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EFFICACY OF CERCLA REMEDIES IN LIGHT OF FIVE-YEAR REVIEWS*

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ABSTRACT

Reviews of several remedies selected and implemented under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, revealed deficiencies in remedy protectiveness although the remedy had only been in place for five years. Many of these deficiencies should have been foreseeable, and therefore preventable, at the time the remedy was selected.

Analysis of successes and deficiencies noted in the CERCLA five-year reviews highlights the pivotal role that monitoring plans and land use controls have in ensuring remedy protectiveness. The analysis demonstrated that remedy protectiveness assessments and remedy modification justifications depend on robust site and remedy monitoring plans as well as on adequately developed conceptual site models.

Comprehensive understanding and inferences regarding past, present, and future land and resource use at the remedy selection stage can enhance remedy protectiveness because stakeholders can determine if land use controls are necessary and if they can be implemented and enforced. The findings from this analysis of five-year reviews of remedy protectiveness are applicable to initial remedy selection decisions and subsequent enhancements of their effectiveness through time.

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BACKGROUND

Remedy Selection

Site remedy selection is preceded by a step-wise process that starts with an investigative environmental forensics phase that results in development of a conceptual site model (CSM). The CSM represents a comprehensive understanding of site contaminants (e.g., types, locations, volumes and/or dimensions of contamination sources); earth science framework (e.g., geology, hydrogeology, soil type, surface water features); and site receptor pathways (i.e., the risk or potential risk to humans and ecological receptors from completed exposure pathways).

The CSM is used to develop remedial action objectives (e.g., achieve a Safe Drinking Water Act maximum contaminant level in affected surface water or groundwater) and general response actions (e.g., pump and treat). Remediation investigators then assemble information about all technologies and process options with the potential to achieve the remedial action objectives. Technologies and process options that "pass" the three screening criteria of cost, effectiveness, and implementability then become candidates for a detailed analysis against nine evaluation criteria, grouped into the following categories in the CERCLA National Contingency Plan (NCP) (40 CFR 300.430):

- Threshold Criteria
  - Overall protection of human health and the environment;
  - Compliance with Applicable Relevant and Appropriate Requirements (ARARs);
- Primary Balancing Criteria
  - Long-term effectiveness;
  - Reduction of the toxicity, mobility, and volume of the contaminants present;
  - Short-term effectiveness;
  - Implementability of the remedy;
  - Cost of the remedy;
- Modifying Criteria
  - State acceptance of the selected alternative, and
  - Community acceptance of the selected alternative.

The evaluation results in remedy selection and documentation in a record of decision (ROD).

Remedy Five-Year Reviews

CERCLA 121(c) and the NCP require that remedies resulting in residual hazardous substances remaining at the site must be reviewed no less often than every five years. The NCP (40 CFR 300.430(f)(4)(ii)) states:

> If a remedial action is selected that results in hazardous substances, pollutants, or contaminants remaining at the site above levels that allow for unlimited use and unrestricted exposure, the lead agency shall review such action no less often than every five years after initiation of the selected remedial action.

Guidance developed by the U.S. Environmental Protection Agency (USEPA) for completing five-year reviews describes their purpose as being to evaluate the "implementation and performance of a remedy in order to determine if the remedy is or will be protective of human health and the environment" [1, pp. 1-1]. In assessing remedy protectiveness, reviewers answer the following questions [1]:

- Is the remedy functioning as intended in the decision documents?
- Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives used at the time of remedy selection still valid?
- Has any other information come to light that could call into question the protectiveness of the remedy?

Since the goal of the five-year review is determination of remedy protectiveness, the USEPA guidance encourages reviewers to expand the scope of the review and make recommendations to ensure protectiveness. For example, the guidance includes the following as examples of appropriate recommendations that could be included in a five-year review report:

- Provide additional response actions;
- Improve operations and maintenance activities;
- Optimize remedy;
- Enforce access controls and institutional controls; and
- Conduct additional studies or investigations [1].

USEPA's five-year review guidance makes it clear that the scope of the review should be more than a mere assessment of whether the terms of the ROD have been implemented and adhered to. Rather, the remedy review should determine whether the remedy is protective of human health and the environment because that is the objective of the ROD.

DESCRIPTIONS OF STUDY SITES

CERCLA five-year reviews published on the Worldwide Web as of early July 2002 were used for initial screening for this investigation. Since the objective of this survey was to determine the issues surrounding the non-effectiveness of selected remedies within five years of their implementation, only those five-year reviews including remedy deficiencies or recommendations were selected for further study. Seven of the thirteen five-year reviews found on the Web during the search period included deficiencies or recommendations and are surveyed here. Brief descriptions of those sites and the remedies selected for them are provided here as background to later discussion of the results of the five-year reviews of remedy effectiveness.

Denver Radium Site (Shattuck Site, Operable Unit VIII)

The 10-acre Shattuck site, the more common name for Operable Unit (OU) VIII of the Denver Radium Site, is located in southwestern Denver, Colorado. It is situated in an area designated for commercial and industrial uses; residential areas are located three blocks east of the property. Water for domestic consumption is supplied by the City of Denver, but it is reported that at least two residents use water from shallow wells for lawn watering. The Shattuck site is about 3,000 feet from the South Platte River and within its drainage basin. The site sits over a shallow unconfined aquifer that is perched on bedrock and joins the alluvial aquifer beneath the South Platte River floodplain.

Uses of the site from the 1920s to 1984 included treating molybdenum ores; extracting ferric vanadate; processing radium slimes for radium recovery; producing radium salts and uranium compounds; and processing uranium compounds, uranium ores, molybdenum, and rhenium.

Shattuck site soil was considered contaminated with radium-226 if the concentration exceeded 5 pCi/g above background in the top 15 cm of soil or 15 pCi/g above background in any layer below the top 15 cm. The total volume of contaminated site soil was estimated at 49,000 cubic yards. Radium-226 concentrations in the buildings and processing portions of the facility operations area averaged 90 pCi/g; the average in the open portions of the area was 69 pCi/g. The highest concentration of radium-226 in the railroad rights-of-way was 570 pCi/g. The primary groundwater contaminant was uranium, but arsenic, cadmium, and selenium were detected in excess of maximum contaminant levels in on-site and off-site well samples.

The selected remedy included on-site stabilization and solidification of contaminated soil and capping of the monolith to prevent radiation exposure. The remedy also included institutional controls and was expected to prevent further groundwater degradation while allowing for natural attenuation of the contaminant [2].

Williams Air Force Base, Operable Unit 2

Williams Air Force Base is 30 miles southeast of Phoenix, Axizona; OU 2 is located at the former Liquid Fuels Storage Area (ST-12). The surrounding land use is primarily agricultural. When the OU 2 ROD was written in 1992, the base was slated for closure, and a 25-year regional development plan created in 1987 called for commercial and residential development of land proximate to the base. In the past, a decline in the water table produced by high irrigation withdrawals created an extensive vadose zone, which at the date of the OU 2 ROD extended to approximately 220 feet below ground surface [3].

JP-4 and aviation fuels had been stored at OU 2 since 1942 in a series of underground storage tanks (USTs) and aboveground storage tanks. The USTs were removed as of 1991, shortly after free-phase product was discovered in a groundwater monitoring system. The volume of free-phase product at ST-12 was estimated to range between 650,000 and 1,400,000 gallons, and the volume of potentially impacted groundwater was estimated at approximately 170,000,000 gallons [4]. The average concentration of benzene in the groundwater was 3.52 mg/L.

The groundwater remedy in the OU 2 ROD, as amended, included removal of free-phase product and contaminated groundwater through extraction wells, groundwater treatment by air stripping, and reinjection of treated groundwater into the shallow aquifer [4].

The remedy was based on a residential future land use, and the cleanup level for benzene in the groundwater was 0.005 mg/L. Two horizontal wells were installed but the exact number, type (horizontal or vertical), and location of extraction wells needed for the site was to be determined as part of the remedial design phase (on the basis of ongoing aquifer testing) as would the monitoring procedures to determine remedy effectiveness [3].

Homestake Mining Company

The Homestake Mining Company site in Cibola County, New Mexico, was an operating uranium mill from 1958 to 1990. It includes the uranium mill site and contaminated portions of the San Mateo alluvial aquifer and the Upper and Middle Chinle aquifers. Site geology and hydrogeology are affected by faults in the Chinle Formation that trend northeast/southwest through the site. These faults extend under two mill tailings impoundments and neighboring residential subdivisions.

The large tailings impoundment covers 170 acres and contains an estimated 21 million tons of mill tailings. The smaller 40-acre impoundment holds approximately 1.2 million tons of tailings. Seepage from the tailing impoundments contaminated the underlying groundwater with uranium, thorium-230, radium-226, radium-228, selenium, and molybdenum.

Four residential subdivisions are located south and southwest of the site. Some land within the subdivisions and land farther south and west of them is used for agriculture and livestock. Land north, east, and west of the site has been acquired over the years by the Homestake Company but has not been put to any specific use. Local residents have used the alluvial aquifer in the past as a domestic water supply.

Groundwater remediation consists of a collection/injection system for the three affected aquifers and a collection well and irrigation system on land owned by

Homestake near the subdivisions. Radium-226 contaminated soil is excavated and placed on the large tailings pile before being covered with a radon barrier [5].

Non-Populated Area Operable Unit 2, Bunker Hill Mining and Metallurgical Complex

The Non-Populated Area OU 2 of the Bunker Hill Mining and Metallurgical Complex is located in Shoshone County, Idaho. The complex has been used for mining since 1883 and for mineral processing and smelting from the early 1900s until 1981. A plank and pile dam constructed along the South Fork of the Coeur d'Alene River (SFCDR) to manage the tailings produced by lead, zinc, and silver ore processing operations failed in 1933, spreading tailings downstream. Surface water, groundwater, soil, and sediment were contaminated throughout the SFCDR valley as a result of the dam failure and the mining, milling, and smelting processes. Among the contaminants are polychlorinated biphenyls (PCBs), arsenic, lead, and asbestos.

The remedy involves source removal, on-site waste consolidation, capping, re-vegetation, and creek reconstruction to achieve remedial objectives that include minimizing direct human contact with contaminants, reducing hillside erosion, and minimizing contaminant migration to groundwater [6].

United Creosoting Company

The United Creosoting Company site is an abandoned, 100-acre wood-preserving facility located 40 miles north of Houston, Texas. It operated from 1946 to 1972 and was redeveloped for residential and commercial use in the mid-1970s.

Pentachlorophenol (PCP) was detected on the site in 1980 when the county used soil taken from the site to improve local roads in a nearby subdivision. The soil was sampled after people living near the roads raised health complaints. Further site sampling revealed the presence of polycyclic aromatic hydrocarbons (PAHs) in addition to PCP in the shallow groundwater and PCP and dioxins/furans in the vadose zone soils.

Remedial actions included purchasing eight residential properties and relocating the residents, consolidating and temporarily capping contaminated surface soil until it could be disposed of off-site, and restoring groundwater through natural attenuation. Part of the site was remediated to residential standards, with the remainder cleaned to an industrial level [7].

Carrier Air Conditioning

Carrier Air Conditioning Corporation used this site in the Town of Collierville, Tennessee, from 1967 to the present to manufacture residential heating and air conditioning units; PCB releases occurred in the early 1970s and 1985. Although low levels of trichloroethene (TCE) were found in 1986 in groundwater from extraction wells supplying one of the town's water plants located next to the Carrier site, it was not found in the treated water leaving the plant. In 1990, Carrier installed air stripper treatment systems in the town water plant to ensure adherence to maximum contaminant levels.

The remedy for the Carrier site included institutional controls limiting water well use and restricting future land use to industrial uses, soil vapor extraction for site contaminated soil, and continued treatment of extracted water at the town water plant through air stripping [8].

Vertac

The 193-acre Vertac site is located about 15 miles northeast of Little Rock, Arkansas. The site is zoned industrial. It is bordered on the south and east by residential areas, the north by the Little Rock Air Force Base, and the west by industrial areas. The site was used in the 1930s and 1940s by the U.S. Department of Defense for munitions manufacturing and from 1948 to 1986 by private companies for the production of herbicides and insecticides. The primary contaminant of concern affecting soil, sediment, and sludge was 2,3,7,8-tetrachlordibenzo-p-dioxin (2,3,7,8 TCDD). The site contained approximately 29,000 drums of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) wastes.

The remedy included sediment removal, on- and off-site incineration of the drummed 2,4-D and 2,4,5-T wastes, excavation of contaminated soil and its disposal in an on-site landfill, long-term monitoring of groundwater and fish for dioxin, and an advisory on sport fishing in two water bodies [9].

FINDINGS

The review conducted for the Shattuck site was the only one of the seven sites surveyed that ended with an assessment that the remedy was not currently protective. Reviewers of the other sites concluded that the remedies were currently protective but that reviewer recommendations should be implemented to ensure future remedy protectiveness. Table 1, CERCLA Five-Year Review Results, lists the site deficiencies, protectiveness findings, and recommendations for future remedy protectiveness for these sites.

The findings fall into two general categories of deficiencies: monitoring, and remedy design or development. Not surprisingly, deficiencies related to monitoring underscored the importance of a well-conceived site-monitoring plan. Somewhat surprisingly, the survey revealed that some of the monitoring deficiencies and many of the remedy design or development deficiencies should have been foreseeable, and therefore preventable, at the time the remedy was selected.

Table 1. CERCLA Five-Year Review Results

Site	Deficiencies noted in five-year review	Remedy protectiveness assessment	Five-year review recommendations or required actions
Shattuck	• Monolith vulnerable to degradation • Absence of institutional control of off-site plume • Inadequate – Monolith-monitoring plan – Groundwater-monitoring plan – Site characterization and modeling – Risk assessment	Deficiencies affect current protectiveness	– Develop institutional controls – Conduct rigorous performance assessment model of monolith – Upgrade monolith and plume monitoring plans – Develop better transport model for natural attenuation assessment – Expand characterization data to support risk assessment – Conduct risk assessment – Re-evaluate community land use goals
Homestake Mining Company	• Monitoring plan does not provide basis for determining if cleanup goals are met • Monitoring plan does not include procedures for verifying that recontamination has not occurred • Absence of institutional controls to restrict groundwater use	Deficiencies do not affect current protectiveness; recommendations to ensure future protectiveness	– Establish monitoring procedures to verify that groundwater restoration objectives will be met and sustained – Implement institutional controls to restrict groundwater use
Bunker Hill Non-Populated Operable Unit	• Access to gulches and hillsides may need to be more restrictive • Inadequate baseline and routine groundwater and surface water site-wide monitoring plans	Remedy expected to be protective	– Determine the need for access controls and tighten access if needed – Evaluate and revise groundwater and surface water monitoring plans – Implement biological monitoring

United Creosoting	• Absence of monitoring plan to assess natural attenuation of groundwater • Absence of institutional controls to ban groundwater use and prohibit future land uses incompatible with the industrial cleanup level	Deficiencies do not affect current protectiveness; recommendations to ensure future protectiveness	– Develop program for long-term monitoring of natural attenuation of groundwater – Consider developing institutional controls to – Prohibit groundwater use, and – Guard against future land uses that are incompatible with the selected cleanup level
Carrier Air Conditioning	• Minor maintenance issues • Lack of communication between Carrier and water plant personnel can affect air stripper operations	Deficiencies do not affect current protectiveness	– Address minor maintenance issues – Carrier and water plant personnel should meet to discuss air stripper operations and maintenance
Vertac	• Landfill cover too sparsely vegetated	Deficiency does not affect remedy protectiveness	– Review status of current fish advisory for adequacy of protection – Establish suitable groundwater remedy
Williams Air Force Base OU 2	• Groundwater remedy could not be implemented because of technical impracticability	Deficiency did not affect remedy performance	– Establish suitable groundwater remedy

Monitoring Deficiencies

Remedy protectiveness, and the subsequent need to modify the remedy if it is proven to be ineffective, can only be determined if monitoring data on contaminant migration, attenuation, or releases are accurate and reliable. Reviewers of the remedies for Homestake, United Creosoting, Shattuck, and Bunker Hill determined that site-monitoring plans were so inadequate that they could not serve as a basis for rendering a judgment on remedy protectiveness or for identifying opportunities for remedy modification. As demonstrated in the Bunker Hill and Vertac five-year reviews, the need for adequate monitoring data applies to the technical as well as the land use controls components of a remedy. The results of the five-year reviews at the Williams and Homestake sites demonstrate the value of a well-designed monitoring plan.

Monitoring Plan Insufficient to Support Remedy Assessment and Modification

Reviewers of Homestake, United Creosoting, Shattuck, and Bunker Hill remedies characterized the existing monitoring plans as being inadequate to determine remedy effectiveness because there was no reliable basis for making "before and after" comparisons; that is, comparisons of environmental and biological metrics before and after the remedial action is performed. Although the remedy at Bunker Hill was still in the process of being implemented, the five-year reviewers observed that the sitewide surface and groundwater monitoring plan needed to be re-evaluated to determine if it is sufficient, in terms of sample numbers and sample analytes, to serve as a basis for making decisions about remedy effectiveness. Shattuck reviewers stressed that an extensive groundwater-monitoring program was necessary in order to develop a better understanding of site groundwater flow and contaminant processes to determine how these groundwater processes relate to the protectiveness of the monitored natural attenuation (MNA) remedy. Reviewers also recommended implementation of improved monitoring at United Creosoting in order to assess the effectiveness of the natural attenuation component of the remedy.

If the site monitoring plan is not adequate to make a determination regarding remedy effectiveness, it obviously would not be adequate to support the justification for a remedy modification. Modifying a remedy would be reasonable either because it is determined to be failing or inefficient.

In the case of Shattuck, reviewers cautioned that the existing monitoring plans were inadequate to provide the information needed to possibly modify the remedy in the event of a failure of the remedy arising before the next five-year review. Reviewers' concern with the monitoring plan for the Shattuck monolith was that it did not include a trigger to warn of pending monolith failure nor a contingency plan describing what would be done if the trigger were activated. The reviewers determined that it was possible that the integrity of the monolith could be seriously compromised before the monitoring system would detect any sign of remedy weakness or failure. The need for some type of early warning system should have been reasonably foreseeable in light of the site's urban location and proximity to groundwater.

Reviewers questioned whether the monitoring data for the Homestake site were adequate to determine whether the pump and treat system would be able to achieve agreed-upon cleanup standards. Homestake officials believe that the background concentrations for several site contaminants actually exceed their designated cleanup levels. If this were true, the selected remedy could be deemed to be inefficient and a remedy modification might be justifiable. Ironically, Homestake officials may be able to use the groundwater monitoring system, criticized as deficient in the five-year review because it could not demonstrate whether cleanup goals were being met, to document that the reason for such deficiency is that background concentrations exceed cleanup levels. Therefore, the monitoring data could be used to build the case for remedy modification.

The five-year reviews done for the Bunker Hill and Vertac sites demonstrate that the need for well-designed monitoring plans applies to the land use control components of remedies as well as their technical components. Land use controls are measures used to restrict use of resources such as land or water. The measures include physical barriers like fences, education/communication approaches, and institutional controls—mechanisms such as deed restrictions, zoning, easements, or permit programs.

Reviewers raised concerns that the contaminated gulches and hillsides of the Bunker Hill site were attractive to recreational trail bikers and suggested that monitoring be done to determine if land access controls were needed to limit or preclude bikers' exposure to contaminants. The need for such monitoring was probably not foreseeable but became obvious as experience was gained with the site remedy.

Fish consumption advisories, considered a land use control, were part of the remedy at the Vertac site because of dioxin levels. Although the Food and Drug Administration's alert level for dioxin in fish is 25 parts per trillion (ppt), the USEPA recommends 0.7 ppt as the screening level for dioxin in fish thus triggering a more intensive monitoring process. Because samples were all above this level and an area previously covered in the initial site fish advisory seemingly had been removed from the existing advisory, the Vertac reviewers recommended that the fish-monitoring program be enhanced, with consideration given to possibly reinstating the original fish advisory area.

Monitoring plan insufficiency found in this survey was caused by a variety of factors such as failures to establish adequate monitoring points (install groundwater wells or designate surface water sampling points); sample/analyze for a remedy-related analytical suite at the existing monitoring points; and use monitoring data to refine the CSM. What appeared to be lacking at these sites were adequately developed CSMs and remedy monitoring plans capable of tracking site and contaminant conditions and gauging remedy performance. For example, two of the sites with remedies including MNA were found to have deficient monitoring plans despite the fact that the USEPA's MNA guidance emphasizes the need for a thorough understanding of the CSM whenever NMA is a part of any remedy [10] .

Post-ROD remedy effectiveness determinations can only be made if the CSM is reasonably accurate, necessary baseline environmental monitoring occurs before the remedy is implemented, and the remedy is appropriately monitored after implementation. These conditions for determining remedy effectiveness should have been foreseeable when the remedy was selected and implemented.

Monitoring and Remedy Modification

The Williams site is an example of how a monitoring plan can support the need for remedy modification. Monitoring data were instrumental in reviewers' determination that the remedy was protective in spite of the fact that the complete pump and treat technical solution envisioned in the ROD was never implemented.

The two horizontal wells that had been installed as part of the pilot study/demonstration study never achieved the contaminant capture performance that had been expected. Local land use patterns changed from agriculture to residential and commercial causing a reduction in groundwater withdrawals for irrigation. The change in water use resulted in a rapid rise of the water table that made the horizontal extraction wells ineffective. Monitoring data were used in a post-ROD feasibility study to demonstrate that the rising water table made impracticable the pump and treat remedy stipulated in the ROD.

The groundwater monitoring data were also used to prove that even without the ROD-mandated pump and treat system, and despite the rising water table, the dissolved contaminant component of the groundwater plume is relatively stable. Plume stability, in combination with established institutional controls restricting groundwater use, convinced reviewers that the remedy was protective even in the absence of the selected technical remedy.

In the case of the Williams site, the impracticability of the selected pump and treat remedy and the basis for an appropriate remedy modification could only be established through monitoring data. The data were used to support an initial remedy modification replacing the pump and treat remedy with MNA and institutional controls until the Arizona Department of Environmental Quality and USEPA Region IX concur on an adequate remedy.

Although the monitoring plan was sufficiently well developed to demonstrate the technical impracticability of the remedy called for in the ROD and that the existing remedy was protective of human health and the environment, there is a touch of irony in the fact that the changing land use patterns and the resultant change in the water table should have been foreseeable. Adequate monitoring of these changes and their affect on the site could have resulted in a more realistic assessment of the feasibility of the horizontal extraction wells and the pump and treat remedy.

As described in the preceding section, the monitoring data for the Homestake site may also be useful to justify a remedy modification. In that case, Homestake officials would need to demonstrate that the cleanup levels established for the site are actually lower than background.

Remedy Design and Development Deficiencies

The deficiencies in remedy design and development identified by the five-year reviewers fall into several categories: remedy technology, public acceptability, information management, and institutional controls. In the cases described below, all these deficiencies should have been reasonably foreseeable at the time of remedy selection and therefore preventable.

Selected Technology

The Shattuck reviewers described the vulnerability of the monolith to degradation as a remedy deficiency. The technological component of the remedy—on-site stabilization of radium-226 contaminated soil in a monolith—was selected on the basis of two assumptions. First, the affected aquifer would not be used, which meant that groundwater monitoring would only be required to ensure the accuracy of that assumption. Second, the monolith would forestall further groundwater contamination.

At the time of the five-year review, the groundwater was indeed not used as a drinking water source, but at least two residents were using water from shallow wells to water their lawns. The aquifer is a Class II aquifer under USEPA guidelines and therefore is a potential source of drinking water and the site is located in Denver, a city experiencing consistent growth for the last several decades. It should have been reasonably foreseeable at the time of remedy selection that groundwater affected by the site could be used in the future, thereby serving as a potential exposure pathway. However, the remedial investigation report and the baseline risk assessment that preceded the remedy selection did not consider the groundwater pathway exposure when assessing site risk.

Although the monolith was expected to deter further groundwater contamination, pilot-study Toxicity Characteristic Leaching Procedure (TCLP) testing of the monolith revealed that the metal content of molybdenum consistently leached in excess of applicable or relevant and appropriate requirements (ARARs), and some samples contained concentrations of cobalt, chromium, and vanadium close to groundwater regulatory limits. The five-year reviewers pointed out that those findings should have raised early questions about the long-term performance of the remedy, one of the key evaluation criteria in the CERCLA remedy feasibility study process. The findings should also have provided the impetus for devising a monolith-monitoring plan capable of detecting early signs of such leaching.

Public Acceptance of Remedy

The reviewers of the protectiveness of the Shattuck remedy expressed a concern that the community's land use goals for the site were not fully understood or addressed when the remedy selection was made. The decision to create an on-site monolith consigned the site to a restricted use thereby severely limiting present and future land use possibilities. Since the monolith was 12-15 feet above normal curb height and in the midst of an urban area, it was probably reasonably foreseeable that community acceptance of the remedy would not be widespread or heartfelt.

Information Management and Dispersal

Another example of an issue that could have been reasonably foreseeable and therefore addressed in the remedy development phase relates to remedy operation and maintenance and information management at the Carrier site. Although the five-year reviewers did not define it as a deficiency, the turnover in administrative and technical staff at the town water plant treating groundwater contaminated from the Carrier site was seen as a possible indicator of potential weakness in remedy protectiveness. Staff turnover resulted in plant personnel being unaware of the air stripper design, maintenance requirements, and operations. Since the air stripper is an important element of the remedy, any system failures or inefficiencies could impact remedy protectiveness. Staff unfamiliarity with the air stripper's required maintenance and operational systems could easily contribute to system malfunction leading to remedy failure or inefficiency.

Institutional Controls

The lack of institutional controls was declared a remedy deficiency at three sites: Shattuck, Homestake, and United Creosoting. The Shattuck ROD included the implementation of groundwater and land use restrictions, but RODs for the other two sites apparently did not. The three sites were similar, however, in that they had contaminated groundwater and were proximate to property used for commercial, industrial, residential, or agricultural purposes where groundwater use could reasonably be expected to occur. Thus, the need for institutional controls should have been foreseeable when the remedies were designed and developed.

Although the Shattuck ROD specified the establishment of institutional controls as part of the remedy, they were never implemented. In discussing the institutional control component of the Shattuck remedy, the reviewers found it "questionable whether the institutional controls required to restrict the use of contaminated groundwater can ever be implemented" for off-site groundwater access, but do not explain why they came to that conclusion [2, p. VI-3].The Shattuck ROD Amendment, issued in 2000, included a statement that the City and County of Denver have the authority to issue an ordinance that would preclude use of water that is downgradient of the site or within the service area of the Denver Water Board but are not willing to do so [11]. Again, there was no explanation as to why that was so.

Institutional control of groundwater use was not built into the remedy at the Homestake site, and at the time of the five-year review, all residents of the subdivisions abutting the site were using the municipal water supply. However, even though the aquifer had been used in the past as a source of potable water, no institutional controls were in place to preclude groundwater use.

Further, although not identified as such in the Homestake review, a possible early indicator of remedy failure was the observation by a New Mexico Environment Department (NMED) representative that "people are unhappy because they cannot use their wells" [5, p. 1 (Landin interview)] and that water rights issues have arisen. The reviewers acknowledged that although the NMED, the Nuclear Regulatory Commission, and the USEPA shared concerns about the potential for site groundwater use, "institutional controls are difficult to enforce in New Mexico" [5, p. 43]. As in the Shattuck five-year review, there was no discussion of why institutional controls would or could not be implemented despite the recognized need for them.

Reviewers of the United Creosoting remedy suggested that institutional controls be considered to prohibit groundwater use and guard against future land uses incompatible with the industrial cleanup level achieved on part of the site. Although no instances of groundwater use or inappropriate land use were reported, an indicator of possible future remedy failure was an incident in which an owner of residential property refused remediation of his land but subsequently sold the property without conveying this information about the land to the new buyer. In the absence of institutional controls, future buyers might not have a way of knowing that the land should have been remediated at some point but was not.

Another possible indicator of future remedy failure at United Creosoting was the request by an on-site commercial property owner for official clarification of what constitutes acceptable uses of property cleaned to an industrial use level. On the positive side, the landowner must have been sufficiently well informed to know that the land had only been cleaned to an industrial level and therefore knew to ask about acceptable land uses. On the negative side, if there are no institutional controls in place there might not be anything binding on the landowner to use the land for industrial uses only and there might not be any mechanism in place to notify future landowners of the fact that the land contains residual contamination and is safe only for limited uses.

RECOMMENDATIONS

As this brief survey of five-year reviews indicates, remedies have not failed, but several significant remedy protectiveness deficiencies were identified within five years of the remedy being selected and implemented. In many cases, these deficiencies could have been avoided because they should have been foreseeable at the time when the remedy was developed and selected.

In one case, Shattuck, the deficiencies were of sufficient concern and the public non-acceptance of the remedy so pervasive that the remedy selected in 1992, construction of a monolith of contaminated soil in an urban area, was modified in 2000 to require removal of the monolith [11]. Although the activities required to address remedy deficiencies and incorporate suggested recommendations for ensuring future remedy protectiveness at the other reviewed sites will not be as extensive as in the case of Shattuck, they will carry a cost in terms of dollars and, possibly, loss of the public's confidence in the selected remedy. This could result, as it did at Shattuck, with re-opening the remedy and possibly needing to re-characterize the site, develop a new CSM, and conduct a new remedy selection process.

Two recommendations, discussed in more detail below, flow from this survey of several five-year reviews. First, a comprehensive monitoring plan must be developed and implemented to demonstrate that the remedy is protective of human health and the environment or that it must be modified to achieve such protectiveness. Second, a thorough analysis of past, present, and future land and resource use must be conducted at the time of remedy development to identify if land use controls are needed and if they can be implemented and effective.

Developing Comprehensive Remedy-Monitoring Plans

The general nature of the remedy-monitoring plan (RMP) should be fully considered during the design phase of the cleanup process. However, a remediation manager may need to be well into the remedial action stage before being able to best craft a comprehensive RMP.

As the cleanup process transitions from site characterization and the associated monitoring required for developing the CSM to the actual remediation work, it is tempting to shift funding and resources away from monitoring in favor of quickly implementing the selected remedy. This examination of five-year reviews suggests that in some cases an actual increase in monitoring frequency and monitoring points in the post-remedy implementation phase of the cleanup process may be cost effective over the long-term. This is so because a robust RMP is needed to substantiate the efficacy of a remedy or develop a case for remedy modification, as at the Williams and Homestake sites. At a minimum the RMP should include:

- Remedy monitoring objectives;
- Remedy monitoring frequency;

- Sampling and analysis strategies and quality assurance/quality control measures;
- Information management and reporting requirements, including the generation, storage, and transmittal of a bifurcated data stream with the parent data stream for the technical staff and a reduced data stream for nontechnical stakeholders;
- Monitoring events that trigger the need to consider modifying the remedy or the monitoring plan; and
- Knowledgeable personnel with the resources to perform remedy monitoring and provide feedback on remedy effectiveness.

In addition to monitoring remedy performance, the RMP should include methods to monitor current and future land use and the exposure assumptions underlying the remedy. Such monitoring can be of vital importance because in most cases a remedy can only remain protective if the land use on which it is based remains the same. If monitoring demonstrates that the land use has changed, the remedy decision may need to be re-opened.

There is no doubt that the costs of remedy maintenance and monitoring can be significant due to the required rigor and the long time frames involved when residual contamination remains on site. In some cases, monitoring needed to support a site remedy may be as rigorous as the monitoring required to characterize the site in preparation for remedy selection. The Department of Defense is expected to spend more than $1 billion per year on the operation, maintenance and monitoring of remediation systems [12]. The U.S. Department of Energy projects spending $100 million annually on site-stewardship in out-years [13]. In light of these costs, remedy custodians might be tempted to reduce the remedy-monitoring regime. But results of these five-year reviews point out the need for a robust monitoring plan. Monitoring optimization [12, 14, 15] should be encouraged as a way to minimize monitoring cost but ensure comprehensive monitoring.

Determining if Institutional Controls are Needed—And Can Be Implemented and Effective

The need for institutional controls at Shattuck was acknowledged when the remedy was selected but apparently was recognized at Homestake and United Creosoting only as a result of the five-year review. Because of prior resource use, existing land use, and reasonable expectations of future development, the need for institutional controls should have been recognized at these two sites when the remedy was selected. But, as this survey of five-year reviews points out, merely recognizing the need for institutional controls is meaningless if they cannot or will not be implemented, as at Shattuck and Homestake.

The apparently effective use of institutional controls at the Carrier site presents a stark contrast to the situation at the Shattuck and Homestake sites. The Carrier remedy involves layering institutional controls in that it relies on several different mechanisms to serve one end—protectiveness of the remedy [16].

Institutional control layers at the Carrier site include zoning for industrial use only, town and county ordinances restricting the use of shallow water bearing zones in the area, and a county program that requires a permit for wells tapping into the Memphis Sand aquifer, the area's primary drinking water source. In addition, the county bans installation of drinking water wells within 0.5 mile of any state or federal Superfund site (subject to appeal if the applicant for the well can demonstrate that the well will not enhance contaminant migration.) Thus, five different layers of institutional controls are in place at the Carrier site. These institutional controls were either already in place at the time of the Carrier remedy selection or were implemented in response to the recognized need for them.

Land use controls, generally in the form of institutional controls, will be required when residual contamination is left on a site as a part of the selected remedy. Just as the technologies and processes of several site remedial alternatives are compared against the nine evaluation criteria of the NCP in order to select a remedy, the land use controls associated with alternatives that include leaving contaminants on site should also be evaluated against those same criteria. Such an evaluation will require remedy selectors to determine the implementability, effectiveness, and cost of land use controls necessary to ensure remedy protectiveness. Had this type of evaluation been done for the proposed remedy of a monolith and land use controls at Shattuck, the non-implementability of the institutional controls might have been recognized early and a more acceptable and realistic remedy might have been identified.

Prior to evaluating the implementability, effectiveness, and cost of land use controls proposed as part of a remedy, remedy investigators will need to understand the strengths, weaknesses, and applicability of the available methods just as they must in the case of the remediation technologies and processes under consideration. Determining what land use controls should be included when designing and evaluating remedial alternatives requires understanding and seeking answers to the following questions, at a minimum:

- Who will own the land;
- What is the reasonably foreseeable use of the land and its resources;
- What is the reasonably foreseeable use of contiguous land and resources;
- How are site and surrounding lands and resources presently being used;
- How were site and surrounding land and resources previously used;
- What institutional controls are available; and
- Are the available institutional controls capable of being implemented and enforced?

Thoroughly understanding these issues should result in selecting land use controls that can be implemented and have a greater likelihood of success in being protective of human health and the environment.

REFERENCES

1. U.S. Environmental Protection Agency, *Comprehensive Five-Year Review Guidance,* EPA 540-R-01-007, Office of Emergency and Remedial Response, Washington, D.C., June 2001.
2. SC&A, *Five Year Review Report,* SC&A, Inc., Denver, Colorado, November 1999.
3. IT Corporation, *Final Record of Decision Operable Unit 2,* prepared for Headquarters, Air Training Command/DEEV Randolph Air Force Base, Texas, December 1992.
4. IT Corporation, *Final Five-Year Review Report for Williams Air Force Base, Mesa Maricopa County, Arizona,* prepared for Air Force Center for Environmental Excellence, Brooks Air Force Base, Texas, June 2001.
5. CH2M Hill, *First Five-Year Review Report for Homestake Mining Company Superfund Site Cibola County, New Mexico,* prepared for Region 6, U.S. Environmental Protection Agency, Dallas, Texas, September 2001.
6. U.S. Environmental Protection Agency, *First 5-Year Review of the Non-Populated Area Operable Unit Bunker Hill Mining and Metallurgical Complex Shoshone County, Idaho,* Region 10, June 2000.
7. CH2M Hill, *First Five-Year Report for United Creosoting Company Superfund Site, Conroe, Montgomery County, Texas,* prepared for Region 6, U.S. Environmental Protection Agency, Dallas, Texas, September 2000.
8. U.S. Environmental Protection Agency, *Carrier Air Conditioning Superfund Site Five Year Review,* Region 4, August 2000.
9. CH2M Hill, *First Five-Year Review Report for Vertac Incorporated Superfund Site, Jacksonville, Pulaski County, Arkansas,* prepared for Region 6, U.S. Environmental Protection Agency, Dallas, Texas, July 2001.
10. U.S. Environmental Protection Agency, *Use of Monitored Natural Attenuation at Superfund RCRA Corrective Action, and Underground Storage Tank Sites,* Office of Solid Waste and Emergency Response, Directive 9200.4-17, Washington, D.C., April 1997.
11. U.S. Environmental Protection Agency, *Record of Decision Amendment, Denver Radium Site, Operable Unit VIII, Denver, Colorado,* Region 4, June 2000.
12. U.S. Air Force, *Final Remedial Process Optimization Handbook,* prepared for Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks Air Force Base, San Antonio, Texas, and Defense Logistics Agency (DLA), Environmental and Safety Office, DSS-E0, Fort Belvoir, Virginia, June 2001.
13. U.S. Department of Energy, *A Report to Congress on Long-Term Stewardship, Vol. 1—Summary Report,* Washington, D.C., January 2001.

14. Radian International, *Guidance for Optimizing Remedial Action Operations (RA), Interim Final,* prepared for Naval Facilities Engineering Service Center, April 2001.
15. M. Ridley and D. MacQueen, *Cost-Effective Sampling of Groundwater Monitoring Wells: A Data Review and Well Frequency Evaluation,* U.S. Army Environmental Center, December 2000.
16. National Research Council, *Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites,* Washington, D.C., 2000.

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