Journal of Soil Contamination, 2(1): (1993)

Screening Site Contamination Using Pathway Exposure Factors

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ABSTRACT: Radian Corporation conducted an investigation of 29 waste sties at an air force base in New Mexico in partial fulfillment of the RCRA operating permit requirements for the facility. The contract required that the investigation be conducted under the Installation Restoration Program (IRP/CERCLA). In an effort to satisfy both RCRA and CERCLA requirements, a hybrid approach was taken for the risk assessment. Site contaminants ranged from petroleum and unconventional fuels to solvents, pesticides, and PCBs. A screening method was developed to classify the level of contamination at each of the 29 sites based on soil and groundwater sampling results. Under this method, sites were classified as "dirty," "clean," or "borderline." Dirty sites did not require a full-scale risk assessment because some form of remedial action would be necessary. However, clean sites and borderline sites required a full-scale risk assessment. For clean sites, the risk assessment served as justification for no further action; for borderline sites, the risk assessment determined whether or not remedial action would be required. The screening method used previously developed multipathway and multimedia models for estimating potential human exposure to environmental contaminants in the air, water, and soil through inhalation, ingestion, and dermal contact routes. Pathway exposure factors (PEFs), which combined information on human physiology, behavior patterns, and models of environmental transport, were used to determine the relationship between the concentration of environmental contaminants and human exposure. The PEF converts concentrations in environmental media to lifetime-equivalent chronic daily intakes (CDI). Three exposure pathways contributing the greatest proportion of the risk were considered for screening these sites: (1) incidental ingestion of soil; (2) dermal contact with soil; and (3) ingestion of water. This project demonstrated that a screening approach could be used effectively to limit the number of full-scale risk assessments required for a multisite investigation.

KEY WORDS: risk assessment, screening, multimedia.

I. INTRODUCTION

Radian Corporation (Radian) conducted a remedial investigation for 29 waste sites at an air force base in New Mexico. The objectives of the work were to investigate these sites and make recommendations regarding site remediation where contaminants exceeded the accepted levels for humans or the environment or both. A baseline risk assessment was planned for each of the sites as part of the investigation. Preliminary review of the site investigation results indicated that groundwater and/or soils at a few sites were heavily contaminated.

Our previous experience for other projects indicated that risk assessments for contamination at such heavy levels would likely result in unacceptable risk. Performing comprehensive baseline risk assessments can require intensive effort, particularly when environmental fate and transport modeling is required. This level of effort is necessary and appropriate when the likelihood of excess risk is uncertain or to justify no action at a site with acceptable risks. The need for this effort is less clear when the levels of contamination are so high that excess risks are likely to result from the site.

Radian developed a method for screening analytical results to determine the likelihood of unacceptable risks and applied the method to the sites at an air force base (AFB). This article provides background on the overall project and the site investigation, describes the methods used to screen the sites, and compares the results of the screen with those of the subsequent comprehensive risk assessment.

A. **Regulatory Background**

The AFB operates a RCRA-permitted on-site storage facility for currently generated hazardous wastes. Because of the facility operating permit, the base is subject to the RCRA corrective action program. The HSWA portions of the permit require the base to conduct a RCRA facilities investigation (RFI) at solid waste management units (SWMUs).

The Department of Defense (DOD) is conducting a nationwide program, called the Installation Restoration Program (IRP), to evaluate waste disposal practices on DOD property, to control the migration of hazardous contaminants, and to control hazards that may result from these waste disposal practices. The U.S. Air Force has modified the IRP to provide for a Superfund-like RI/FS program. An IRP investigation is being conducted at the base.

Both the IRP and the RCRA corrective action programs are ultimately intended to ensure remediation of contaminated sites that pose an actual or potential threat to public health, welfare, or the environment. There are differences, however, and EPA has confirmed that because the two programs are independent environmental requirements, federal facilities must comply with the requirements of both programs (McKone and Daniels, 1991). The investigation conducted by Radian was designed to comply with the requirements of both these programs.

B. **Base Background**

Originally established as a transitional flight-training facility, the base was reactivated after World War II with emphasis on guided missile research and testing. The primary mission remained guided missile and aerospace research until 1968, when a Tactical Fighter Wing was assigned there. Aerospace research continues at the base through activities at the Test Track Sled Facilities.

The base is located in the Tularosa Basin in Otero County of southern New Mexico. The nearest city of any size is located approximately 7 miles east of the facility. Much of the land on the base is open space, but development is constrained by environmental and operational factors.

The climate in the Tularosa Basin is arid, with low annual rainfall and low relative humidity. Most of the surficial soils at the base are well-drained, sandy loam and gypsum; the soils are moderately permeable, calcareous, and mildly-to-moderately alkaline. Groundwater occurs under water table conditions at depths ranging from 2- to 40-feet below land surface. The primary source of recharge is percolation of rainfall and stream runoff from the mountains. The site investigation results indicate that background water quality is poor in the shallow groundwater, with total dissolved solids (TDS) typically greater than 10,000 mg/l. Therefore, groundwater underlying the base is classified as nonpotable.

C. **Field Investigation Overview**

The field investigation involved a series of activities to collect environmental data. Soil borings and hand auger borings were drilled to investigate possible soil contamination and to characterize subsurface conditions. Monitor wells were installed to investigate possible groundwater contamination and to characterize local groundwater conditions. Other investigative techniques, such as an electromagnetic survey, a soil gas survey, grid sampling for PCBs, waste excavation and characterization, and trenching were used at several sites.

Samples were analyzed using EPA-approved methods. Analyses performed for particular sites were selected based on site history and past waste disposal practices. Soil and groundwater samples were analyzed for one or more of the following: volatile organic compounds, semivolatile organic compounds, total recoverable petroleum hydrocarbons, oil and grease, total metals, organic lead, organochlorine pesticides, PCBs, organophosphorus pesticides, chlorinated herbicides, total organic carbon, anions, total dissolved solids, and explosives. Appropriate field and method blanks were included in the analyses, and spiked samples were analyzed to assess method recovery.

II. RISK SCREENING METHODS

Because of the size and complexity of the project, 25 of the sites were subjected to a risk screening procedure prior to the comprehensive risk assessment. The sites were ranked and classified according to their level of contamination. The ranks used were "clean," "borderline," and "dirty." Sites given a rank of clean or borderline were included in the comprehensive risk assessment. Sites ranked as dirty were automatically considered candidates for remediation.

A. Site Contaminants and Pathways

Soil and groundwater were assessed separately. The maximum chemical concentrations found at each site were used for risk screening. Use of the maximum concentration rather than an average could overestimate the risk associated with the site. The intent, however, was to devise a method that would be reasonably fast and easy to implement. Moreover, because sites with unacceptable screening results were automatically considered candidates for remediation, overestimation of the risk erred on the side of conservatism.

For screening purposes, two pathways were chosen: soil ingestion and water ingestion. Soil ingestion is the soil exposure pathway providing the greatest exposure. Because the soil was known to be contaminated, and ingestion of soil could occur at least at some of the sites, this pathway was chosen to be conservative. Groundwater is not currently being consumed on- or off-base; the water underlying the base is nonpotable.

Ingestion of groundwater was included in the screening assessment, nonetheless, to ensure conservatism.

B. Pathway Exposure Factors

The screening method is based on multimedia, multipathway models previously developed by McKone and Daniels. These models link concentrations in the environment to human exposure through ingestion and other pathways. The models allow incorporation of physiological data, such as average daily drinking water intake, along with lifestyle data, such as time spent living at one residence. They convert concentrations of chemicals in the environment, such as mg/kg in soil or mg/l in water, into lifetime-equivalent chronic daily intakes in mg/kg/day. These models are defined as pathway exposure factors, or PEFs.

The PEFs are constants, specific to each pathway that combines all of the exposure variables for that pathway into a single factor. Standard values for the exposure variables were obtained from EPA guidance (U.S. Environmental Protection Agency, 1989b, 1989c, 1991, 1992). The PEF for water ingestion was derived using the standard value for daily water intake (2 l/d) and the standard adult body weight (70 kg) to give a factor of 0.034 l/kg/d. Multiplying the concentration of a contaminant in water (in mg/l) by the water ingestion PEF of 0.034 l/kg/d gives the chronic daily intake of that contaminant in mg/kg/d. The assumed daily soil ingestion rates for children are higher than those for adults,[4] and body weights for these ages differ. Therefore, a lifetime soil ingestion PEF was calculated using age-specific ingestion and body weight assumptions and amortizing the resulting values over a lieftime. The lifetime PEF for soil ingestion was 1.5×10^6 (mg/kg/d)/(mg/dg). Multiplying the concentration of a contaminant in soil (in mg/kg) by the soil ingestion PEF of 1.5×10^6 (mg/kg/d)/(mg/kg) gives the chronic daily intake of that contaminant in mg/kg/d.

The chronic daily intakes for both the soil and the groundwater pathways were used to estimate the carcinogenic and noncarcinogenic risk. To determine the potential pathway-specific carcinogenic risk for a chemical, the chronic daily intake determined using the PEF was multiplied by the slope factor for that chemical. The potential pathway-specific noncarcinogenic risk was determined by dividing the chronic daily intake by the Reference Dose (RfD) for the chemical. Slope factors and RfD values were obtained from EPA publications (U.S. Environmental Protection Agency, 1992). Thus, a maximum of four screening values was determined for each site: carcinogenic and noncarcinogenic risk estimates for the groundwater ingestion pathway and carcinogenic and noncarcinogenic risk estimates for the soil ingestion pathway.

C. Risk Ranking

Risk ranking was performed in two phases. In phase I, an overall rank was determined for carciongenic risk and for noncarcinogenic risk separately as follows. The carcinogenic risk due to ingestion of groundwater was added to that for ingestion of soil. Similarly, the noncarcinogenic risk due to ingestion of groundwater was added to that for ingestions of soil, so that a total was determined separately for potential carcinogenic and noncarcinogenic risk. This is the same process as that used in a comprehensive risk assessment to

TABLE 1
Ranking Estimated Risks

	Clean	**Borderline**	**Dirty**
Carcinogenic risk estimate	$<10^5$	10^5 risk$<10^3$	$>10^3$
Noncarcinogenic risk estimate	<1	1 < risk <3	>3

determine total risks resulting from a particular site (U.S. Environmental Protection Agency, 1989b). The total carcinogenic or noncarcinogenic risk for a site was used to classify the site as clean, borderline, or dirty in accordance with the criteria shown in Table 1. Therefore, each site was given two ranks: one for carcinogenic risk and one for noncarcinogenic risk.

Some of the sites received different ranks for carcinogenic and noncarcinogenic risk (such as clean for carcinogenic risk and borderline for noncarcinogenic risk). These sites were evaluated in phase II of the ranking to determine the most appropriate overall rank. Three combinations were possible: clean/dirty, borderline/dirty, and borderline/clean. In addition, some sites that received dirty ranks for both risks were located in remote parts of the base where no receptors or pathways were expected. Phase II of the ranking for these sites evaluated location-specific parameters qualitatively to determine if there were, in fact, receptors for those sites. Based on this evaluation, an overall rank was determined for all sites; a few sites were downgraded from dirty to borderline. After phase II ranking was complete, four sites were ranked as dirty, 14 as borderline, and 7 as clean. The four sites considered dirty were automatically selected as candidates for remediation. The sites classified as clean or borderline were subjected to a comprehensive risk assessment.

III. COMPARISON OF SCREENING RESULTS TO COMPREHENSIVE RISK ASSESSMENTS

The purpose of the risk screening method was to determine which sites were contaminated to the point that human health risk resulting from the site would be unacceptable. Those sites were selected automatically as candidates for remediation, whereas sites considered borderline or clean were subjected to a comprehensive risk assessment. The risk assessment would be used either to support a no-action decision leading to a recommendation for site closeout or to identify unacceptable risks and support a feasibility study (FS). Thus, the effort required to perform the risk assessment was expended only on those sites that would benefit from the detailed risk information.

If the risk screening method were too conservative, sites could be selected for remediation that might not actually require it. If the risk screening method were not conservative enough, many sites considered borderline might actually require remediation, so that the effort expended on the detailed risk assessment might not be entirely useful. Therefore, it was important to compare the results of the risk screen with the results of the comprehensive assessment to evaluate whether the screen was sufficiently, but not excessively, conservative. Conversely, the sites selected as candidates for remediation had to be evaluated to determine whether the risk screen was too conservative and sites with potentially acceptable risks screened out.

A. **Comparison of Risk Screen with Comprehensive Risk Assessment**

The 21 sites receiving screening ranks of clean or borderline were evaluated in a comprehensive risk assessment. The comprehensive assessment was conducted in accordance with EPA guidelines (U.S. Environmental Protection Agency, 1989b). Three exposure scenarios were identified: direct residential exposure, which included pathways such as inhalation of chemicals in ambient air volatilized from the waste site as well as recreational exposure when appropriate; indirect residential exposure, based on transport of contaminants to an agricultural well used to provide water for grazing cattle; and occupational exposure. At least one of these scenarios was applicable for most sites, and more than one scenario was evaluated for some sites. No exposure scenarios were identifed for four sites that are located in remote parts of the base, are distant from the residential areas, and have no on-site workers.

*1. **Sites with Potential Residential Exposure***

Five sites were found to have the potential for on- or off-base receptors for contaminants. Table 2 compares the results of the risk screen with those of the comprehensive assessment. The waste storage/spill site was considered clean for carcinogenic risk and dirty for noncarcinogenic risk. The comprehensive assessment found acceptable carcinogenic risk, but potentially unacceptable noncarcinogenic risk (Hazard Index value of 1). Although a Hazard Index value of 1 is normally considered acceptable, there was concern that the comprehensive assessment underestimated the potential for noncarcinogenic risk. Therefore a FS will be performed for this site.

Recreational exposure was responsible for the majority of the risk for this site. Because recreational exposure emphasizes the soil contact pathways for children, and because carcinogenic risks are rarely estimated for children, the dirty screening rank for noncarcinogenic risk for this site correlates positively with the finding of potentially unacceptable noncarcinogenic risk for this site. Nonetheless, the risk screen result for noncarcinogenic effects (12.1) substantially overestimated the actual risk for this site (1.0).

The Main Substation and the Old and New Entomology Shops were found by the risk screen to be borderline for carcinogenic risk and clean for noncarcinogenic risk. For each of these three sites, the comprehensive assessment found both carcinogenic and noncarcinogenic risk to be acceptable, so site closeout was recommended. The Grit Burial Site received ranks of borderline and dirty for carcinogenic and noncarcinognic risk, respectively, from the risk screen. The comprehensive assessment found that both carcinogenic and noncarcinogenic risks were acceptable, so site closeout was recommended.

TABLE 2
Comparison of Results for Sites with Potential Residential Exposure

	Screening results			Comprehensive assessment		
Site	Carcinogenic	Noncarcinogenic	Risk[a]	Carcinogenic	Noncarcinogenic	Result
Waste storage/spill	1.6E-7	12.1	C/D	7E-8	1.0	Feasibility study
Main substation	1.7E-5	0.16	B/C	8E-7	—[b]	Site closeout
Old entomology shop	9.0E-4	0.3	B/C	5E-9	3E-6	Site closeout
New entomology shop	3.2E-4	0.2	B/C	5E-12	5E-8	Site closeout
Grit burial site	6.0E-4	7.1	B/D	2E-10	0.002	Site closeout

[a] Rank for carcinogenic risk/rank for noncarcinogenic risk.
[b] No noncarcinogenic constituents were confirmed at the site.

These results suggest that the risk screen overestimated carcinogenic and noncarcinogenic risks. The risk screen, however, assumes the soil and groundwater direct contact pathways are complete; in the comprehensive assessment these pathways were found not to be complete for these four sites. In any case, the risk screen served the purpose of selecting for comprehensive assessment those sites with potentially acceptable risks.

2. ***Sites with Indirect Residential Exposure***

Six sites were located distant from the on-base residential areas, and the comprehensive assessment found that receptors were not expected to come into direct contact with contaminants found at these sites. Indirect residential exposure was possible due to migration of contaminants in groundwater to an agricultural well used to provide stock water for cattle grazing off-base. The risk screen results for these are compared with the comprehensive assessment in Table 3.

The Landfill Disposal site was the only one of the six receiving a screen rank of clean for both carcinogenic and noncarcinogenic risk. Environmental fate and transport modeling, conducted as part of the comprehensive risk assessment, found that none of the contaminants at this site would reach the receptor well; therefore, there were no risks associated with this site. The Possible Fuel Spill Site and West Landfill No. 2 received screen ranks of clean for carcinogenic risk and bordlerline for noncarcinogenic risk. The comprehensive assessment found that risks associated with these two sites are also accpetable. The Golf Course Landfill received screen ranks of clean for carcinogenic risk and dirty for noncarcinogenic risks; the comprehensive assessment indicated that risks were acceptable.

The Former Maintenance Area was found to be borderline for both carcinogenic and noncarcinogenic risks by the risk screen. Again, environmental fate and transport modeling, used for the comprehensive assessment, found that no contaminants reached the receptor well, so no risks were associated with the site. Finally, West Landfill No. 1 received screen ranks of dirty for both carcinogenic and noncarcinogenic risks. Because environmental fate and transport modeling found that no contaminants reached the receptor, there were no risks associated with this site.

Comparison of the results for these sites demonstrates overprediction of risk by the screening procedure. The screen assumes that direct contact with soil and groundwater occurs at a particular site. For these six sites, no direct contact was found to occur. Moreover, environmental fate and transport modeling found that for two sites, the carcinogenic contaminants would not reach the receptor well and for three sites, none of the contaminants would reach the receptor well. Although the risk screen appeared to markedly overpredict the risk for these six sites, the phase II assessment of location-specific parameters prevented any of these sites from being selected for remediation. The results for these sites underscores the

TABLE 3
Comparison of Results for Sites with Indirect Residential Exposure

	Screening results			Comprehensive assessment		
Site	**Carcinogenic**	**Noncarcinogenic**	**Rank[a]**	**Carcinogenic**	**Noncarcinogneic**	**Result**
Landfill disposal trench	2.7E-6	0.1	C/C	NC[b]	NC	Site closeout
Possible fuel spill site	3.2E-6	1.8	C/B	2E-7	0.02	Site closeout
West landfill no. 2	3.2E-6	2.4	C/B	—[c]	0.002	Site closeout
Golf course landfill	5.6E-6	13.7	C/D		0.04	Site closeout
Former maintenance area	2.7E-5	1.5	B/B	NC	NC	Site closeout
West landfill no. 1	6.6E-3	14.7	D/D	NC	NC	Site closeout

[a] Rank for carcinogenic risk/rank for noncarcinogenic risk.
[b] NC: No contaminants reached the receptor.
[c] Carcinogenic contaminants did not reach the receptor.

importance of the phase II screening to avoid selection of remediation for sites with no (or distant) receptors.

3. *Sites with Occupational Receptors*

Four sites were located at or adjacent to areas where workers were expected to be present daily. The results of the risk screen are compared with the comprehensive assessment in Table 4. The Old Entomology Shop site received a risk screen rank of borderline for carcinogenic risk and clean for noncarcinogenic risk. The comprehensive assessment was unacceptable for both carcinogenic and noncarcinogenic risk. Contamination at this site was present in surface soils. The site area is currently used intermittently for storage of materials, either on pallets or in direct contact with the soils (and possibly in contact with the contaminants). Exposures evaluated for this site included dermal contact with and direct ingestion of soil. Although the risk screen included the soil ingestion pathway, the screen assumed standard adult ingestion rates of 100 mg soil/d. In contrast, the comprehensive assessment used a higher soil ingestion rate based on work in a dusty environment. Moreover, dermal contact with soil was included in the comprehensive assessment at levels higher than those used for incidental dermal contact in a residential scenario. Therefore, it is not surprising that the screen underestimated the risk.

The Maintenance Area also received ranks of borderline for carcinogenic risk and clean for noncarcinogenic risk. The comprehensive assessment found that risks associated with this site were acceptable. Occupational exposure assessed for this site did not include extensive contact with soil, because most maintenance activities are conducted inside the shop. The Grit Burial Site and the Missile Fuel Spill Area each received ranks of borderline for carcinogenic risk and dirty for noncarcinogenic risk. In each case, the comprehensive assessment found the risks to be acceptable. These latter two sites also demonstrate the need for phase II screening to avoid selection of remediation for sites that do not require it.

B. Sites Selected for Remediation

Four sites were selected for remediation based on the results of the risk screen. Because comprehensive assessments were not performed for these sites, the risk screen results cannot be compared directly with comprehensive results. Table 5 reviews these sites, their risk screen results, and the important exposure pathways for each. The POL Spill Site ranked dirty overall for carcinogenic risk and borderline for noncarcinogenic risk. As shown in Table 5, groundwater underlying the site discharges into an arroyo where children play. Based on the high concen-

TABLE 4
Comparison of Results for Sites with Occupational Exposure

	Screening results			Comprehensive assessment		
Site	**Carcinogenic**	**Noncarcinogenic**	**Rank[a]**	**Carcinogenic**	**Noncarcinogenic**	**Result**
Old entomology shop	9.0E-4	0.3	B/C	1E-4	3	FS
Maintenance area	1.3E-5	0.8	B/C	1E-20	—[b]	Site closeout
Grit burial site	6.0E-4	7.1	B/D	1E-8	0.05	Site closeout
Missile fuel spill area	7E-4	50.6	B/D	1E-17	7E-13	Site closeout

[a] Rank for carcinogenic risk/rank for noncarcinogenic risk.
[b] No noncarcinogenic contaminants were confirmed at the site.

TABLE 5
Sites Selected as Candidates for Remediation

Site	Pathway	Carcinogenic	Noncarcinogenic	Rank	Pathway evaluation
POL spill site	Water	2.9E-3	0.66	D/C	Water discharges directly into an arroyo where children play
	Soil	2.1E-5	1.6	B/B	Site access is controlled
Lead disposal trench	Water	4.8E-3	12.7	D/D	Water discharges directly into arroyo where children play
	Soil	2.0E-8	1.9	C/B	Trench located on the side of the arroyo
Truck washrack	Water	1.1E-2	4.2	D/D	Water travels ~$^1/_2$ mile to discharge to arroyo
	Soil	1.6E-4	13.9	B/D	Site access not controlled; surface runoff likely
Disposal pits and trenches	Water	7.9E-4	12.3	B/D	Water travels several miles to discharge to arroyo
	Soil	2.3E-3	50.6	D/D	Site access uncontrolled, pits are open

trations of contaminants in groundwater, it is unlikely that the risk for this site would have been acceptable.

The Lead Disposal Trench received overall ranks of dirty for both carcinogenic and noncarcinogenic risk. The risk screen values for this site were even higher than those for the waste storage/spill site (see Table 2), which was found to require an FS. Because the waste at this site had even higher concentrations of some contaminants, and there is some possibility that children playing in the adjacent arroyo could come into direct contact with the waste body, it is highly unlikely that risks for this site would have been acceptable in a comprehensive assessment.

The Truck Washrack received overall risk screen ranks of dirty for both carcinogenic and noncarcinogenic effects. These ranks were due primarily to the presence of high concentrations of pesticides in surface soil and (to a lesser extent) in groundwater. Although this site is located not far from the on-base residential area, the greatest risk from site contaminants would likely result from occupational exposure. Contact of workers with the contaminated soil is expected to be equal to or (more likely) greater than that for the Old Entomology Shop site (see Table 4). The risk screening values were much higher for the Truck Washrack than for the Old Entomology Shop. Therefore, it is likely that the risks calculated for the Truck Washrack in a comprehensive assessment would be unacceptable as were the risks for the Old Entomology Shop.

The Disposal Pits and Trenches received overall risk screen ranks of dirty for both carcinogenic and noncarcinogenic effects. This was due primarily to high concentrations of contaminants in shallow and deep soils. The site is located some distance away from on-base or potential off-base residential areas, and workers are not present at the site regularly. Some of the pits are open, however, with waste materials clearly exposed, and there are no institutional controls (such as a fence) in place to limit site access. Because of the nature of the site contaminants, an administrative decision was made to proceed with the FS to evaluate primarily institutional controls to limit site access. Therefore, a comprehensive assessment was not performed, even though the site could have passed the phase II ranking procedure based on the lack of receptors.

C. **Risk Screen Predictions**

Table 6 presents an evaluation by exposure scenario of the number of sites for which the risk screen over- or underestimated the risks. If a screening rank of clean for a site was found to be too low compared with the results of the comprehensive assessment, the screen would have underestimated the risk. This was not found to occur for either the direct or indirect residential exposure scenarios, but was found for one of two occupational scenarios given a rank of clean. Conversely, if the screening rank of dirty was found to be too high, then the screen would be grossly overestimating the risk. This was found for two of the three residential scenarios

TABLE 6
Assessment of Risk Screen Ranks

Scenario	Number of clean ranks too low	Number of borderline ranks: Too low	Number of borderline ranks: Too high	Number of dirty ranks too high
Residential	0/4	0/4	4/4	1/2
Indirect residential	0/3	0/2	2/2	1/1
Occupational	1/2	1/4	3/4	2/2

and both of the occupational scenarios ranking as dirty. Analysis of the borderline ranks indicates that this rank was usually too high.

The risk screen appears to overestimate risk more often than it underestimates risk. This is most likely due to the fact that the risk screen approach assumes direct contact with both soil and groundwater, wherease the majority of the sites with potential residential exposure did not have the potential for direct contact. In contrast, the risk for the occupational scenario with significant direct soil contact was underestimated by the screen. These results underscore the importance of the phase II ranking, in which actual exposure pathways are considered qualitatively to evaluate the screen results. Although our initial approach used the phase II screen only to reduce the risk rankings for sites with no direct residential exposures, the results for the occupational scenarios suggest phase II screening should also be used to increase the risk ranks where known exposures are expected to be higher than those used by the screen.

IV. CONCLUSIONS

The risk screening procedure was quick and easy to use, as expected. The results in the previous section indicate that the risk screen may over- or underestimate the risk for a site, depending on the relationship between the pathways used for screening and the magnitude of that pathway for the site. Nonetheless, based on a comparison with the results of the comprehensive assessment for similar sites, the screen appeared to predict correctly the four sites that require remediation. Out of the remaining 21 sites, only two were found from the comprehensive assessment to require an FS. Thus, for 19 of 21 sites, performing the comprehensive assessment was justified to support a no-action decision and a recommendation for site closeout. Therefore, the risk screen developed by Radian accomplished with reasonable success its primary goal: selection of sites requiring remediation without expending the effort required to perform a comprehensive assessment, while selecting only sites for the full assessment requiring support for a no-action decision.

It is likely that better concordance between the risk screening results and the comprehensive assessments would be obtained for sites with direct residential exposure. Such sites would be expected to have potential for ingestion of soil and groundwater, the two pathways on which the screening method is based. Although the groundwater ingestion pathway does not represent the only risk associated with domestic use of groundwater, and other water-use pathways (such as inhalation in the shower of chemicals volatilized from domestic water) may result in levels of risk equal to that of ingestion, use of the maximum contaminant concentration for risk screening rather than an average would likely avoid underprediction of risk. This risk screening method can also be used to rank sites in order of likely risk. Many facilities, both DOD installations and commercial (such as refineries or chemical plants), have numerous SWMUs for which RFIs, and potentially corrective action, will be required. The risk screening procedure provides a simple and fast method for ranking such sites on the basis of the limited information that might be available from a preliminary assessment, for example. Because few data are required to use this procedure, the ranking could be done early in the RFI process to focus the efforts on the SWMUs that are likely to present the greater potential risks to human health.

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