selection of Applicable or Relevant and Appropriate Requirements (Unsubmitted Volume II). MS Thesis, AFIT/GEEM/CEC/92S-5. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1992.

25. Schafer, Lt Col Bernard K., Lecture in ENV 417, Environmental Restoration Project Management, School of Civil Engineering and Services, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, July 1992.

26. Simmons, Asa B. and Steven G. Chappel. "Artificial Intelligence - Definition and Practice," IEEE Journal of Oceanic Engineering, 13: 14-42 (April 1990).

27. Travis, Curtis C. and Carolyn B. Doty. "Can Contaminated Aquifers at Superfund Sites be Remediated," Environmental Science Technology, 24: 1464-6 (October 1990).

28. Turban, Efraim and Jack R. Meridith. Fundamentals of Management Science. Homewood IL: BPI/Irwin, 1988.

29. United States Air Force. U.S. Air Force Installation Restoration Program Remedial Project Managers Handbook. Washington:HQ USAF/CEV, January, 1992.

30. United States Congress. "Superfund Amendments and Reauthorization Act of 1986- Public Law 99-499." Laws of the 99th Congress - 2nd Session. Washington DC, October 17, 1986.

31. United States Environmental Protection Agency."40 CFR Part 300: National Oil and Hazardous Substances Pollution Contingency Plan:Final Rule," Federal Register, Volume 55, Number 46. March 6, 1990.

32. United States Environmental Protection Agency. A Guide to Developing Superfund Records of Decision. Publication 9335.3-02FS-1. Cincinnati OH: US EPA Office of Solid Waste and Emergency Response, 1989.

33. United States Environmental Protection Agency. ARARs Q's & A's. Publication 9234.2-01FS. Cincinnati OH: US EPA Office of Solid Waste and Emergency Response, 1989.

34. United States Environmental Protection Agency. CERCLA Compliance with Other Laws Manual (Interim Final). EPA/540/G-89/006. Washington: US EPA Office of Solid Waste and Emergency Response, 1988.

35. United States Environmental Protection Agency. CERCLA Compliance with Other Laws Manual: Part II. Publication 9234.1-02. Cincinnati OH: US EPA Office of Solid Waste and Emergency Response, 1989.

36. United States Environmental Protection Agency. Compendium of CERCLA ARARs Fact Sheets and Directives. Publication 9347.3-15. Washington: US EPA Office of Emergency and Remedial Response, 1991.

37. United States Environmental Protection Agency. Conducting Remedial Investigations/Feasibility Studies for CERCLA Landfill Sites. EPA/540/P-91/001. Washington: US EPA Office of Emergency and Remedial Response, 1991.

38. United States Environmental Protection Agency. Control of Air Emissions From Superfund Air Strippers at Superfund Groundwater Sites. OSWER Directive 9355.0-28. Cincinnati OH: US EPA Office of Solid Waste and Emergency Response, 1989.

39. United States Environmental Protection Agency. Engineering Bulletin: Air Stripping of Aqueous Solutions. EPA/540/2-91/022. Cincinnati OH: US EPA Risk Reduction Engineering Laboratory, 1991.

40. United States Environmental Protection Agency. Getting Ready- Scoping The RI/FS. Publication 9355.3-01FS1. Cincinnati OH: US EPA Office of Solid Waste and Emergency Response, 1989.

41. United States Environmental Protection Agency. Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (Interim Final). Publication 9355.3-01. Washington: US EPA Office of Emergency and Remedial Response, 1988.

42. United States Environmental Protection Agency. Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites. EPA/540/G-88/005. Washington: US EPA Office of Emergency and Remedial Response, 1988.

43. United States Environmental Protection Agency."Improving Groundwater Cleanup: A Need for Action," Federal Remediation Technology Roundtable Special Meeting Summary . CLU-IN BBS Bulletin. Washington: US EPA Office of Technology Innovation, May 14, 1992.

44. United States Environmental Protection Agency. Information on Developing Expert Systems for EPA's Hazardous Waste Program. Practice Paper (EPA Contract 68-01-7481). Washington DC: USEPA, 1988.

45. United States Environmental Protection Agency. Methods for Evaluating the Attainment of Cleanup Standards, Volume I: Soils and Solid Media. Washington: US EPA Office of Policy, Planning, and Evaluation, 1988.

46. United States Environmental Protection Agency. Overview of ARARs: Focus on ARAR Waivers. Publication 9234.2-03/FS. Cincinnati OH: US EPA Office of Solid Waste and Emergency Response, 1989.

47. United States Environmental Protection Agency. Record of Decision System. On-Line Database. Washington: US EPA Office of Solid Waste and Emergency Response, April 15, 1992.

48. United States Environmental Protection Agency. Superfund Federal-Lead Remedial Project Management Handbook. Publication 540 G-87 001. Washington: US EPA Office of Emergency and Remedial Response, 1986.

49. United States Environmental Protection Agency. Superfund Remedial Design and Remedial Action Guidance. Publication 9355.0-4A. Washington: US EPA Office of Emergency and Remedial Response, 1986.

50. United States Environmental Protection Agency. The Remedial Investigation: Site Characterization and Treatability Studies. Publication 9355.3-01FS2. Cincinnati OH: US EPA Office of Solid Waste and Emergency Response, 1989.

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13. ABSTRACT *(Maximum 200 words)* Applicable or Relevant and Appropriate Requirements (ARARs) are the basis used in establishing threshold limits for hazardous waste cleanups performed under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). ARARs selections must be applied consistently at numerous cleanup locations concurrently. The purpose of this research was to analyze activities required for the development of a heuristic knowledge base used for selection of ARARs. The problem domain for the research was limited CERCLA cleanups of contaminated groundwater, through the use of a pump and treat strategy, using air stripping as the as the cleanup technology. The research examined literature concerning the importance of ARARs in the CERCLA restoration process and the knowledge acquisition and representation methods. The research then analyzed the activies required to acquire and represent the knowledge required for the selection of ARARs. A byproduct of the research was a proof-of-concept prototype expert system which was used to validate knowledge acquired and represented in the problem domain. Prototype validation included comparing the results of consultations with the expert system with ARARs identified in the Record of Decisions (RODs) for actual CERCLA cleanups. In three of four cases, the expert system successfully identified all ARARs germane to the cleanups.

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