Radiological Assessment for Cabot Corporation Revere, PA Site

Technical Evaluation Report

Prepared by: Mark Thaggard, Sr. Systems Performance Analyst
Environmental and Performance Assessment Branch

Introduction

The Cabot Corporation Revere site encompasses roughly 40 hectares (100 acres) in Bucks County, Pennsylvania. The site is located about 60 km (36 mi) north of Philadelphia and about 26 km (16 mi) southeast of Allentown. Radioactively contaminated slag from a former niobium metal processing facility is present in four distinct areas at the site. {The presence of radioactive slag under the former warehouse/loading dock area cannot be ruled out based upon the site characterization completed to date. Given that part of the area is paved and part is beneath a structure, gamma surveys performed on the site are considered inconclusive. Therefore, a basis for classifying this as an unaffected area needs to be provided.}

The purpose of the Cabot Corporation's Revere site radiological assessment is to demonstrate that doses from exposure to residual radioactive material at the site is sufficiently low to allow unrestricted release of the site in accordance with 10 CFR 20.1402 (i.e., unrestricted release of the site).

Staff reviewed the radiological assessment using guidance provided in NUREG-1727 (NRC, 2000) for conducting dose assessment to demonstrate compliance with the license termination rule. Specifically, the following aspects of the assessment were reviewed: the source term abstraction; the critical group, scenario, and pathways identification, the conceptual model development, and calculations and input parameter selections. Staff review of these aspects of the assessment is addressed separately below.

Source Term Abstraction

As previously stated, radioactively contaminated slag is present in four known areas at the site. A brief description of these areas is provided in Table 1.

For their radiological assessment, Cabot estimated radionuclide concentrations for slag based on a single slag sample. This sample contained 122 pCi/g of U-238 and 13.6 pCi/g of Th-232. The licensee assumed bulk densities for the slag (2.9 g/cm^3) and soil (1.9 g/cm^3) and that the radioactive slag only accounts for 5% of the volume of material in any of the contaminated areas. The effective concentrations for U-238 and Th-232 of 9 pCi/g and 1 pCi/g respectively were used in the assessment. U-238 and Th-232 progenies were assumed to be in secular equilibrium. The staff has reviewed these assumptions and finds them acceptable.

Staff considers the concentrations used in the assessment to be appropriate based upon gamma surveys performed on the site. External gamma measurements at the site suggest a U-238 concentration of less than 2 pCi/g and a Th-232 concentration essentially at background for the upper several inches of the contaminated areas. Even subsurface measurements in the

container storage, parking, and old pit areas indicated near background conditions. Therefore, the concentrations used in the assessment are probably conservative.

Table 1. Brief description of contaminated areas.

Contaminated Area	Area m^2 (ft^2)	Thickness m (ft)	Brief Description
Parking area	3259 (35,500)	1.8 (6)	Building rubble, slag, and soil
Container storage area	1744 (19,900)	1.22 (4)	Slag and soil
Building 4&5 area	1469 (16,000)	0.61 (2)	Slag, rock, and soil
Old pit area	5040 (54,900)	2.7 (9)	Building debris, slag, and soil

The radionuclide concentrations used in the radiological assessment are listed in Table 2.

To estimate releases of radioactive material from the slag (in their radiological assessment, Cabot assumed that only slag is radioactively contaminated), Cabot modeled releases of radionuclides as a surface process where the radionuclides are assumed to be adsorbed onto the surface of the contaminated media (i.e., slag). Because in reality the radioactivity is tightly bound in the slag matrix, modeling releases as a surface process requires an assumption of strong adsorption (i.e., represented by a high distribution coefficient) between the radionuclide and the solid medium. Cabot calculated a distribution coefficient (K_d) using the readily available uranium (RAU) concentration measured in a leach test performed on a slag sample. A K_d value of 17,000 cm^3/g was used to calculate the leach rate of radionuclides from the source zone (i.e., slag). The same K_d value was also used for the U-238 progenies and Th-232 and its progenies. Although radionuclides are believed to leach incongruently from the slag, it is reasoned that using the uranium K_d value is appropriate because thorium and

Table 2. Radionuclide concentrations used in the Cabot assessment.

Radionuclide	Concentration (pCi/g)
Ac-227	0.41
Pa-231	0.41
Pb-210	9.0
Ra-226	9.0
Ra-228	1.0
Th-228	1.0
Th-230	9.0
Th-232	1.0
U-234	9.0
U-235	0.41
U-238	9.0

radium (the other key radionuclides) are believed, based on information from the literature, to leach at a slower rate.

Staff agrees that based upon the nature of the slag (i.e., its glass-like structure) and its low weathering rate (believed to be on the order of $2x10^{-6}$ to $1.5x10^{-5}$ mm/y) the leach rate of radionuclides from the source zone should be low (i.e., radionuclides should be fairly immobile). Based on the range of leach rates reported for uranium and thorium for slag (Felmy et al., in press), the leach rate for uranium and thorium at the Cabot site would be expected to be on the order of $1x10^{-12}$ to $1x10^{-10}$ yr^{-1} for thorium and $1x10^{-11}$ to $4x10^{-9}$ yr^{-1} for uranium. The leach rate assumed in the Cabot assessment is on the order of $1x10^{-5}$ yr^{-1}.

Critical Group, Scenario, and Pathways Identification and Selection

Scenarios represent possible realizations of the future state of the site. They are needed in a dose assessment to establish potential future conditions which might lead to human exposure to residual radioactivity at the site. The area surrounding the Cabot-Revere site is characterized as generally rural with land uses that include industrial, commercial, residential, and agriculture.

Two scenarios were considered by Cabot in their radiological assessment; specifically, a worker and resident scenario were considered. In addition, hybrids of these two scenarios were considered as a means of conducting a sensitivity analysis. Both Cabot's sensitivity analysis and staff's own independent assessment show the calculated doses to be highly sensitive to the assumptions made about the future use of the site.

For its worker scenario, Cabot assumes that the site will continue to be used for industrial purposes. The industrial worker is assumed to be exposed by external gamma radiation and inhalation of re-suspended dust. The hypothetical worker is assumed to spend very limited time in the contaminated area (40 hr/yr). No indoor exposure is assumed to occur because there are currently no buildings in the contaminated areas. Cabot believes this to be the more likely scenario; however, no explanation is provided as to why. In addition to this base-case worker scenario, Cabot also looked at the possibility of the worker spending 1920 hr/yr in a building constructed in the contaminated area, along with 80 hr/yr outdoors; and the workers spending 1600 hr/yr in a building along with 400 hr/yr outdoors as part of its sensitivity analysis. Both of these scenarios, which still demonstrated that the dose limit would not be exceeded, resulted in slightly more than an order of magnitude increase in the dose over that calculated for the base-case worker scenario. The base-case and two hybrid scenarios show that the worker scenario is not the limiting scenario in terms of demonstrating compliance with the license termination rule. However, it should be stressed that staff finds it difficult to accept the notion that the contaminated areas will essentially remain undeveloped for the next thousand years, as assumed under the base-case worker scenario. Accordingly, staff considers the two hybrid scenarios to be more credible in terms of looking at exposure to a future hypothetical worker.

For its resident scenario, Cabot assumes that the residence is constructed entirely in the contaminated area and that the resident spends 50% of his time in the area (80% indoors and 20% outdoors). Exposure is assumed to occur through direct gamma radiation, inhalation, soil ingestion, and drinking water. A six-inch layer of topsoil is assumed to be permanently maintained over the slag to support grass, but would not be deep enough to support growing

edible vegetables. It should be noted that the assumption of a permanent soil layer, even one as thin as 0.15 m (6 inches), obviates the need for considering doses from the inhalation pathway; that is, the hypothetical future resident will not receive any doses through inhalation of dust as long as a soil layer is kept over the slag. The resident scenario is considered by Cabot to be a less likely scenario than the worker scenario; however, no explanation is provided as to why. Given that the current surrounding land-use around the site includes residences and agriculture, staff believes that some type of future residential use of the site is highly credible. As a hybrid of this scenario, Cabot also looked at a resident scenario assuming that there is no six-inch soil layer. The results of this sensitivity analysis give doses a little below the release limit, but five to nine times higher than the doses calculated for the base-case resident scenario. This reflects the importance of the assumption that a six-inch soil layer will be permanently maintained over the whole area. {Staff does not believe that it is appropriate to assume that a cover will be permanently maintained over the slag without active maintenance. Thus, the assumption of a permanent soil cover will require some form of restrictions on the land use. Given the significance of this assumption on the calculated dose, Cabot needs to either provide a basis to support this assumption or eliminate it in their assessment.}

Staff supports the exclusion of the aquatic pathway in the Cabot resident scenario. Because of the relative immobile nature of the radionuclides it is unlikely that any contaminants will reach nearby surface waters. Further, the depth of the ground water (approximately 20 m) would likely make it rather expensive to maintain a fish pond.

Cabot argues that it is appropriate to exclude the agriculture pathway in their resident scenario because the surficial layer of the contaminated areas is composed principally of slag which do not support the growth of vegetation (as evident by current site conditions). {Staff does not agree that this is an appropriate basis for excluding the agricultural pathway. First, it is not clear why Cabot believes that it is reasonable to assume that someone would haul in topsoil to grow grass, but would not haul in topsoil to maintain a small garden. Second, with suitable fertilizers or soil amendments, plants can be grown in "soil free" material such as mineral sand, gravel, etc.; however, this seems less likely to occur than someone bringing in topsoil to grow a small garden. Consequently, the absence of soil does not constitute a sufficient basis for eliminating the plant-ingestion pathway. Staff's own assessment shows that inclusion of the plant-ingestion pathway has a significant effect on the calculated dose. Therefore, Cabot should either provide a stronger basis for eliminating the plant-ingestion pathway or should include it in the assessment.

The staff assessment looking at the effects of including the plant-ingestion pathway is based upon using the same model inputs as that used by Cabot, with and without the soil cover, and inclusion of the plant-ingestion pathway. A key assumption in such an analysis is the environmental availability of the uranium in the environment (U-238 progenies are the prime contributors to the calculated dose). Because incorporation of uranium in food involves uptake of uranium by plants from an aqueous solution, the plant-ingestion pathway assumes that the uranium is soluble. NUREG/CR-6232 (Amonette et al., 1994) suggest that doses for both soil ingestion and plant ingestion should be calculated on the basis of the total available uranium instead of total uranium. Because the total available uranium has been determined to be only a small fraction of the total uranium within the slag, the resulting doses should be only a fraction of the calculated dose based upon the total uranium. Therefore, Cabot may want to consider using the total available uranium in assessing potential doses from any ingestion pathways.}

Because of the cost, it is difficult to envision someone purchasing enough topsoil to cover an area large enough to grow commodity crops or raise livestock. Further, because soilless gardening require more management than more traditional gardening methods and given that the presence of slag in the area would not lend itself to mechanized agriculture, staff believe that it is unlikely that the contaminated areas will be used to grow commodity items such grains or livestock fodder. Therefore, it is appropriate to exclude these pathways in the assessment. In addition, the relative small size of the container storage and former building 4&5 areas, which are both less than the default area assumed in the NRC's screening approach for the residential farmer scenario (i.e., 2400 m^2), would also tend to support an argument that these areas will not be used for growing commodity items.

Conceptual Model Development

Analyzing the release and migration of radionuclides through the environment is an essential part of assessing potential doses someone might receive from exposure to various concentrations of the radionuclides in the accessible environment. This analysis requires an interpretation of site conditions and processes that are likely to affect the transport of radionuclides through the environment to receptors. The interpretation of site conditions and processes as reflected in the dose assessment forms the conceptual model.

The predefined conceptual model in RESRAD was used in the Cabot-Revere radiological assessment with a limited number of input parameters tailored to model the site conditions and features. The predefined conceptual model in RESRAD is described in the RESRAD User's Manual (Yu et al., 1993). Specifically, the predefined conceptual model assumes that the individual resides immediately atop the contaminated media. Further, the individual is assumed to have a well located either in the center of the contaminated area or immediately down-gradient from the contaminated area. For the Cabot-Revere assessment it was assumed that the well is located down-gradient from the contaminated area. No justification is provided for why this assumption was made as oppose to the more conservative assumption that the well is located in the center of the contaminated area. Guidance in NUREG-1727 (NRC, 2000) states that the less conservative assumption can be used when the area of contamination is larger than the capture area of the hypothetical well. Staff, through its own assessment, has determined that the capture area of the hypothetical well is very unlikely to be greater than the contaminated area for each of the four areas; therefore, it is appropriate to make the less conservative assumption that the well is located at the down-gradient edge of the contamination zone.

Figure 1 shows a schematic of the general conceptual model used in the Cabot-Revere radiological assessment, based upon staff's interpretation of the information presented in the report.

It should be noted that a default irrigation rate of 0.2 m/y was used in the analysis although the licensee assumed no irrigation as part of either scenario. However, the 0.2 m/y irrigation rate assumed in the analysis only has the effect of slightly increasing the calculated infiltration rate, which slightly increases the calculated leach rate.

Based on regional information, the unsaturated zone is believed to be roughly 20 m thick; however, for the assessment nominal credit is taken for the possible hold-up of contaminants

migrating through the unsaturated zone. This is reflected by the small unsaturated zone thickness (0.01 m) assumed for the analysis and the fact that the K_d for the unsaturated and saturated zones were set to zero. Staff believes that this adds conservatism to the calculated doses for the water-dependent pathways.

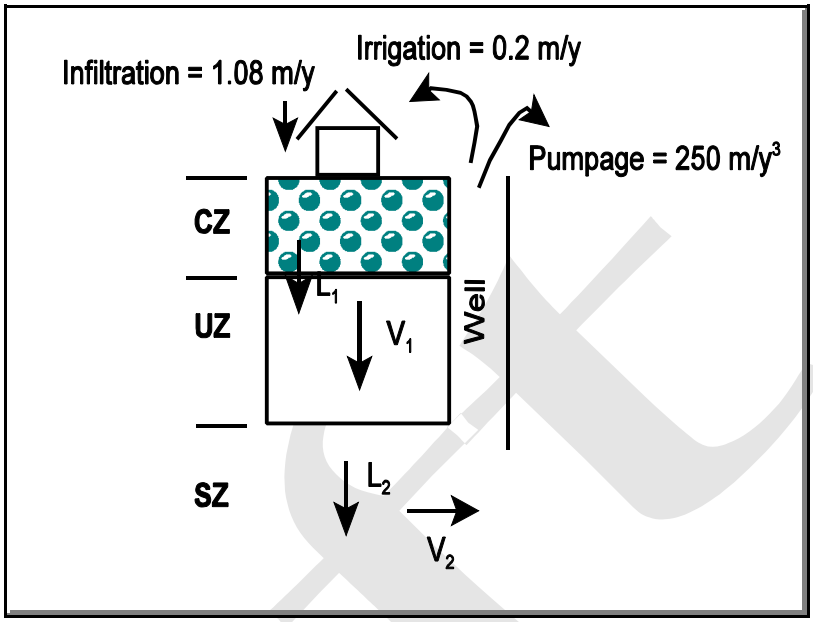

Figure 1. Generalized conceptual model used in the Cabot-Revere assessment.

Calculations and Input Parameters

RESRAD Version 5.62 was used to calculate doses from potential exposure through inhalation, soil ingestion, and drinking water. {Given that the latest version of the RESRAD code (i.e., version 6.0) is readily available for downloading from the Internet, Cabot should use the latest version of the code for conducting any additional analyses in support of demonstrating compliance with the license termination rule. Several changes to recent updates of the code could specifically affect the calculated results for the Cabot-Revere site, these would include: (1) incorporation of a new area factor model for inhalation, (2) changes in the default mass loading factor, and (3) incorporation of a time integration routine for calculating

Table 2. Values of parameters reflected in the schematic in Figure 1.

Parameter	Contaminated AreaSection			
	Parking Area	Container Storage	Bldg. 4&5	Old Pit
CZ≡ cont. zone thickness (m)	1.8	1.22	0.61	2.7
UZ≡unsat. zone thickness (m)	0.01	0.01	0.01	0.01
L_1≡leach rate from CZ (pCi/y)	1.9e-5	2.7e-5	5.5e-5	1.2e-5
V_1≡ velocity in UZ (m/y)	6.4	6.4	6.4	6.4
V_2≡ velocity in SZ (m/y)	0.2	0.2	0.2	0.2
Note: L_2≡leach rate from the unsaturated zone = L_1- radioactive decay.				

doses.} The total dose calculated by RESRAD was then combined with a separately calculated dose from gamma radiation calculated from measured gamma radiation readings.

As previously stated, Cabot evaluated external doses on the basis of external gamma measurements and estimated exposure rates. {In the radiological assessment, Cabot states that use of the measured gamma readings as oppose to calculating them with RESRAD, results in estimated external doses that are roughly a factor of three less. Given that the doses calculated by RESRAD assumes uniform contamination, this would suggest that either the estimated concentrations used in the analysis are too high or most of the radiation is in the subsurface. As part of their characterization, Cabot dug a number of pits and trenches on-site, but they apparently do not have a reliable estimate of average subsurface concentrations. The assumption of homogenized contaminated media assumed in the RESRAD calculation would appear to be consistent with the modeling assumptions used for the analyzing the other exposure pathways. Further, there is no reason to believe that the contaminated media will not be disturbed (i.e., homogenized) at some time in the future. To support the use of the gamma measurement readings to estimate external doses, Cabot needs to clarify the assumptions of the analysis; that is, whether or not a concentration gradient is assumed. If the primary radiation is assumed to occur in the subsurface, Cabot needs to explain why it is appropriate to assume that these conditions will be maintained throughout the assessment period without land-use restrictions. Further, Cabot needs to explain how this assumption is consistent with the approach used to analyze doses for the other exposure pathways. As an alternative to supporting the use of the gamma measurement readings, Cabot can use RESRAD to calculate doses from external gamma radiation. This may necessitate reassessing the concentrations used in the assessment.}

The fraction of time spent indoors and outdoors, which is important in calculating doses from exposure to external gamma radiation, assumed for the resident scenario were taken from PG-8-08 (NRC, 1994). Although the NRC is no longer accepting the use of PG-8-08 as a sufficient basis for establishing parameter values (NRC, 2000), the values used in the assessment appear reasonable for the assumed land-use. Specifically, they are close to the default values recommended by the NRC for doing screening analyses for a residential farmer scenario.

	Fraction of time	
	Indoors	Outdoors
Cabot-Revere	0.4	0.1
NRC default	0.6571	0.1101

Metabolic and behavioral parameters used in RESRAD in the Cabot-Revere radiological assessment were largely taken from PG-8-08 (NRC, 1994). A comparison of calculated doses using the licensee's input parameters against those recommended by the NRC for conducting screening analysis assuming a residential farmer scenario show that use of the licensee's input parameter actually give higher doses. Therefore, use of the PG-8-08 metabolic and behavioral parameter values should be acceptable.

Parameter values for physical parameters used in the assessment were taken as RESRAD default values, PG-8-08 recommended values, or from literature. These parameters primarily

affect the calculated doses from the water-dependent pathways. No sensitivity or uncertainty analysis was done to identify key parameters where additional justification might be required. Some of the justification provided for the selection of the parameter values used in the assessment does not appear to be adequate or appropriate. For example, hydrologic parameter values for the contaminant zone are based on the average for loam taken as the average for sand and silt. Given that the contaminant zone is suppose to consist almost exclusively of slag, it is not clear why loam was selected as a suitable surrogate for slag. As another example, the b-parameter was selected to represent sandy loam. In addition to the concern with the appropriateness of sandy loam being a suitable surrogate for slag, a comparison of the selected value (4.9) against the range of values recommended by Meyer et al. (1997) for sandy loam show that the selected value falls outside of this range. Because the radionuclides are fairly immobile, both the Cabot assessment and the staff's own assessment show the water-dependent pathways to contribute very little to the total dose. Therefore, while the staff has some concerns with the justification for some of the physical parameters, they are not expected to significantly affect the estimated total dose.

It should be noted that parameter values for parameters used to calculate infiltration were selected to over estimate infiltration with the intent of being conservative. For radionuclides such as Th-232, where gamma radiation is a significant contribution of the dose, assuming a high infiltration rate is actually non-conservative. However, in the case of the Cabot-Revere site, where radionuclides are fairly immobile, the assumed infiltration rate is not very important.

References

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