Multimedia Assessment of Health Risks for the Weldon Spring Site Remedial Action Project

Lynne A. Haroun, Margaret M. MacDonell,
John M. Peterson, and Donald J. Fingleton

Environmental Assessment and Information Sciences Division
Argonne National Laboratory
9700 South Cass Avenue, Argonne, Illinois 60439

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DISCLAIMER

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INTRODUCTION

The U.S. Department of Energy (DOE), under its Surplus Facilities Management Program (SFMP), is responsible for cleanup activities at the Weldon Spring site, Weldon Spring, Missouri. The site is located in St. Charles County, Missouri, about 48 km west of St. Louis (Figure 1). The site consists of two noncontiguous areas: (1) the chemical plant area, which includes four raffinate pits, and (2) the quarry. The quarry is located about 7 km southwest of the chemical plant area and less than 2 km northwest of an alluvial well field that constitutes a major source of potable water for St. Charles County (Figure 2). The Weldon Spring site became radioactively and chemically contaminated as a result of processing and disposal activities that took place from the 1940s through the 1960s. The site is listed on the National Priorities List of the U.S. Environmental Protection Agency (EPA).

The U.S. Department of the Army used the Weldon Spring site to produce dinitrotoluene (DNT) and trinitrotoluene (TNT) explosives from 1941 to 1946. The U.S. Atomic Energy Commission (AEC, predecessor of the DOE) used the site to process uranium and thorium ore concentrates from 1957 to 1966. The quarry was excavated into a limestone ridge that borders the Missouri River alluvial floodplain; prior to 1942, it was mined for limestone to support various construction activities. The quarry is about 300 m long and covers approximately 3.6 ha. The main quarry floor covers approximately 0.8 ha and currently contains about 11,000 m^3 of water covering about 0.2 ha. The quarry was used by the Army and the AEC for waste disposal beginning in the early 1940s; it was last used for disposal in 1969. Wastes placed in the quarry include TNT and DNT residues and radioactively contaminated materials. A summary of disposal activities at the quarry is presented in Table I.[1-8]

As part of the environmental compliance process at the Weldon Spring site, a baseline risk evaluation (BRE) was prepared to assess the potential risks associated with contamination present at the quarry. Details of the BRE are published elsewhere.[9]

CONTAMINANTS OF CONCERN

The radioactive materials disposed of in the quarry consist of wastes from the Weldon Spring chemical plant area as well as wastes brought in from other locations including (1) materials associated with the processing of uranium and thorium concentrates, (2) uranium- and thorium-contaminated rubble, (3) high-thorium-content materials (most of which were subsequently removed from the quarry for the purpose of recovering rare earth elements), and (4) 3.0% thorium residues. Of the estimated 73,000 m^3 of the bulk wastes in the quarry, a majority is radioactively contaminated. The radioactive contaminants of concern are those associated with the uranium-238 and thorium-232 decay series. The concentrations of radionuclides in the quarry wastes are summarized in Table II. The radiological hazards of the various radionuclides in these series were determined from the activity concentrations of uranium-238, thorium-232, thorium-230, radium-228, and radium-226 and from measured values of radon-222, radon-220, and their short-lived decay products. The risks associated with gamma radiation were also assessed.

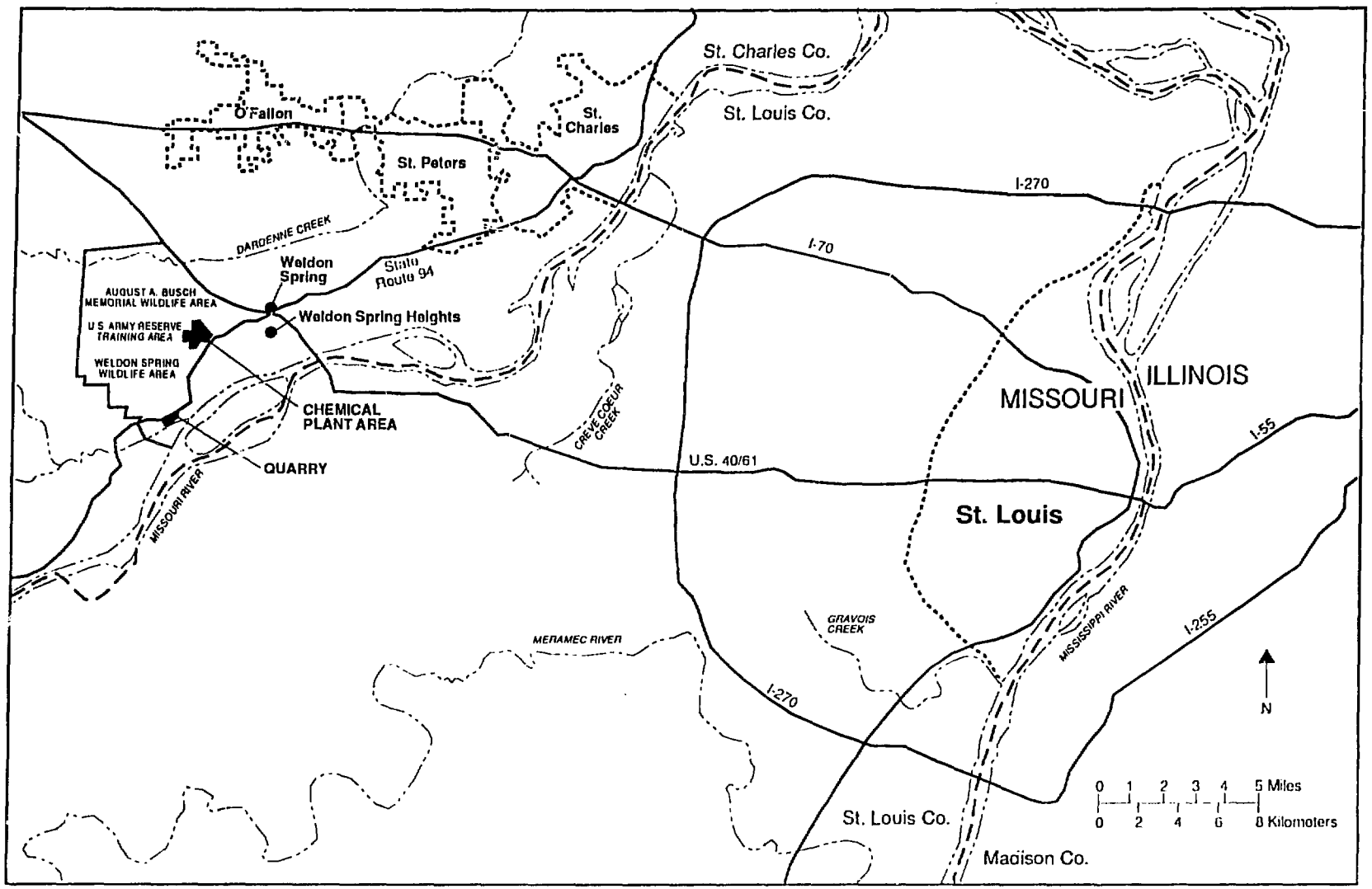

FIGURE 1 Location of the Weldon Spring site, Weldon Spring Missouri.

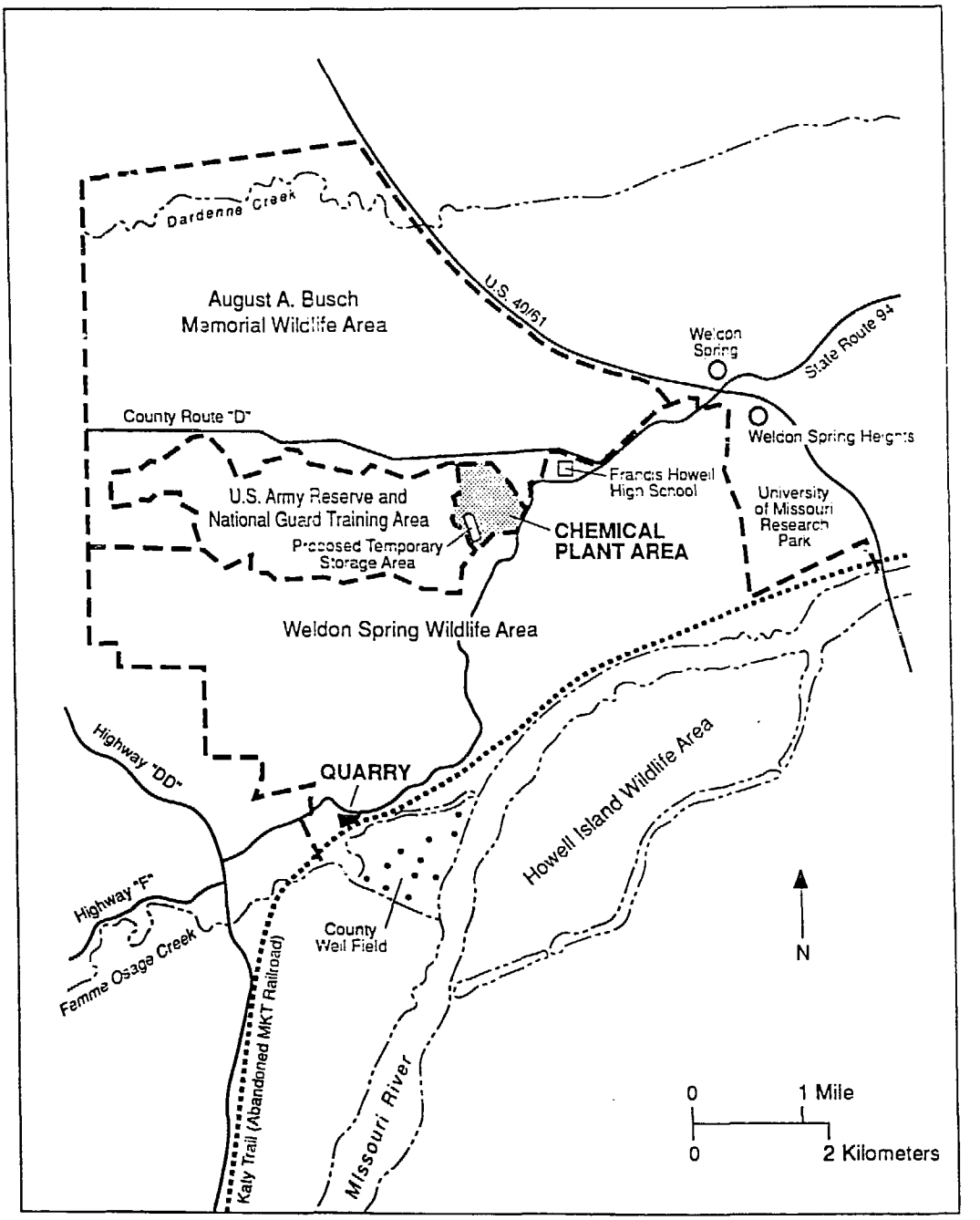

FIGURE 2 Map of the Weldon Spring site and vicinity.

TABLE I History of disposal activities at the Weldon Spring quarry.

Time Period	Waste Type	Estimated Volume[a] (m^3)
1942-1945	TNT and DNT process waste (burn areas)	-
1946	TNT and DNT process waste (burn areas)	b
1946-1957	TNT and DNT residues and contaminated rubble from cleanup of the ordnance works (in deepest part and in northeast corner of quarry)	-
1959	3.8% thorium residues (drummed, currently below water level)	150
1960-1963	Uranium- and radium-contaminated rubble from demolition of the St. Louis Destrehan Street feed plant (covering 0.4 ha to a 9-m depth in deepest part of quarry)	38,000
1963-1965	High-thorium-content waste (in northeast corner of quarry)[c]	760
1963-1966	Uranium and thorium residues from the chemical plant and off-site facilities; building rubble and process equipment (both drummed and uncontained)	-
1966	3.0% thorium residues (drummed, placed above water level in northeast corner of quarry); TNT residues from cleanup of the ordnance works (placed to cover the drums)	460
1968-1969	Uranium- and thorium-contaminated rubble and equipment from interiors of some chemical plant buildings	4,600

[a]A hyphen indicates that the waste volume estimate is not available.

[b]An estimated 90 tons of TNT/DNT waste was burned in 1946.

[c]This was a portion of the waste originally stored at the Army Arsenal in Granite City, Illinois; most of this material was subsequently removed from the quarry for the purpose of recovering rare earth elements.

Sources: References 1-8.

TABLE II Concentrations of radionuclides in the quarry bulk wastes.

Radionuclide	Average Surficial Concentration[a] (pCi/g)	Average Bulk Waste Concentration[b] (pCi/g)
Uranium-238	170	200
Thorium-232	c	26
Thorium-230	150	330
Radium-228	20	96
Radium-226	110	110

[a]Samples obtained from the top 15 cm of the quarry bulk wastes.

[b]Average concentration for all bulk wastes in the quarry.

[c]No data available.

Source: Reference 1.

Nonradioactive contaminants in the quarry bulk wastes are consistent with those expected from the quarry's disposal history (see Table I). Both the type of waste material present and the contaminant concentrations in this material are highly variable. Results of chemical contamination studies of the quarry bulk wastes are summarized in Tables III, IV, and V. Indicator chemicals were selected mainly on the basis of their toxicological properties and their concentrations in surface soils at the quarry (under current site conditions, the only complete exposure pathways at the quarry result from surface soil contamination). With the exception of volatile organic compounds, the chemical contaminants selected represent the major chemical classes present at the quarry. Volatile organic compounds were not selected as indicator chemicals because their presence in method and field blanks suggested laboratory contamination. The indicator contaminants for the BRE were nitroaromatic compounds (2,4,6-TNT; 2,4-DNT; 2,6-DNT; and 1,3,5-trinitrobenzene), metals (arsenic, lead, nickel, selenium, and uranium), PCBs, and PAHs. Of these compounds, TNT, DNT, arsenic, lead, nickel, PCBs, and PAHs are considered to be potential carcinogens.

TABLE III Concentrations of chemicals detected in the quarry bulk wastes in the 1984-1985 characterization study and background concentrations in Missouri soils.

Chemical[a]	Composite Borehole Sample Concentration (mg/kg) Range[b]	Average[b]	Number of Boreholes in which Chemical was Detected	Surface Sample Concentration (mg/kg)	Average Background Concentration[c] (mg/kg)
Priority Pollutant Metals and Cyanide					
Antimony	<20[d]		0	71	<200[d]
Arsenic	73-120	100	6	100	8.7
Beryllium	0.45-0.83	0.62	6	0.61	0.8
Cadmium	1.8-98	19	6	2.0	<1
Chromium	19-49	30	6	24	54
Copper	38-160	100	6	140	13
Lead	130-410	280	6	950	20
Mercury	0.18-6.3	2.0	6	0.7	0.039
Nickel	19-120	43	6	300	14
Selenium	17-28	23	6	22	0.28
Silver	5.8-8.3	7.0	3	7.5	<0.7
Thallium	3.0-6.2	4.7	6	5.1	<50[d]
Zinc	68-870	340	6	39	49
Cyanide	0.2-0.6	0.38	5	0.2	NA[e]
Organic Priority Pollutants[f]					
α-Benzene hexachloride	0.0051-0.0053	0.0052[g]	2	-	NA
δ-Benzene hexachloride	0.019-0.095	0.045[g]	3	0.0035	NA
γ-Benzene hexachloride (lindane)	0.0013	0.0013[g]	1	-	NA
PCBs (Aroclor 1254)	0.56-46	12	5	1.0	NA
PCBs (Aroclor 1260)	9.0	9.0	1	-	NA

TABLE III (Cont'd)

Chemical[a]	Composite Borehole Sample Concentration (mg/kg) Range[b]	Composite Borehole Sample Concentration (mg/kg) Average[b]	Number of Boreholes in which Chemical was Detected	Surface Sample Concentration (mg/kg)	Average Background Concentration[c] (mg/kg)
Other Organic Pollutants					
2-Pentanone-4-hydroxy-4-methyl (diacetone alcohol)	2-6[h]	4.6[h]	5	14[h]	NA
2-Methylnaphthalene	0.67	0.67	1	<0.06[d]	NA

[a]All compounds that had one or more positive results above detection limits are listed; concentrations are rounded to two significant figures. Samples were taken from six boreholes in the bulk wastes and from a surface waste pile.

[b]Ranges and averages are for detected values only and do not necessarily indicate the average concentration for the entire waste material.

[c]Concentration in Missouri agricultural soils.[10]

[d]Lower limit of detection.

[e]NA means data not available.

[f]The 29 volatile priority pollutants measured for were not detected at a sensitivity level of 20 µg/kg. Thirteen semivolatile organic compounds were detected in one borehole; these compounds are indicated in Table IV (identified by footnote f). The presence of PCBs prevented the detection of most pesticides.

[g]Concentrations of α-, δ-, and γ-benzene hexachloride, were reported for only 2, 3, and 1 of the borehole samples, respectively.

[h]Estimated concentrations.

Sources: Reference 11, except as noted.

TABLE IV Concentrations of chemicals detected in the quarry bulk wastes in the 1986 characterization study.

Chemical[a]	Concentration (mg/kg) Range[b]	Average[b]	Number of Boreholes in which Chemical was Detected[c]
Volatile Compounds[d,e]			
Acetone	1.4-52	13	6
2-Butanone	0.86-1.7	1.4	2
Ethylbenzene	0.68-1.8	0.99	8
Methylene chloride	0.79-6.4	2.9	8
Toluene	0.75	0.75	1
Total xylenes	0.66-1.4	0.95	2
Trichloroethene	0.9	0.9	1
Semivolatile Compounds[e]			
Acenaphthene	1.7-18	7.6	4
Dibenzofuran[f]	1.4-3.6	2.5	2
Fluorene[f]	6.6-19	13	2
Phenanthrene[f]	0.73-150	26	6
Anthracene[f]	0.34-37	9.7	6
Fluoranthene[f]	0.78-190	24	6
Pyrene[f]	0.68-170	23	6
Benz(a)anthracene[f]	0.53-86	15	6
Chrysene[f]	0.46-89	13	6
Benzo(b)fluoranthene[f]	0.62-110	17	6
Benzo(k)fluoranthene[f]	0.78-0.98	0.88	2
Benzo(a)pyrene[f]	0.46-68	11	6
Indeno(1,2,3-cd)pyrene	0.45-49	9.3	6
Dibenz(a,h)anthracene	0.33-17	2.9	4
Benzo(g,h,i)perylene	0.41-50	10	6
2,4-DNT[g]	1.7-10	6.3	1
2,6-DNT[g]	0.53-3.7	1.6	1
Di-n-butylphthalate[f]	0.47-0.58	0.53	2
Bis(2-ethylhexyl)phthalate	0.66-1.6	1.0	3
Naphthalene[f]	1.3	1.3	1
PCBs[e]			
Aroclor 1254[f]	0.46-120	21	9
Aroclor 1260[f]	9.1-12	11	1

TABLE IV (Cont'd)

Chemical[a]	Concentration (mg/kg) Range[b]	Concentration (mg/kg) Average[b]	Number of Boreholes in which Chemical was Detected[c]
Nitroaromatic Compounds[h]			
2,6-Diamino-4-nitrotoluene	0.33-0.58	0.47	3
2,4,6-TNT	0.38-1600	260	6
2,4-DNT[i]	0.46-33	8.1	3
2,6-DNT[i]	0.36-68	9.5	3
2,4-Diamino-6-nitrotoluene	1.3-7.3	4.8	2

[a]All compounds that had one or more positive results above detection limits are listed; concentrations are rounded to two significant figures. Samples were taken in the last quarter of 1986 from 17 boreholes in the bulk wastes.

[b]Ranges and averages are for detected values only and do not necessarily indicate the average concentration for the entire waste material.

[c]Detection of a chemical indicates that the species was detected in at least one incremental sample from a borehole. Each incremental sample was not necessarily tested for all chemical species.

[d]Except for trichloroethene, all of the volatile compounds detected in the samples were also detected in method and field blanks.

[e]Analyses for volatile organics, semivolatile organics, and PCBs were performed in accordance with the EPA Contract Laboratory Program.

[f]This compound was also detected in the 1984-1985 study.[11]

[g]This compound is also listed in this table under nitroaromatic compounds (see footnote i).

[h]Analyses for nitroaromatic compounds were performed according to Method 4B of the U.S. Army Toxic and Hazardous Materials Agency using high-pressure liquid chromatography.

[i]This compound is also listed in this table under semivolatile compounds. Split samples were analyzed in accordance with the EPA Contract Laboratory Program and Method 4B of the U.S. Army Toxic and Hazardous Materials Agency. Information is not provided in Reference 12 to explain the discrepancy in results or in the number of boreholes in which these compounds were detected based on the two methods.

Source: Reference 12.

TABLE V Concentrations of nitroaromatic compounds in surface soils at the quarry.[a]

Nitroaromatic Compound	Concentration (mg/kg) Range	Average
2,4,6-TNT	4,900-20,000	13,000
2,4-DNT	6.6-29	18
2,6-DNT	<1.2-8.6	5.0
Nitrobenzene	8.4-130	78
1,3,5-Trinitrobenzene	18-280	140
1,3-Dinitrobenzene	<0.8[b]	-

[a]Three surface samples were taken from the exposed slope in the northeastern corner of the quarry.

[b]Lower limit of detection.

Source: Reference 13.

EXPOSURE ASSESSMENT

The key factors considered in developing the exposure pathways at the quarry include (1) the quarry is fenced, closed to the public, and surrounded by wildlife areas; (2) the nearest resident is 0.8 km east of the quarry; and (3) no remedial action activities are currently taking place at the quarry. The assessment was based on current land-use conditions and contaminant concentrations.

The main source of contamination within the quarry is the bulk wastes, and the exposure pathways considered in the health risk evaluation are those directly associated with these wastes. Groundwater at the quarry has been shown to contain elevated concentrations of chemical and radioactive contaminants, but it is not used as a drinking water source. The groundwater south of the quarry at the nearby St. Charles County well field is monitored routinely, and mitigative measures would be taken if elevated concentrations were detected in the well field. Thus, because there are no known or indicated points of current exposure, the groundwater pathway is incomplete and was not considered in the analysis.

Based on an evaluation of waste characteristics and potential release mechanisms, the principal contaminants at the Weldon Spring quarry to which individuals could be exposed and potential routes of human exposure to these contaminants have been identified as:

- Inhalation of radon-222, radon-220, and their short-lived decay products;
- Exposure to external gamma radiation;
- Dermal contact with chemically contaminated surface soils; and
- Ingestion of radioactively and chemically contaminated surface soils.

The exposure scenarios developed for this evaluation are considered to be realistic, but conservative, descriptions of possible human activities that could result in exposure to contaminants associated with the quarry bulk wastes. The potential for human contact with site contaminants is low because (1) the quarry is situated in a relatively isolated setting and fenced and closed to the public and (2) no private residences or other structures are located within the area currently impacted by site releases. Therefore, scenarios were developed for hypothetical individuals temporarily occupying the impacted area, i.e., "passerby" and "trespasser" scenarios. Under both scenarios, two cases were developed to estimate "representative exposure" and "plausible maximum exposure." The passerby and trespasser scenarios were defined such that the nature and duration of the exposures would provide upper bound estimates of the potential risks to any individual exposed to releases outside the quarry fence or to an individual who might trespass into the quarry.

The passerby scenario considered potential exposures to an individual who routinely walks by the northern boundary of the quarry along State Route 94. For the representative exposure case, it was assumed that the individual walks by the quarry twice per day, 250 days per year over a period of 5 years; for the plausible maximum exposure case, the exposure period was increased to 365 days per year over a period of 10 years. The exposure pathways evaluated for this scenario were inhalation of radon-222 and radon-220 and their short-lived decay products, exposure to external gamma radiation, and inhalation of dusts contaminated with nitroaromatic compounds and uranium. (Nitroaromatic compounds and uranium are the only contaminants found in exposed areas in the quarry that are subject to fugitive dust emissions.)

The trespasser scenario considered exposures to an individual (presumably a youth) who enters the quarry several times per year. For the representative exposure case, it was assumed that the individual (11 to 15 years old) enters the quarry, remains there for a period of 2 hours, and repeats this activity 12 times per year over a period of 5 years. For the plausible maximum exposure case, it was assumed that the individual (9 to 18 years old) enters the quarry once per week for a period of 4 hours, 50 weeks per year over a period of 10 years. The exposure pathways evaluated for the trespasser scenario included the same pathways considered for the passerby as well as direct contact with contaminated soils, which could result in dermal absorption of the organic indicator chemicals and incidental ingestion of all compounds.

The conditions of the passerby scenario were selected to represent (1) the exposure occurring at the location of highest off-site radon and airborne particulate concentrations (i.e., along State Route 94) and (2) a frequency and duration of exposure that, over the long term, would not be exceeded by an individual routinely entering any

area impacted by contaminant releases from the quarry. The trespasser scenario is considered to be a conservative estimate of potential exposures to any individual coming into direct contact with the contamination in the quarry.

SUMMARY OF HEALTH RISKS

Health effects resulting from radiation exposure were evaluated in terms of the increased likelihood of inducing fatal cancers and serious genetic effects in future generations. The probability of serious genetic effects from exposure to the radionuclides in the quarry is low relative to the probability of fatal cancer induction. Hence, this assessment focuses on the potential carcinogenic risks associated with these radioactive contaminants. Potential carcinogenic risks from chemical exposures were also assessed.

The potential for the occurrence of adverse health effects (other than cancer) from exposure to chemical contaminants was assessed by dividing the average daily exposure estimates (intakes) by established reference doses* to determine the "hazard index." A hazard index of less than one is considered to indicate a nonhazardous situation or, conversely, a hazard index of greater than one is considered to indicate a potential for adverse health effects.

The estimated carcinogenic risks and hazard indexes for the passerby and trespasser scenarios are summarized in Table VI. The carcinogenic risks from radiation exposures range from 4×10^{-6} for the passerby representative exposure case to 9×10^{-5} for the trespasser plausible maximum exposure case, and the carcinogenic risks from chemical exposures range from 1×10^{-9} to 4×10^{-5}, respectively. The risk from radiation exposure exceeds that from chemical exposure for both scenarios. The major exposure pathway for the radiological risk in all cases is inhalation of radon-222 and its short-lived decay products. The major contributor to the chemical carcinogenic risk for the trespasser is 2,4,6-TNT, which accounts for approximately 40% of the risk; arsenic, PCBs, and PAHs account for the remaining 60%.

The very low hazard indexes estimated for the passerby scenario (less than 2×10^{-3}) indicate that there is little potential for noncarcinogenic health impacts to individuals outside the quarry. However, for the trespasser, the hazard index is 2 for the representative exposure case and 9 for the plausible maximum exposure case. For both cases, the major contributor to the noncarcinogenic hazard is exposure to 2,4,6-TNT. This is not unexpected given the presence of this contaminant at concentrations greater than 1% in surface soils at the quarry. The estimated hazard indexes for 2,4,6-TNT are about 2 and 7 for the representative and plausible maximum trespasser exposure cases, respectively. These results indicate the potential for the occurrence of adverse health effects to an unprotected individual frequently entering the quarry.

*A reference dose is the average daily dose that can be incurred by an individual without likely adverse effects.

TABLE VI Estimated carcinogenic risks and health hazard indexes for the passerby and trespasser scenarios.

Exposure Scenario/Case	Carcinogenic Risks		Health Hazard Index for Noncarcinogenic Effects[c]
	Radiological[a]	Chemical[b]	
Passerby			
Representative	4×10^{-6}	1×10^{-9}	0.001
Plausible maximum	1×10^{-5}	3×10^{-9}	0.002
Trespasser			
Representative	6×10^{-6}	4×10^{-6}	2
Plausible maximum	9×10^{-5}	4×10^{-5}	9

[a]Risk of a fatal cancer; the rate of cancer induction will be higher.

[b]Rate of cancer induction. The EPA has recommended a range of 1×10^{-4} to 1×10^{-7} for exposure to carcinogenic chemicals.

[c]The health hazard index is a measure of the potential for adverse chronic health effects other than cancer. A value greater than one is considered to indicate a potential for adverse health effects.

Source: Reference 9.

INDICATIONS FOR WASTE MANAGEMENT DECISIONS

The scope of the baseline risk evaluation focuses on quantifying potential health impacts of exposures to the bulk wastes if they remain in the quarry during the short term under current conditions. That is, the health evaluation is limited to risks that could result from direct contact with and ingestion of contaminated surface materials and inhalation of airborne releases from these materials. This scope is consistent with the definition of the bulk waste management as an interim remedial action within the overall cleanup strategy for the Weldon Spring site. The limited availability of data on the nature and extent of contamination and the pathways and mechanisms for contaminant migration from the quarry precluded preparation of a comprehensive baseline risk assessment at this time. The in-situ characterization of the bulk wastes and subsurface that is needed for a comprehensive assessment is infeasible due to the types and placement of wastes (i.e., the bulk wastes are a heterogeneous mixture of soils and sediments, rubble, metal debris, and equipment distributed over 3.6 ha to depths of 12 m). Within these constraints, the baseline risk evaluation identifies the need for a response action at the quarry because the results indicate that a frequent trespasser could incur adverse noncarcinogenic health impacts. However, this evaluation was not prepared to support the development of cleanup criteria or an evaluation of the effectiveness of final remedial action alternatives for the quarry. These objectives will be satisfied by a second, comprehensive quarry risk assessment that will be prepared following the removal of the contaminant source, which will permit a thorough characterization of the quarry subsurface to support final quarry cleanup decisions.

Various alternatives were considered for managing the quarry bulk wastes during the short term in a manner that would not bias the ultimate waste management decisions for the project. These alternatives included in-situ containment (surface and combined surface-subsurface) and/or treatment, delaying action at the quarry until after the comprehensive record of decision for the project is issued, and expediting action. Pursuant to the baseline risk evaluation, the interim response selected for the quarry was expedited excavation of the bulk wastes with transport to an engineered storage facility at the chemical plant area, pending a final disposal decision for all site wastes. Comprehensive waste management decisions for the Weldon Spring site will be facilitated by this interim quarry action because the bulk wastes can be characterized following excavation to support decisions on treatment and ultimate disposition. Hence, the baseline risk evaluation led to the selection of an alternative that will (1) reduce potential impacts at the quarry and mitigate impacts that could result from future contaminant releases (compared to current uncontrolled conditions), (2) facilitate the follow-on risk assessment and final remedial action decision for the quarry, and (3) support waste management and disposal decisions for the overall project.

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