

CABOT

November 6, 1996

40-9027

Robert A. Nelson  
Low-Level Waste and Decommissioning  
Projects Branch  
U.S. Nuclear Regulatory Commission  
Washington, DC 20555-0001

Re: Decommissioning of the Revere, Pennsylvania Facility,  
NRC License SMC-1562

Dear Mr. Nelson:

By letter dated June 25, the Nuclear Regulatory Commission provided comments on the Risk Assessment prepared by Cabot Corporation in support of the company's Decommissioning Plan for the Revere, Pennsylvania facility. Since that time, Cabot has been developing the technical information necessary to address several issues raised by NRC Staff. The purpose of this letter is to present that information and to otherwise respond to the NRC's comments. For ease of reference, our responses are numbered to correspond with those appearing in the NRC letter.

1. The NRC has indicated that a different methodology should be used to calculate the leach rate of uranium and thorium from slag. Cabot has developed such a methodology in connection with the Reading site, which is the subject of a separate decommissioning plan. That alternative approach was submitted to the NRC on July 11 and has been accepted by NRC Staff. Therefore, Cabot has derived a leach rate for the Revere facility using that same methodology. Attachment A to this letter describes the leach rate methodology in detail for both uranium and thorium leaching.
2. The NRC questioned the well depth parameter used by Cabot. The company has reviewed information concerning wells placed in the Brunswick formation of eastern Pennsylvania and has determined that this parameter may be revised to 300 feet. Cabot will use this depth in its rerun of the RESRAD computer model.

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3. The NRC noted that Cabot has not modeled the radon pathway. Current NRC regulations do not explicitly address how doses attributable to radon emissions from licensed material and from background sources are to be considered in the decommissioning process. The SDMP Action Plan, which is referenced in the NRC's comment, also does not explicitly discuss radon, but states that until the NRC's current decommissioning criteria rulemaking is complete, the NRC will "consider existing guidance, criteria and practices" in determining whether to release sites for unrestricted use. None of the guidance documents referenced in the Action Plan explicitly address calculation of doses from radon. Policy and Guidance Directive PG-8-08, which discusses criteria for consideration in developing exposure scenarios, does recommend modeling of radon doses.

Subsequent to the issuance of PG-8-08, however, the NRC has expressed strong reservations about the practicality and need for estimating doses from radon associated with very low levels of radon precursors (such as uranium and thorium) and of distinguishing doses from radon attributable to licensed material from those attributable to natural sources. In particular, the preamble accompanying the NRC's proposed decommissioning criteria rule states:

The NRC Staff believes that it is not possible to measure or distinguish concentrations of radon which will produce radiation doses of a few mrem TEDE/y above background using current technology... [E]xposure to radon at decommissioned sites [under the proposed rule] would be controlled by requiring the licensee to reduce the residual concentrations of radon precursors like uranium, thorium, and radium to levels within the limit for unrestricted use and, using the ALARA principle, toward levels which are indistinguishable from background levels.

59 Fed. Reg. 43210 (August 22, 1994) (emphasis added).

Cabot's Decommissioning Plan for the Revere site proposes release of the site for unrestricted use based on calculated potential doses from the "Old Pit" area in the range of 1-2 mrem/yr. -- which is well below the NRC's 15 proposed mrem/yr criterion for unrestricted use. An ALARA analysis has also been submitted to the NRC which confirms that

potential doses associated with implementation of the proposed plan are as low as reasonably achievable. Under the circumstances, and as suggested by the NRC Staff's remarks in the pending rulemaking, Cabot believes that modeling the radon pathway is neither necessary nor practicable.

4. The NRC requested clarification of the terms "clean rubble" and "clean soil". Clean rubble refers to the building demolition materials which are present at the site. Clean soil includes all of the soil at the site. It should be noted that neither the soil nor the building rubble is contaminated. The Risk Assessment will be edited to incorporate these definitions.
5. The NRC offered several comments concerning the exposure scenarios utilized in the Risk Assessment. The following are clarifications regarding the parameters used for those scenarios.
  - (a) The industrial scenario does not assume that a soil cover will be placed over the Old Pit Area. Given the nature of the material being relocated to that area (i.e. slag, building debris, etc.), however, it was necessary to make certain assumptions regarding site-specific conditions in order to realistically model this exposure scenario. While it is unlikely that the Old Pit Area will ever be used as an active industrial area, for modeling purposes it was assumed that an individual would work full time on a year-round basis at the Old Pit Area. This includes a hypothetical 400 hours spent outdoors annually, which could only occur if the surface is made accessible and suitable for routine business activities. Cabot selected a grassed area as a reasonable site-specific factor and incorporated a minimal growing medium parameter of 0.15 meter into the RESRAD model to support the grassed area. Another reasonable site-specific factor which could have been selected is a paved parking area, which is a less conservative assumption than that which was used. Alternatively, the industrial scenario could have been modeled without any outdoor time factor, on the assumption that the Old Pit Area would not be made suitable for outdoor use. Again this would have produced a less conservative result.

- (b) Cabot's technical consultant has conducted a literature review of studies of the weathering rate of obsidian, a natural material which can be considered a reasonable analog to the slag at Revere. Based upon those studies, the consultant has estimated that the degree of weathering would likely be in the range of 0.002 millimeters to 0.015 millimeters of surface thickness over 1,000 years. This is essentially inconsequential from the standpoint of soil formation.
  - (c) The NRC requests that the residential scenario be modeled assuming "someone lives on the site, receives his or her water from an onsite well, and builds the foundation of his house on the slag". The residential scenario as developed in the Risk Assessment already incorporates these assumptions.
- 6. The NRC noted that the input parameters for the inhalation rate and the soil ingestion rate were erroneous. Cabot acknowledges this and is rerunning the RESRAD model using corrected values. Also, in its own review of the parameters, Cabot determined that several other inputs should be modified to better reflect site conditions. These modifications will be incorporated into the RESRAD rerun.
- 7. The NRC questioned why the "drinking water intake rate" parameter is 510 liters per year rather than 730 liters per year. The 510 l/yr value was selected because it represents the nationwide mean for annual water use by adults. In contrast, the 730 l/yr value is recognized as an unusually high (90th percentile) consumption rate. There is nothing to suggest that water consumption in Nockamixon Township, Bucks County is greater than the national average, and there is no site-specific reason to assume that a hypothetical farmer residing on the Old Pit Area would consume an inordinate volume of water on a routine basis.
- 8. The NRC requested that the Risk Assessment reference NUREG-1500 with respect to an offsite slag use scenario. The Risk Assessment will be modified to include the information in NUREG-1500 concerning the on-site scenarios being conservative enough to bound the doses which could occur off-site.

9. The NRC noted that the decommissioning documentation should include a discussion of the NRC's exposure rate criterion of  $10\mu\text{R}$  per hour. Such a discussion appears in the Decommissioning Plan submitted in April 1996 at page 4-1, which reads as follows:

The unrestricted release criteria for the Container Storage Area, Parking Area, and Building 4&5 Area will follow the specifications of the USNRC SECY-81-576, "Disposal or On-site Storage of Residual Thorium or Uranium From Past Operation" (Ref. 3). These radiological limits are given in Table 4.1. A combined concentration level of  $10\text{ pCi/g}$  will be used for the release criteria in the Container Storage Area, Parking Area and Building 4&5 Area since all slag material will have been removed from these areas. Exposure rates of  $10\mu\text{R/hr}$  over background or twice background, whichever is limiting, will be used for exposure criteria. Contamination and exposure levels in these three areas will fall under these limits to be released for unrestricted access.

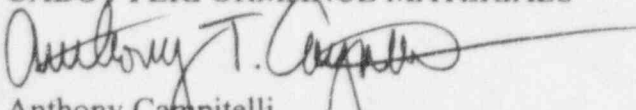
Thus, implementation of the Decommissioning Plan will result in attainment of the  $10\mu\text{R}$  per hour criterion at three of the four areas being addressed.

As soon as we receive an indication from you that the above-noted changes are acceptable, Cabot will rerun the RESRAD model and submit a revised Risk Assessment. Based upon preliminary indications, we do not expect the revised results to differ significantly from those presented in the April 1996 Risk Assessment.

Please call me if you have any questions concerning this matter.

Very truly yours,

CABOT PERFORMANCE MATERIALS

  
Anthony Campitelli,  
Manager, Environmental Affairs

Enclosure



# LEACHING ANALYSIS FOR URANIUM AND THORIUM FROM THE CABOT REVERE SITE SLAG

## INTRODUCTION

Environmental Resources Management, Inc. (ERM) has been retained by Cabot Corporation to assess the potential rate of leaching of radionuclides from slag produced by the Kawecki Chemical Company and proposed to be consolidated in the Old Pit Area at the Cabot Performance Materials facility in Revere, Pennsylvania. The area also contains building debris and soil. It is necessary to determine the rate at which the in-place slag may leach the radionuclides uranium and thorium, for input into a fate and transport model which will support a decision on decommissioning the site in keeping with the requirements of the Nuclear Regulatory Commission (NRC). The NRC has requested that this determination be made, on the basis of modeling, for a period of 1000 years. In support of this type of determination, the NRC has published guidance document NUREG/CR 6232 PNL 9750 ("Assessing the Environmental Availability of Uranium in Soil and Sediments"), which discusses the behavior of uranium in the natural environment.

Cabot has submitted to the NRC a Risk Assessment for the decommissioning of the Revere facility, which was prepared by NES, Inc. As a part of that work, NES submitted a slag sample to an independent laboratory for leach testing. As described in NUREG/CR - 6232, the results were reported in terms of totally available uranium (TAU), readily available uranium (RAU) and slowly available uranium (SAU). The analytical results for uranium and thorium in the slag sample are presented in Appendix A of the Risk Assessment.

In order to develop a leach rate using the NRC guidance, it is necessary to understand the implications of the TAU, RAU, and SAU determinations. This is briefly described as follows:

- The TAU is determined by a 5% hydrochloric acid extraction of all potentially available uranium, which goes far beyond geochemical conditions actually encountered in the natural environment.
- The RAU is determined by a modified Toxicity Characteristic Leaching Procedure (TCLP) leach in water adjusted to pH 2.9 using acetic acid, and performed four times sequentially on the same sample aliquot. The guidance considers this procedure to extract essentially all exchangeable and surface-bound uranium, and hydrous uranyl oxide minerals, and some uranyl silicates, under the assumption that these would be available to dissolve most readily under natural

environmental conditions. This is a very conservative assumption, as the pH of natural rain water is closer to the range of 5 to 5.5.

Furthermore, the sample aliquot is ground before the procedure, vastly increasing the surface area of the material which is available for contact with the leaching waters.

- The SAU is extracted under basic conditions, using a pH 8.3  $\text{NaHCO}_3$  solution, and adding hydrogen peroxide to oxidize uranium into soluble form. Such conditions are not encountered in the natural environment.

Of these three analytical procedures, the RAU procedure best approximates what might be available under natural environmental conditions in eastern Pennsylvania, although this procedure is extremely conservative. In Pennsylvania, acid rain can create ground water recharge below pH 5, at times; however, the pH of rainfall in Pennsylvania is not continuously 2.9.

In addition to geochemical conditions associated with leaching, the NRC is concerned about changes in the physical state of the slag as it weathers over a 1000-year period. If such weathering occurs and some "soil" is formed out of the slag, there would be increased slag surface area available for contact with infiltrating waters. The grinding of the sample aliquot prior to the leaching can reasonably be assumed to simulate this. However, literature reviews of studies of the weathering rate of obsidian (which can be considered a reasonable analog to the slag), show that soil formation by weathering of the slag would be limited. The literature reviews indicate that the degree of weathering would likely be in the range of 0.002 mm to 0.015 mm of surface thickness over 1000 years, which is essentially inconsequential. Therefore, performance of the leaching test on a ground slag sample results in a much higher slag surface area in contact with the leaching water than will actually occur in the environment. This provides a very conservative result which overestimates the rate of radionuclide leaching.

Given these factors, ERM has used the TAU and RAU results to estimate the leaching rates for uranium and thorium from the Old Pit Area once all the slag is consolidated at that location. Again, it should be recognized that the leaching analysis is very conservative, as:

- the pH 2.9 water used in the leach test is between 10 and 100 times more acidic than in the natural environment; and
- the surface area of slag available in the consolidated area to contact infiltrating waters will be much lower than that in the leaching

procedure, due to the thorough grinding of the sample into small particles before leaching analysis.

### *DEVELOPMENT OF LEACHING MODEL*

The leaching model presented herein was developed by ERM based on the nature of the TAU and RAU leaching tests and on the characteristics of the slag, after conversations with NRC staff responsible for development of the leaching model for the Shieldalloy site in Ohio. It should be noted that the approved Shieldalloy model approach is very similar to ERM's; however, the Shieldalloy method is less conservative, as it is based on the ASTM Synthetic Precipitation Leaching Procedure (SPLP) test, which is conducted at a pH more similar to that of recharge in the natural environment.

The TAU should represent a practical upper bound on potentially environmentally available uranium, while the RAU represents that most easily leached. Although they are not determined by exactly the same analytical method, the TAU and RAU are both acid extractions, and respectively provide conservative upper bound estimates of what might leach from the consolidation area, and at what rate. Therefore, ERM has modeled the rate of leaching from the Old Pit Area slag using the following assumptions:

- All water which infiltrates into the area comes in contact with radionuclide-bearing slag material. This assumption is very conservative, as such slag constitutes only a portion of the total material contained in the area.
- The leaching will be a linear partitioning process, which will occur as a first order reduction of radionuclide mass in the consolidation area.
- The TAU was determined to be 0.824  $\mu\text{g}$  of uranium per/gram of slag (or ppm). This represents all of the environmentally available uranium.
- The RAU can be used to determine the rate at which the TAU will leach out of the consolidation area. This is very conservative, as after the RAU (determined by NES to be 0.128  $\mu\text{g}$ /gram (or ppm)) has all leached, the remainder of the TAU will leach much more slowly.
- Of the total volume of material to be located at the Old Pit Area, NES has estimated that only 5% will consist of slag containing uranium and thorium.



- The slag containing uranium and thorium is uniformly mixed with the balance of the material to be consolidated in the Old Pit Area.

### *Partitioning Coefficient*

The partitioning coefficient ( $K_d$ ) describes the equilibrium ratio between the concentration of available uranium in the slag ( $C_{slag}$ ) and the concentration of uranium dissolved in the water which is in contact with the slag ( $C_l$ ).  $K_d$  is determined from the relationship  $TAU/C_l$ , where  $C_l$  is the concentration of uranium in the leachate. The  $C_l$  is determined from the RAU analysis results. For the RAU analysis, the laboratory combined four aliquots of leachate into one sample and analyzed that sample for dissolved uranium. Thus the RAU represents the concentration of uranium leachable from one gram of slag in 80 ml of pH 2.9 water (the four 20 ml sequential leaches). Therefore, the concentration in the leachate,  $C_l$ , was  $(0.128 \mu\text{g}/80 \text{ ml}) \times (1000 \text{ ml}/\text{L}) = 1.6 \mu\text{g}/\text{L}$ , or 0.0016 ppm. From this, the partitioning coefficient for the uranium in the slag can be determined:

$$K_{d\text{slag}} = C_{\text{slag}} / C_l = 0.824 \text{ ppm} / 0.0016 \text{ ppm} = 515$$

This  $K_d$  is for the slag containing uranium and thorium. However, the material in the consolidation area is a mixture of slag, debris, and soil. For modeling purposes, it is necessary to determine a  $K_d$  for this consolidated mixture of the slag with uranium and thorium with clean materials (which do not contain uranium or thorium). The  $K_d$  for the consolidation area is smaller than the  $K_d$  for the slag due to the additional volume of solid material.

To determine the  $K_d$  for the consolidation area,  $K_{d\text{area}}$ , the mass of the individual components of the fill has to be determined. The materials to be consolidated in the Old Pit Area will have a surface area of 54,900 ft<sup>2</sup>, and a depth of 15 ft, or 823,500 ft<sup>3</sup>. It has been estimated by NES that the fill contains the following materials by volume: 5% slag with uranium and thorium, 5% slag without uranium and thorium, and 90% clean soil and debris. It can be assumed that the slag has a density of 2.9 g/cm<sup>3</sup>, similar to lava rock. However, the 2.9 value holds for a single solid mass of slag, not a broken up aggregate like the slag at the site. To account for the true nature of the slag, a porosity must be assumed and the density adjusted. Using a porosity of 0.30 (a mid-range value for sand and gravel materials from Domenico and Schwartz, 1990 Physical and Chemical Hydrogeology), the true density of the slag would be  $2.9 \times (1-0.30) = 2.03 \text{ g/cm}^3$ . A reasonable estimate of the soil density is 1.87 g/cm<sup>3</sup>.

The mass of material in the consolidation area can now be determined as follows:

Mass of the slag with uranium and thorium

$$= 0.05 \times 54,900 \text{ ft}^2 \times 15 \text{ ft} \times 2.03 \text{ g/cm}^3 \times \frac{62.4 \text{ lb/ft}^3}{1.0 \text{ g/cm}^3}$$

$$= 5,215,720 \text{ lbs}$$

Mass of the slag without uranium and thorium

$$= 0.05 \times 54,900 \text{ ft}^2 \times 15 \text{ ft} \times 2.175 \text{ g/cm}^3 \times \frac{62.4 \text{ lb/ft}^3}{1.0 \text{ g/cm}^3}$$

$$= 5,215,720 \text{ lbs}$$

Mass of other fill materials

$$= 0.90 \times 54,900 \text{ ft}^2 \times 15 \text{ ft} \times 1.87 \text{ g/cm}^3 \times \frac{62.4 \text{ lb/ft}^3}{1.0 \text{ g/cm}^3}$$

$$= 86,483,311 \text{ lbs}$$

Total area mass = 96,914,751 lbs

The average concentration of TAU in the consolidation area is then determined as:

$$C_{\text{area}} = C_{\text{slag}} \times 5,215,720 / 96,914,751$$

$$= 0.824 \text{ ppm} \times 0.0538$$

$$= 0.0443 \text{ ppm}$$

The  $K_d$  for the consolidation area material is the average concentration of available uranium in the consolidation area divided by the leachate concentration,  $C_l$ :

$$K_{d\text{area}} = 0.0443 \text{ ppm} / 0.0016 \text{ ppm} = 27.7$$

### *Leaching Rate Model*

The rate of leaching by a first order reduction of mass is described by the equation:

$$dM/dV = -kM, \text{ where:} \quad (1)$$

$M$  = mass remaining in the slag after a volume  $V$  has been leached; and

$-k$  = mass reduction rate.

This can be integrated to:

$$M = M_0 e^{-kV}, \text{ where:} \quad (2)$$

$M_0$  = mass of uranium in soil at time  $T=0$ ; and

$V$  = total volume of leaching solution added since time = 0.

It is assumed that the partitioning of uranium into the leaching waters occurs instantaneously.

The mass reduction rate  $k$  in equation 2 can be readily determined by rearranging the equation:

$$k = (1/V) * \ln(M/M_0) \quad (3)$$

From equation 2, the rate of leaching can then be determined:

$$dM/dV = -k M_0 e^{-kV} \quad (4)$$

Using equations 2 and 4, the concentration of uranium in the leachate and the mass remaining in the consolidation area can be determined after any volume of leaching water passes through the consolidation area.

### *ANALYSIS OF URANIUM LEACHING*

The leaching rate model determines the uranium concentration in leachate as volumes of water continuously infiltrate through the consolidation area. Thus, Figure 1 depicts the results of the model with cumulative leachate volume (in  $\text{ft}^3$ ) passing through the consolidation area shown on the X-axis, and a modeled leachate concentration shown on the Y-axis.

The modeled leachate concentration as a function of time is shown on Figure 2. This is determined using the rate at which infiltrating water will be added to the consolidation area. At the Revere Site, the volume of water infiltrating the consolidation area is determined by the rate of precipitation recharge into the consolidation area, which is the area ground water recharge rate. In the Triassic Basin geologic setting which occurs through out southeastern and south-central Pennsylvania, an average recharge rate of  $0.5 \text{ ft}^3/\text{yr}$  per square foot of land surface is commonly used (Pennsylvania Topographic Geologic Survey, Water Resources Report 49, 1980).

The consolidation area will have a surface area of 54,900 ft<sup>2</sup>. At a recharge rate of 0.5 ft<sup>3</sup>/yr per foot of surface area, 27,450 ft<sup>3</sup> of water will recharge the consolidation area annually. This amount of infiltration is assumed to enter the consolidation area every year; thus the cumulative volume through the consolidation area, as shown on the X-axis of Figure 1, is:

$$V_c = 27,450 \text{ ft}^3 \times T$$

where

$V_c$  = cumulative volume in ft<sup>3</sup>, and

$T$  = time, in years

To convert the Figure 1 X-axis to time, the equation is rearranged to be:

$$T = V_c / 27,450 \text{ ft}^3/\text{yr}$$

On Figure 2, the X-axis has been divided into 100-year increments:

$$T = V_c / (2,430 \text{ ft}^3 \times 100 \text{ yr})$$

For example, the 100-year line on the X-axis of Figure 2 represents 2,745,000 ft<sup>3</sup> of cumulative leachate volume on the X-axis of Figure 1.

The concentration of uranium in the leachate at any given year can be taken from Figure 2, and used in a fate and transport model to simulate environmental effects beginning in that year. Again, because the TAU and RAU leach conditions are much more rigorous than the actual conditions at the site, the fate and transport model results will significantly overestimate the effects of the slag on environmental systems and/or receptors modeled.

The rate of leaching from the slag can also be represented as a percentage of mass removed per year. For the first year:

$$R_l = M_y / \text{TAU}$$

Where:

$M_y$  = mass leached per year; and

$R_l$  = the leach rate in % of available mass/year.

This rate will remain constant over time, with the uranium available in the slag decreasing every year as leaching occurs, and the  $M_y$  also decreasing by the same factor.

The total slag at the site has been estimated above as 5,215,720 lb. The TAU (0.824  $\mu\text{g/g}$ ) is equivalent to 0.824 ppm. Therefore, the environmentally available uranium in the entire consolidation area is  $5,215,720 \text{ lb} \times (0.824 / 1,000,000) = 4.30 \text{ lb}$ . The beginning concentration as derived from the RAU is 0.0016 ppm. Therefore, the mass of uranium leached (My) during year 1 is  $(27,450 \text{ ft}^3 \times 62.4 \text{ lb/ft}^3) \times (0.0016 / 1,000,000) = 0.00274 \text{ lb}$  (where 62.4 lb is the weight of 1 cubic foot of water). Thus, the leaching rate, expressed in percent of remaining mass, is  $0.00274 \text{ lb} / 4.30 \text{ lb} = 0.00064$ , or 0.064 percent.

## *ANALYSIS OF THORIUM LEACHING*

The NRC Guidance used for the above analysis addresses only uranium. However, thorium is known to be present in the Revere slag and may also leach from the consolidation area. To complete a leaching analysis for thorium consistent with the analysis for uranium presented above, two critical factors needed to be determined: the  $K_d$  for thorium, and the mass concentration (in ppm) of the available thorium in the consolidation area.

Several references were identified which concluded that thorium will leach less than uranium, i.e., the thorium  $K_d$  will be greater; however, these references did not include sufficient data to derive a  $K_d$  value for thorium. The results of a study conducted by Sheppard and Thibault (Journal of Environmental Quality, 20:101-114, 1991), however, did provide the necessary information to determine the ratio of the  $K_d$  for uranium to the  $K_d$  for thorium.

Sheppard and Thibault performed controlled leaching tests for uranium and thorium on natural soil columns, and obtained  $K_d$  values for both elements. To achieve this, they introduced uranium and thorium into soil columns by adding a liquid solution containing dissolved uranium and thorium. The uranium and thorium partitioned from liquid onto the soils in the column. The cores were placed in lysimeter sleeves and left in an outdoor area to leach under natural conditions. One half of the cores were collected and analyzed after one year, the other half were collected and analyzed after four years. The results after four years were used for the analysis described herein because the  $K_d$  data were more complete from the 4-year analysis. Interestingly, Sheppard and Thibault described the leaching of both uranium and thorium as "negligible" and observed that there was no significant migration of thorium over the four year study time.

Given the method by which uranium and thorium were introduced to the soil column, it is reasonable to expect that those elements would be more



easily leached from the test soil columns than from the Revere slag material. First, the uranium and thorium in the soil were introduced only to the surface of the soil, and thus adsorption was the only operative attenuation mechanism. The uranium and thorium in the Revere Site slag are components of the crystalline rock matrix itself, and as such should be far less available for leaching. Second, the soil in the field study exposes much greater surface area to infiltrating water than does the Revere slag. Thus, the  $K_d$  values from the Sheppard and Thibault study should be lower than the  $K_d$  values from the slag.

After four years,  $K_d$  was evaluated at four soil horizons in the column: Litter (surface to approximately 1 inch deep), Ae (approximately 1 inch to 5 inches deep), Upper B (approximately 5 to 10 inches deep), and Lower B (approximately 10 to 20 inches deep). The table below describes the  $K_d$  values determined after four years of leaching:

Soil Horizon	$K_d$ Thorium	$K_d$ Uranium	$K_d$ Ratio
Litter	1,600	58	27.6
Ae	1,900	295	6.44
Upper B	1,150	160	7.19
Lower B	207	45.4	4.56

The surficial soil, the litter, contained a high concentration of organic material and is considered inappropriate for comparison with the consolidation area. The three lower samples exhibited similar ratios of the thorium to uranium  $K_d$ , with an average value of 6.06. For purposes of the Revere slag analysis, it is reasonable to assume that the ratio of the  $K_d$  for uranium versus the  $K_d$  for thorium reported from the study would be comparable to the ratio for the Revere slag. From this, the partitioning coefficients for thorium are calculated as:

$$\begin{aligned} K_{d\text{slag}} &= 6 \times 515 = 3090, \text{ and} \\ K_{d\text{area}} &= 6 \times 27.7 = 166 \end{aligned}$$

The mass concentration of thorium in the consolidation area is calculated based on the thorium activity concentrations reported in Appendix A of the Risk Assessment. The  $^{232}\text{Th}$  activity is 10.8 pCi/g of slag. As with uranium, only a portion of the total thorium (which is what the activity represents) is available for leaching. Unlike uranium, no laboratory leaching analyses are available for thorium. However, an estimate of total available thorium (TAT) equivalent to the TAU concentration can be made by assuming that the ratio of total thorium to the TAT is equal to the ratio of total uranium to the TAU. From the NES data, that ratio is 220 ppm/0.824 ppm = 267.

Thus, the activity of the total available  $^{232}\text{Th}$  is converted to a mass concentration of  $^{232}\text{Th}$  by the following units conversion formula:

$$C \text{ (g/g)} = \frac{\text{Activity} \times (t_{1/2}/0.693) \times 2.2 \times \text{Atomic Mass}}{6.023 \times 10^{23} \times 267}$$

where: Activity is in pCi/g  
 $t_{1/2}$  is the isotope half life in minutes  
 $(t_{1/2}/0.693)$  is average number of minutes between decay events in minutes/decay  
 2.2 is the number of decays per minute per pCi  
 Atomic Mass is in g/mole  
 $6.023 \times 10^{23}$  is Avogadro's Number, the number of atoms per mole  
 267 is the ratio of total thorium to TAT

The half life of  $^{232}\text{Th}$  is  $1.41 \times 10^{10}$  years, or  $7.42 \times 10^{15}$  minutes and the atomic mass is 232.038. The activity of  $^{232}\text{Th}$  is was reported by NES to be 10.8 pCi/g, and the concentration of available  $^{232}\text{Th}$  in the slag is:

$$\begin{aligned} C_{\text{slag}} \text{ (}\mu\text{g/g)} &= \frac{10.8 \times (7.42 \times 10^{15} / 0.693) \times 2.2 \times 232.038}{6.023 \times 10^{23} \times 267} \\ &= 0.367 \times 10^{-6} \text{ g/g} \\ &= 0.367 \mu\text{g/g or } 0.367 \text{ ppm} \end{aligned}$$

Although thorium has numerous isotopes,  $^{232}\text{Th}$  is essentially 100% of the thorium mass in the slag. As a result, the total thorium mass concentration is essentially the same as the concentration of  $^{232}\text{Th}$ .

As presented for uranium, the average concentration of total available thorium in the consolidation area is then:

$$\begin{aligned} C_{\text{area}} &= C_{\text{slag}} \times 5,215,720 / 96,914,751 \\ &= 0.367 \text{ ppm} \times 0.0538 \\ &= 0.0198 \text{ ppm} \end{aligned}$$

A leaching rate can be determined from the total mass of available thorium in the slag and the mass leached out in one year. The total mass of available thorium in the consolidation area is:  $(5,215,720 \text{ lb slag with uranium and thorium}) \times 0.367 \text{ ppm} \times (1/1,000,000 \text{ ppm}) = 1.92 \text{ lb}$ . The concentration of thorium in the leachate is given by:

$$\begin{aligned} C_l &= C_{\text{area}} / K_{d\text{area}} \\ &= 0.0198 \text{ ppm} / 166 \\ &= 0.000119 \text{ ppm} \end{aligned}$$

The mass of thorium removed in one year is:  $(27,450 \text{ ft}^3 \text{ water} / \text{yr} \times 62.4 \text{ lb} / \text{ft}^3 \text{ water}) \times 0.000119 \text{ ppm} \times (1 / 1,000,000 \text{ ppm}) = 0.000204 \text{ lb} / \text{yr}$  of thorium leached. Figure 3 shows the 1000-year leaching curve for the thorium. The leaching rate is  $0.000204 \text{ lb} / \text{yr} / 1.92 \text{ lb} = 0.00011$ , or 0.011 % per year. It should be noted that this leaching rate is 6 times less than the leaching rate for uranium, as would be expected from the 6 times greater  $K_d$  for thorium versus uranium.

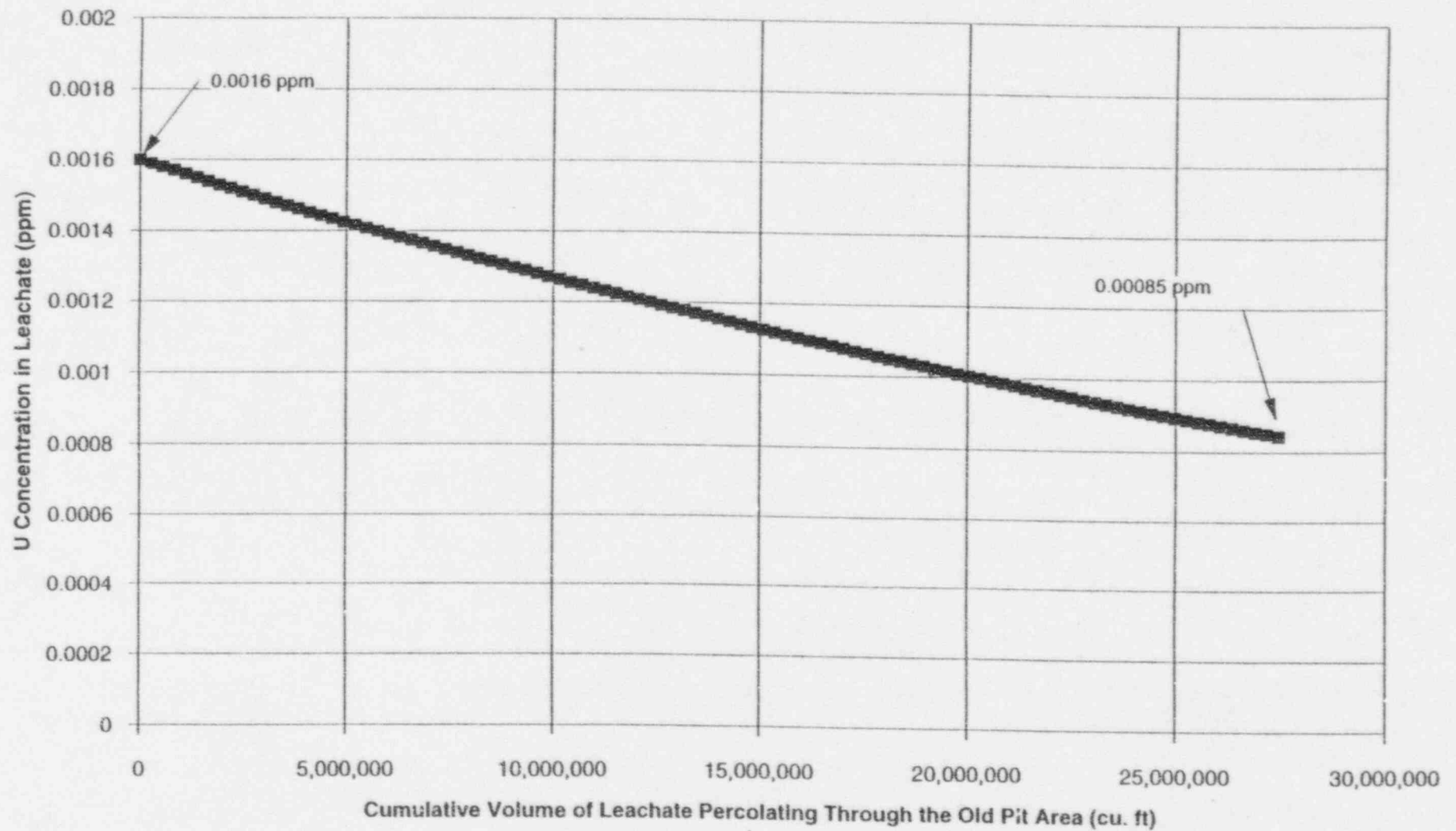
## CONCLUSIONS

ERM has drawn the following conclusions regarding the rate of leaching of radionuclides from the Old Pit Area at the Cabot plant in Revere, Pennsylvania:

- Of the available data, the TAU represents a very conservative upper bound on what might ever leach from the consolidation area.
- The RAU represents a conservative upper bound on what might leach most readily from the consolidation area under natural environmental conditions.
- Using the available data, the best model for predicting leaching is a first order reduction of available mass from the slag, with the rate of leaching dependent on the volume of water entering the slag on an annualized basis.
- The partitioning coefficient between the slag with uranium and thorium and water is 515 for uranium. The rate of leaching is 0.064% of uranium mass remaining in the consolidation area per year.
- Based on the work of Sheppard and Thibault, 1991, the partitioning coefficient for thorium is estimated to be 6 times greater than that for uranium. Because  $K_d$  is increased by a factor of 6, the leaching rate of thorium is 6 times less than the leaching rate for uranium. The thorium leaching rate is thus 0.011 % per year.
- Because the RAU leach is more rigorous than the actual conditions at the site, fate and transport model results will overestimate the effects of the uranium and thorium in the slag on environmental systems and/or receptors modeled.
- ERM's model results can be used to determine the theoretical concentrations of uranium and thorium in leachate within the slag, for any year between 1 and 1000, for input to a fate and transport model.

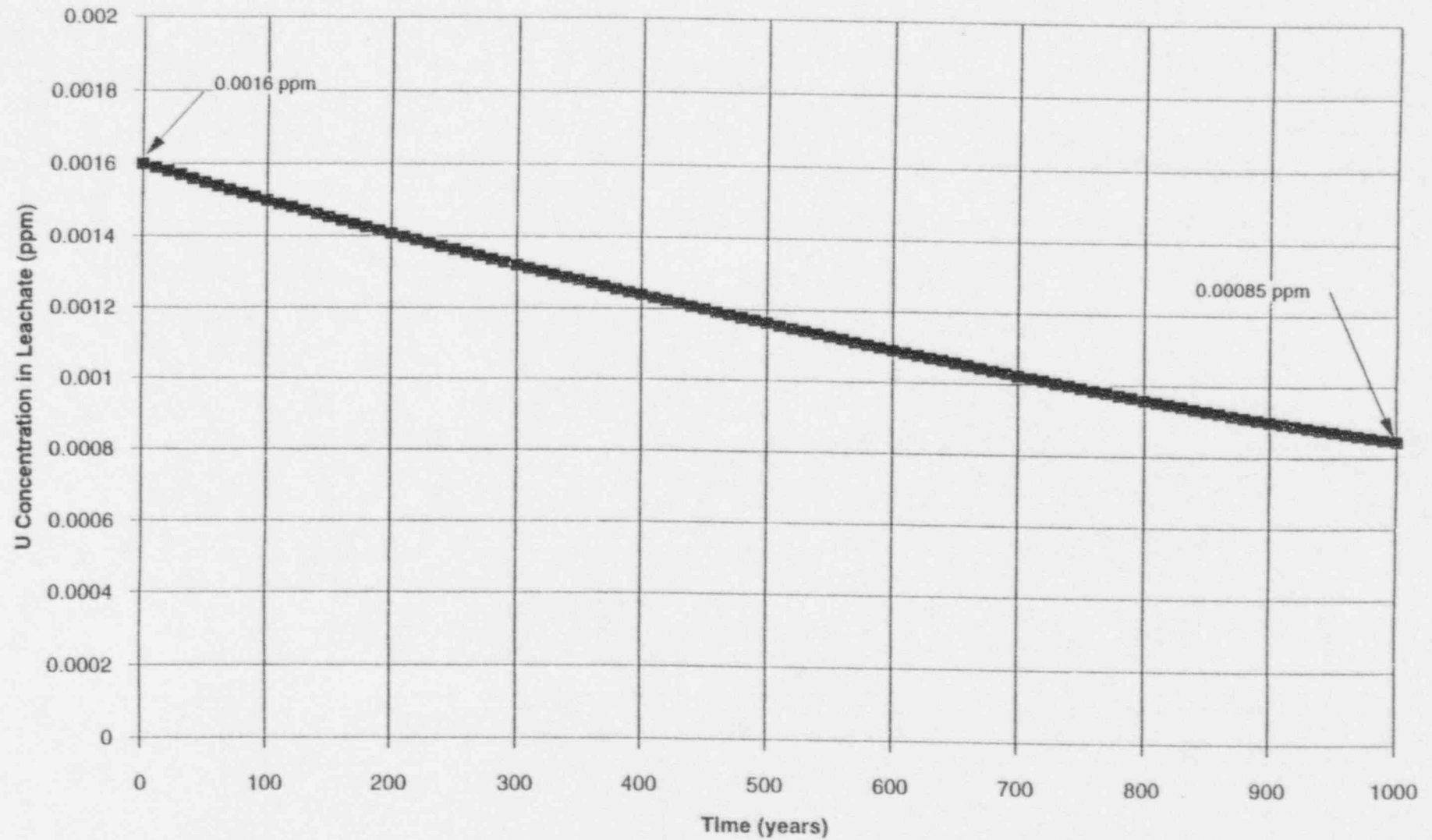
**Figure 1**  
**Modeled Uranium Concentration in Leachate vs**  
**Cumulative Leachate Volume**  
**Revere Site**

(6 inches per year infiltration rate)



**Figure 2**  
**Modeled Uranium Concentration in Leachate vs Time**  
**Revere Site**

(6 inches per year infiltration rate)





**Figure 3**  
**Modeled Thorium Concentration in Leachate vs Time**  
**Revere Site**

(6 inches per year infiltration rate)

