TABLE 3-2. Phases of Evaluation of Remediation Alternatives

General response actions:	Development of remediation alternatives in which technologies are assembled into remediation scenarios
Assembly of technologies as alternatives:	Screening of alternatives in which the scenarios from the initial FS phase are evaluated in a general way to eliminate all but those that are most promising
Screening of alternatives:	Detailed analysis of alternatives in which the remaining remediation scenarios are evaluated in detail so that an informed decision can be made regarding the choice of a preferred alternative

3.3.1 General Response Actions

The first step in the development of remedial alternatives is to formulate general response actions. A general response action is defined as one approach to remediation of contaminants in one medium (e.g., soil or groundwater). For example, one general response action for fuel hydrocarbon contaminants in shallow soil might be excavation. Response actions may include combinations of actions addressing contamination in a medium, such as excavation of soil, transport, and off-site disposal (Table 3-3).

General response actions are not restricted to active remediation but can include institutional actions. Institutional actions are governmental or administrative processes that reduce risk by preventing contact between receptors and the medium of concern. Examples include deed restrictions used to limit future site use as a substitute water supply where wells are contaminated.

"No action" is considered a general response and a remedial alternative. Consideration of no action allows comparison with active remediation alternatives, particularly in regard to cost and long-term effectiveness. No-action alternatives may include minimal actions, institutional controls, or monitoring. Natural attenuation might be considered a no-action alternative, although regulatory acceptance of this alternative generally requires that natural breakdown of chemicals is indeed occurring. In certain cases, no action can provide a low-cost option or may be applicable to sites where active remediation is judged not feasible.

Appropriate general response actions are often recognized during the early stages of site investigation, after it becomes clear which media are affected and which contaminants are present. These conceptual response actions are refined throughout the investigative and evaluation processes as a better understanding of site conditions is gained and action-specific ARARs are identified.

TABLE 3-3. Typical Response Actions

Containment of contaminated media, for example, a low permeability cap placed above a volume of contaminated soil
Excavation of contaminated soil, followed by treatment and disposal of the soil
Extraction (pumping) of groundwater
In situ (in-place) treatment of groundwater
On-site, ex situ treatment of excavated soil or extracted groundwater
Transportation of contaminated media within the site and off the site
Off-site treatment
Off-site disposal in a landfill

3.3.2 Identification of Volumes and Impacted Areas

During the development of alternatives, an initial determination may be made of the areas and volumes of media needing remediation. These initial estimates will be refined during the alternatives evaluation process. The risk levels associated with concentrations of contaminants of concern will sharpen definition of areas subject to remediation. If a baseline risk assessment has been developed, it may be possible to determine the risk associated with different concentrations of indicator chemicals. This type of analysis may not be possible if risk data are lacking or contaminant distributions are complex.

The results of the estimating process may be organized into a table listing the areas where volumes of soil, groundwater, or other media have been contaminated. With this information, the practicality, cost, and relative merit of various response actions may be assessed. The relative merit of various response actions may differ depending on the areal extent, depth, and volume of contaminated material.

It may be possible to estimate risks for different levels of contamination. Development and preliminary evaluation of alternatives can proceed based on this information. At some point a risk management decision will be made regarding the need to remediate all or some portion of the contaminated soil.

3.3.3 Identification and Screening of Technologies

Investigators proceed from identification of general response actions to identification of technology types and specific remediation processes. Technology types, each of which may include several process options, are generally evaluated first because entire technologies may be screened out as inappropriate for the medium or contaminants. For example, process options included within the technology of in situ soil vapor extraction could be treatment of extracted vapor by thermal oxidation, catalytic oxidation, or carbon adsorption.

Many sources describe technology types and processes. One of the easiest to use, and one that will provide general information about technologies for use in screening, is the Vendor Information System for Innovative Treatment Technologies database (EPA 1995b). This computer database, updated periodically, is available on diskette from EPA or by downloading from the EPA Internet site. Users are able to view information about technology descriptions, types of contaminants, media applicability, vendor names, cost ranges, treatability study information, and limitations. Users can search by contaminant, medium, technology type, vendor name or location, site name or location, waste source, regulatory agency, and other factors. Another database is the Remediation Technologies Screening Matrix (EPA and U.S. Air Force 1993).

Other sources of information on remediation technologies include EPA, the U.S. Department of Defense, the U.S. Department of Energy, and other agency guidance documents; project files and staff of regulatory federal, state and local regulatory agencies; vendors; scholarly and trade journals; trade shows; environmental consultants; and engineering and other departments of universities. In addition, the American Academy of Environmental Engineers, using a consortium of government agencies, consultants, and professional organizations, has developed a series of remediation handbooks that are valuable references for the project manager (AAEE 1997). This *Innovative Site Remediation Technologies* series provides the scientific foundations, applications, and limits of more than 48 innovative remediation technologies.

Factors that commonly influence screening decisions include contaminant types, contaminated media, and subsurface conditions. Because the screening process is site-specific, other factors, for instance, receptor-specific information, may require consideration. Table 3-4 provides an example matrix summarizing the technology screening process for a former industrial site.

3.3.4 Evaluation of Technologies

One approach for evaluating technologies in greater detail, recommended by EPA (1988), is to select one process option to represent each technology type. This simplifies the subsequent development and evaluation of alternatives without limiting flexibility during remediation design. The representative process provides a basis for developing performance specifications during preliminary design. For example, one thermal destruction pro-

TABLE 3-4. Example Tabulation of Technology Screening for Soils, Former Industrial Site

Technology	Environmental Protection	Effectiveness	Reliability	Implementability	Potential Limitations	Est. Costs ($ millions)	Results
Handling							
Excavation	Control of atmospheric emissions may be necessary	Proven effective	Technique has been utilized on site in many instances	Implementable by commonly available equipment	Equipment may require extensive decontamination	0.4–0.5	FI
Transportation							
Rail	Possibility of accidental spill; rail lines may be more isolated from population than roads	Effective	Generally reliable	Site has rail access; need destination on rail line	Destination not on rail line	2.4–3.5	FI
Truck	Possibility of accidental spill	Effective	Generally reliable	Generally implementable	Availability of sufficient trucks	2.0–3.4	E: cost; equipment availability
Remediation Alternative							
Off-site incineration	Destroys contaminants; permitted incinerator is used	Contaminants completely destroyed by heat	Incineration is proven technology	Can permitted facility be found with rail access that can take this volume?	Finding permitted incineration on rail line; costs	33.8–40.5	FI
On-site incineration	As above. Need to ensure air quality and other standards; produces ash on site which requires disposal	Contaminants completely destroyed by heat	Incineration is proven technology	Permitting could be difficult in southern California air basin; community concerns could restrict on-site treatment; size limitation on unit could increase treatment time	Community acceptance; disposal of ash; time; air permits; costs	27–33.8	E: permittability; community concerns
Soil washing	Contaminants removed from soil; residual wastes will require treatment	May not be effective on PNAs	Technology used in other applications; unproven for PNAs	Generally implementable; need to treat residual	Unknown cost; ability to remove PNAs is suspect; treatment of residual	7.5–13.5	FI

Bioremediation	Contaminant concentrations reduced by microbial destruction	May not be effective on PNAs	Technology effective in other applications; unproven for PNAs	Generally implementable	Ability to destroy PNAs is not proven; technology may need further development	7.5–13.5	FI
Thermal desorption	Contaminants removed by distillation	Effective for many compounds	Generally reliable; has been used in many applications	Permitting will be necessary	Effectiveness on PNAs; disposal of residual	25–30	FI
Fixation	End product will need on- or off-site disposal	Stabilizes soil material; however, contaminants still remain	Site testing and published information indicates that fixation of high concentrations of PNAs is difficult; proven reliable for metals	Technology needs additional development for PNAs; implementable for metals	Permittability in doubt; would need to identify existing disposal site or permit; future liability	20.2–27	FI: for CTSB area only
In situ vapor extraction	Contaminants extracted from ground in vapor phase	Effective for VOCs; ineffective for PNAs	Generally reliable for VOCs if soil conditions are good	Generally implementable	Will not work on PNAs; will require vapor treatment apparatus	0.3–0.5	FI: for UST area only
Disposal							
Containment in place	Cover and monitor to separate from potential receptors, but leaves impacted soil on site	The proposed design will be effective	Owner will ensure proper maintenance	Site will be regulated waste impoundment	Permitting; design of cover support; leaves contaminants on site; potential damage to containment by flood, etc.	2.5–3.5	FI
Off-site land disposal	Remove soil from site; may impact disposal site	Could remove soil from site relatively rapidly	Depends on disposal site; fixation method	Does not meet land disposal restrictions; fixation probably necessary	Permittability in doubt; future liability	10.1–13.5	E: permittability; future liability
Institutional							
No action	No additional protection; site access now controlled	Site-access controls limit direct contact	Site access controls can be circumvented	No additional implementation necessary	Restricts potential future uses of surrounding area	0	FI

NOTE: See text for explanation of criteria. FI, further investigate; E, eliminate; PNAs, polynuclear aromatic hydrocarbons; CTSB, cooling tower sludge bed; UST, underground storage tank; VOC, volatile organic compound.

cess might be selected from several available to treat hydrocarbon-containing vapor from in situ soil vapor extraction. This representative process could be used for preliminary cost estimates and evaluation of the effectiveness of the technology.

Technologies are initially evaluated on the basis of effectiveness, implementability, and cost. Because data on innovative technologies are limited, it may not be possible to evaluate these on the same basis as established technologies. If use of innovative technologies is considered important to the project, which may be the case at high-profile sites, and innovative technologies are judged potentially effective and implementable, they may be retained for evaluation even if cost data are few.

3.3.4.1 Effectiveness Evaluation. The primary definition of effectiveness is the ability of the technology to treat the contaminated media and meet remedial action objectives. Overall effectiveness is also influenced by the time required for remediation, reduction in volume or toxicity of contaminants, and whether the technology works in the short term as well as the long term.

The information that will be needed to evaluate the effectiveness of technologies includes the type of impacted media, contaminant type and concentration, area and volume of contaminated media, and the location of contaminated media (e.g., depth of contaminated soil volumes).

A preliminary review of available information may indicate a need for additional data to describe the concentration or distribution of contaminants or physical and chemical properties of media. For example, evaluation of groundwater remediation processes, whose performance depends on rates of extraction, requires knowledge of permeability, porosity, hydraulic gradients, aquifer thickness, concentration and spatial distribution of contaminants, and heterogeneity of the aquifer.

Modeling of transport processes such as groundwater flow may be needed. Use of a few indicator chemicals in place of all contaminants present at the site will facilitate assessment of how effectively technologies meet remediation objectives. Indicator chemicals are usually selected on the basis of occurrence or concentration, toxicity, and mobility. Those chemicals found most commonly or at highest concentration, those most mobile in the environment, and those most toxic (taking into account concentration and mobility) are frequently selected as indicator compounds.

3.3.4.2 Implementability Evaluation. Implementability includes technical and institutional feasibility, including obtaining approval for installation and operation of the remediation process. At this stage in the process, technical implementability has already been used as an initial screen to eliminate those technologies that are clearly unworkable, so greater emphasis is placed on the institutional aspects of implementability. Implementability evaluation includes assessment of the ability to obtain necessary permits, acceptability to neighbors, availability of necessary equipment and skilled workers, and availability of ancillary facilities and services, such as those that might be necessary for off site disposal.

3.3.4.3 Cost Evaluation. In development and screening of remediation alternatives, relative capital and operations and maintenance (O&M) costs are normally used, rather than detailed cost estimates. Cost analysis may be based on engineering judgment, cost ranges derived from literature, or preliminary inquiries with manufacturers or suppliers. In many cases, the amount of material to be treated is the primary sensitivity factor of cost rather than the technology type.

3.3.5 Assembly of Technologies as Alternatives

Alternatives to be assessed during the remedial alternatives evaluation are scenarios for the total remedial action. Each may include several individual remedial actions for different portions of the site and involve different media. Each alternative scenario may include several different general response actions and many technologies.

In the CERCLA process, response actions and technologies are commonly combined for the site as a whole, so that each alternative is a complete remediation scenario. Other approaches are possible. In cases where interactions among media are not significant, alternatives for each medium can be evaluated separately. This produces an alternatives evaluation that, for example, describes several soil remediation options and several groundwater remediation options. The advantage to this approach is that it simplifies the analysis of alternatives. However, it makes comparisons between complete remediation scenarios more difficult.

Figure 3-2 is a simple example of a matrix summarizing alternatives for a site to be remediated. A "no-action" alternative is required for CERCLA sites and is prudent for non-CERCLA sites. This alternative involves no active remediation of any of the site media, but often involves monitoring. It is provided for purposes of comparison with other alternatives.

Although development and screening of alternatives may eventually be formally described in the alternatives evaluation report, it is important to keep key decision makers informed as the work progresses. Technologies and alternatives should be discussed with the lead regulatory agency before they are included. This will avoid wasting effort on alternatives not acceptable to the regulators.

Community relations activities are often necessary during the assembly of alternatives. Project managers should provide information for communication to community representatives and obtain feedback regarding various alternatives so that surprises are avoided when the alternatives evaluation

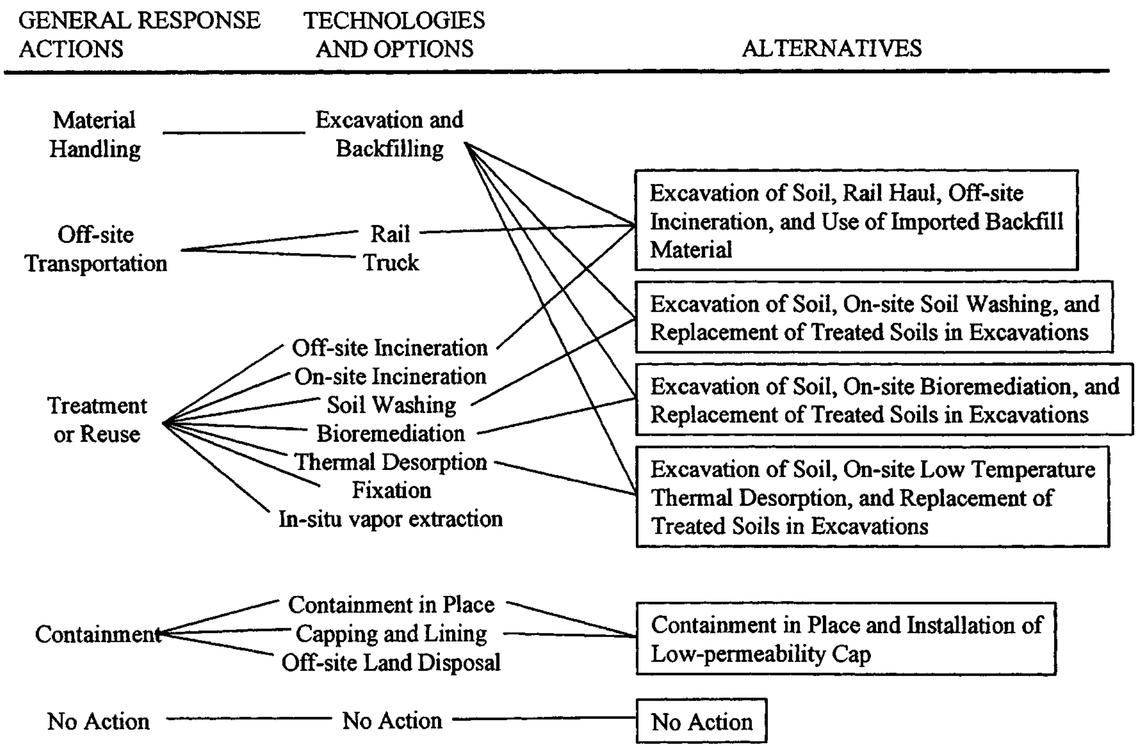

Figure 3-2. Example Matrix Alternative Development Process.

report is issued. Community members may be concerned by some aspects of some alternatives. For example, questions might be raised regarding emissions of chemicals to the atmosphere during excavation. Definitive answers to community questions or modifications of the excavation procedure can then be prepared. The community can be informed by mailings (fact sheets), public meetings, and notices in local periodicals.

3.3.6 Screening of Alternatives

The purpose of alternative screening is to narrow the list of alternatives to be evaluated in detail. Alternatives are screened principally on effectiveness, implementability, and cost. Even though this is a defined step in the procedure, screening is actually done throughout the alternative evaluation process to reduce the options being considered to those likely to be viable remediation alternatives. One purpose of alternatives evaluation reporting is to document the screening process so that a reviewer can check the procedure that was used to select the final list of alternatives.

The boundaries between the phases of the alternatives evaluation are not hard and fast and may vary with the scope of the project and the nature of the site. The scope of screening depends on the number and type of alternatives developed and the amount of information necessary for conducting the detailed analysis.

The screening portion of the alternatives evaluation occurs in three steps:

- alternatives are further refined, as appropriate;
- alternatives are evaluated on a general basis to determine their effectiveness, implementability, and cost; and
- a decision is made regarding which alternatives should be retained for detailed analysis.

Alternatives can be further refined by better quantification of areas and volumes of contaminated media; definition of sizes and capacities of remediation process options available; firming up cost of implementing technologies; gathering additional information on permitting, community acceptance, and other aspects of implementability; revision of remedial action objectives as necessary to accommodate any new risk assessment information; and reevaluating effects of interactions between media.

Certain tools are available to aid the investigator in screening alternatives. These include *Presumptive Remedies* guidance documents, which describe established technologies that have been accepted at a number of sites (EPA 1993b); the Remediation Options software package, with process diagrams on proven technologies (Battelle 1992); and the databases mentioned earlier in Section 3.3.3, Identification and Screening of Technologies.

Information available at the time of screening should be used primarily to identify and distinguish differences among the alternatives. Only the alternatives judged best or most promising on the basis of effectiveness, implementability, and cost should be retained for more detailed analysis. Alternatives that are screened out need not be considered further.

3.3.6.1 Further Definition of Alternatives. Prior to screening, few details describing the technologies of each alternative are known. Size and remediation time requirements have not been determined. Interactions between media and site-wide issues have not been addressed. Screening includes further definition of these aspects for each alternative.

To give an example of how medium may affect alternatives, consider a case in which removal of a contaminant from one medium increases its concentration in another. In situ soil vapor extraction removes VOCs from subsurface soils but may increase emissions to the atmosphere and the health risk to nearby residents. If this increased risk cannot be kept within acceptable levels, alternatives involving soil vapor extraction may not be useable.

Interactions between media also may affect alternative selection in that migration of contaminants between media may favor an approach that cuts off this intermedium transfer. Contaminants in subsurface soil might not be present in sufficient concentration to pose a direct risk to receptors, whereas migration of contaminants to groundwater and subsequent receptor contact with contaminated drinking water would result in a significant health risk. Cleanup of soil contaminants thus may be performed to lessen the risks posed by contaminated groundwater.

In this example and similar situations, consideration of remediation of media independent of one another could result in underestimation of risks and required remedial effort. By evaluating soil and groundwater together, overall risks are more realistically assessed, and sizing for remediation is more accurate. More accurate cost projections will follow.

The following estimates may be needed to properly screen alternatives:

- size and configuration of extraction and treatment systems or containment structures;
- time in which treatment, containment, or removal goals can be achieved;
- rates of treatment;
- spatial requirements for constructing treatment or containment systems or for staging materials, excavated soil, and waste;
- transport distances; and
- required permits and other imposed limitations.

3.3.6.2 Screening. One important difference between screening evaluation and detailed evaluation of alternatives is that comparisons during screening