Review of the Occupational Air Sampling Program at the Cabot Supermetals, Incorporated Boyertown, Pennsylvania Plant

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1. EXECUTIVE SUMMARY

This report provides a review of the occupational air-sampling program at the Cabot Supermetals, Inc. (CSM) plant in Boyertown, Pennsylvania. The CSM plant receives and handles radioactive materials under license SMB-920, which was issued by the U.S. Nuclear Regulatory Commission (NRC). Tantalum and niobium are extracted from ore materials that contain low concentrations of natural uranium and thorium. The radioactive constituents are not extracted or concentrated from the ore during this process. A second operation involving radioactive materials at CSM is thorium doping. This process uses thorium nitrate and is described in section 2.9 of this report.

Historical air sample data have demonstrated that workers are exposed only to low concentrations of airborne uranium, thorium, and their radioactive progeny during routine ore processing operations and thorium doping activities. Data are not available to document airborne concentrations that occasionally may be present during non-routine operations such as maintenance activities. These non-routine exposures are limited in duration and so the dose consequences are usually not expected to be significant.

This report documents the results of an evaluation of the CSM occupational air-sampling program and it represents an update of a detailed evaluation of the air-sampling program that was performed during 1995 by Applied Radiological Control, Inc. (1995). The review documented in this report was initiated in response to item B of a Notice of Violation issued on October 23, 2001 by the NRC (Kinneman 2001).

This report touches on several topics that affect the current sampling program, including derived air concentration (DAC) values for the ore processing and thorium doping activities at the plant, and placement of samplers to obtain representative dust samples. In addition, this document provides current area and breathing zone sample data and makes recommendations for calculation of a gross alpha DAC, effective DAC, and continued air sampling.

This report is an update of a draft occupational air-sampling program evaluation that was submitted for review by the NRC in September 2002. It now incorporates revisions that address comments provided in a letter to CSM from the NRC dated 14 January 2003 titled "Request For

Additional Information On The License Renewal Application For The Cabot Boyertown Facility, SMB-920 (L52461)". John McGrath of the NRC, Region I reviewed that draft. This revision of the air sampling evaluation does not pursue a prior request for approval to use dust cyclones. Instead, it provides a rationale for why CSM should be permitted to use a DAC based on a 10-micron activity median aerodynamic diameter particle size distribution for ore processing activities. It then calculates mixture DAC values and gross alpha DAC values based on this particle size. All mixture DAC and gross alpha DAC values presented herein are strictly based on standard ICRP Publication 30 metabolic models and methodology, which form the basis of the system of dose limitation adopted by the NRC.

This document proposes DAC values based on an activity ratio in ores of 3 U-238: 1 Th-232 in place of the previous DAC, which was based on a ratio of 2 U-238: 3 Th-232. A technical description of how the earlier ratios were chosen has not been found, but the ratios presented herein are based on a rigorous statistical evaluation of analytical data from 207 ore samples collected throughout 2001, as presented in Section 2.1. In addition, this report concludes that respirators are not required for adequate protection of workers during routine operations and that specific work control plans, such as radiation work permits, should document appropriate worker protection and special monitoring requirements for non-routine operations.

2. DERIVATION OF GROSS ALPHA DAC VALUES

This section establishes a rationale for a gross alpha DAC that may be used to estimate a committed effective dose equivalent from inhalation of ore dust at the CSM Boyertown plant. The DAC is believed to be protective of workers and is reflective of the historical variability of the uranium-238 to thorium-232 ratio.

2.1 COMPOSITION OF THE ORE MATERIALS

This evaluation of the uranium and thorium content of ores processed by CSM is based on the ores received and sampled in 2001. During 2001, CSM received a total of 207 shipments. The uranium and thorium concentrations in each of those ore shipments are listed in Appendix A.

The data in Appendix A were sorted by the rank of the uranium-238 activity fraction, that is, by how much of the radioactivity in an ore batch was produced by uranium-238:

U-238 activity / (U-238 activity + Th-232 activity).

Figure 1 is a graph of the activity percent uranium-238 versus the rank of the uranium-238 activity fraction for the ore received in 2001. This is an important factor because the dose per picocurie (pCi) of intake increases as the ratio decreases.

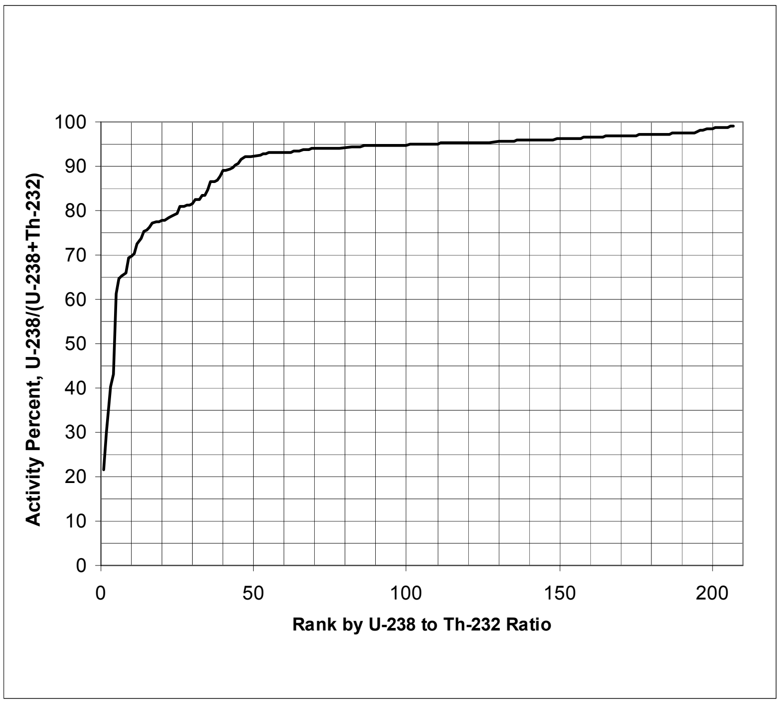

Figure 1. Plot of the Activity Percent Uranium Versus the Rank by U-238 to Th-232 ratio

Figure 1 illustrates that most of the ore materials processed by CSM during 2001 had high activity ratios of uranium-238 to thorium-232. To be conservative, the 95% lower confidence limit on the 0.1-quantile uranium-238 activity ratio for 2001 data is recommended for derivation of the gross alpha DAC.[1] This corresponds to 75% uranium-238 activity and 25% thorium-232

[1] This is based on statistics of rank. The 0.1 quantile activity ratio is the activity ratio for the ore lot that has a rank of 21 out of 207. The 95% lower confidence limit on the 0.1 quantile value is the activity ratio that corresponds to the rank of: $21 - (1.645*[207*0.1 * 0.9]^{0.5})$ or rank 14, which is 75% uranium-238: 25% thorium-232.

activity (or a ratio of 3:1). Ninety percent of the ore mixtures processed at the Boyertown site will have an activity ratio of uranium-238 to thorium-232 of 75% to 25% or greater. Summary statistics for ores received in 2001 are provided in Table 1.

Table 1. Summary Statistics for Ore Shipments Received by CSM During 2001

Average activity ratio: U-238 / U-238 + Th-232	0.91
Median activity ratio: U-238 / U-238 + Th-232	0.95
0.1 quantile activity ratio: U-238 / U-238 + Th-232	0.78 (Rank 21 of 207)
95% lower confidence limit on 0.1 quantile activity ratio	0.75 (Rank 14 of 207)

2.2 DEGREE OF EQUILIBRIUM IN THE DECAY CHAINS

The ore material processed by the Boyertown plant is expected to have uranium and thorium more or less uniformly distributed through its volume since the ore is composed of niobium/tantalum minerals in which uranium and thorium are randomly substituted for calcium and rare earth elements (Frondel 1958). Therefore, radon is formed throughout the matrix of these materials. Very little of the radon in the ore materials is produced at the surfaces of mineral grains, and so very little is expected to emanate from mineral grains. Since very little radon is expected to emanate from the ore, a high degree of equilibrium in the uranium-238 and thorium-232 decay chains is also expected.

Like the ore processed at CSM, oil field barite pipe scale contains radioactive materials (radium-226) that are distributed more or less uniformly throughout the matrix of the scale. As with niobium/tantalum minerals, very little of the radon is available for emanation. The EPA has assigned pipe scale materials a radon emanation fraction of 5% (EPA 1993).

To assess the equilibrium of the CSM ore materials, gross gamma was counted on a sample of feed material. A sample of ground ore material weighing 800 grams was placed into a 410-ml low-form polyethylene container that was allowed to sit open for 12 hours. The container was then sealed shut using black electrical tape. The sample was counted for a series of 10-minute counts in the configuration shown in Figure 2. The net count rate in counts per minute (cpm) was plotted versus time, as shown in Figure 3. The time scale on the graph represents the elapsed time in days since the sample was sealed.

Figure 2. Counting Container Configuration

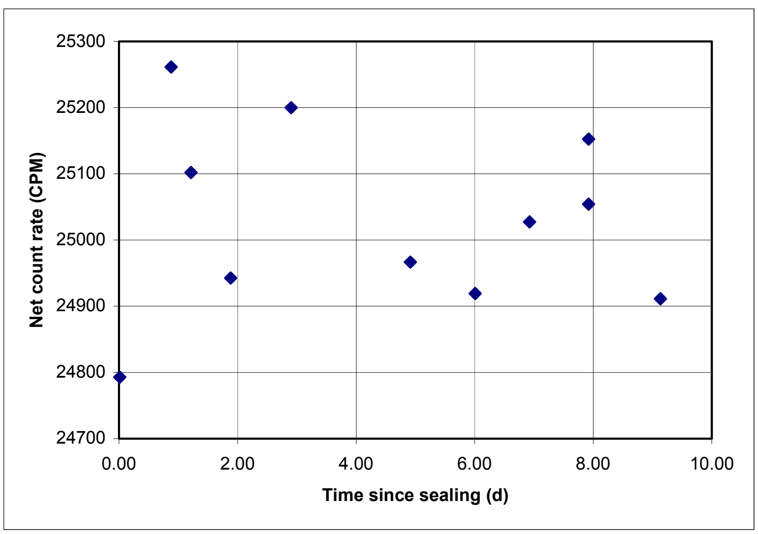

Figure 3. Net Count Rate Versus Time Since Sealing.

The gamma emitters in the uranium-238 and thorium-232 chains are largely progeny from radon-222 and radon-220. Therefore, a significant increase in the count rate with time since sealing would indicate that a significant amount of radon was lost when the container was open for the 12-hour period. Figure 3 indicates that the count rate remained essentially constant after sealing; therefore the material must maintain a high degree of equilibrium between radium and radon progeny during handling. It is concluded that the material would retain nearly all of its radon during handling and grinding, and the elements below radium-226 and radium-224 are assumed to be at 90% of their equilibrium activity. The 10% loss takes into account the 5% emanation loss described earlier and allows an additional 5% loss as a conservative factor.

2.3 DAC VALUES FOR THE URANIUM-238 DECAY CHAIN (ORE PROCESSING)

The uranium-238 decay chain is depicted in Figure 4. The degree of equilibrium and number of alpha emissions per uranium-238 decay are given in Table 2.

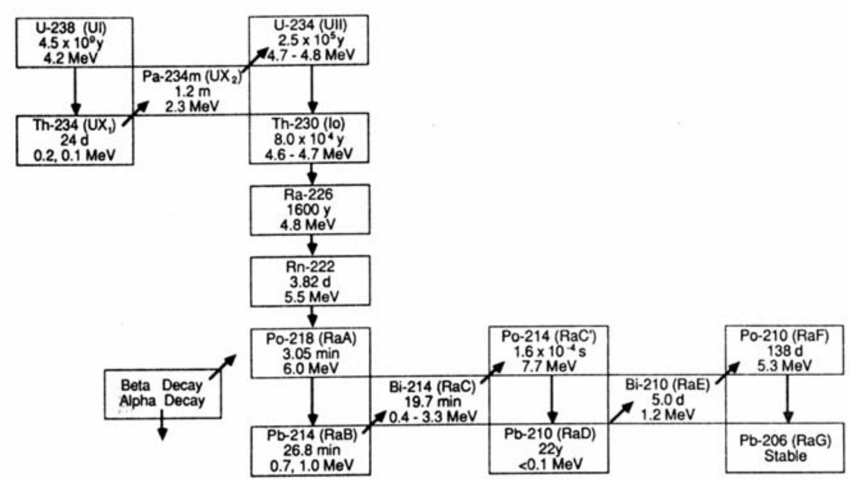

Figure 4. Uranium-238 Decay Chain (after NCRP 1988)

Table 3 provides stochastic derived air concentration (SDAC) values for the isotopes in the U-238 decay chain for 10-micron activity median aerodynamic diameter (AMAD) particle sizes. Title 10 CFR Part 20, Appendix B provides a DAC for the grinding and milling of natural uranium, which is based on a 10-micron AMAD. Tantalum ore grinding is a very similar process to grinding uranium ore, so the assumption of a 10-micron AMAD is reasonable for CSM's feed material grinding, too. The SDAC values were calculated for 10-micron AMAD aerosols using equations 5.8 and 2.1 of ICRP publication 30 along with data provided in the supplements to ICRP publication 30. Additional details on the calculations for the 10-micron values are provided in a technical calculation provided to CSM (Weston Solutions, 2003a).

Table 2. Uranium-238 Decay Chain and Equilibrium Assumptions

Isotope	Equilibrium pCi per pCi U-238	Number of Alphas per Decay	Minimum Fraction of Equilibrium expected	pCi Alpha Activity per pCi U-238	pCi activity per pCi of U-238
U-238	1.00E+00	1	1	1	1.00E+00
U-234	1.00E+00	1	1	1	1.00E+00
Th-234	1.00E+00	0	1	0	1.00E+00
Th-230	1.00E+00	1	1	1	1.00E+00
Rn-222	1.00E+00	1	0.9	0.9	9.00E-01
Ra-226	1.00E+00	1	1	1	1.00E+00
Po-218	1.00E+00	1	0.9	0.9	9.00E-01
Po-214	1.00E+00	1	0.9	0.9	9.00E-01
Po-210	1.00E+00	1	0.9	0.9	9.00E-01
Pb-214	1.00E+00	0	0.9	0	9.00E-01
Pb-210	1.00E+00	0	0.9	0	9.00E-01
Pa-234m	1.00E+00	0	1	0	1.00E+00
Pa-234	1.30E-03	0	1	0	1.30E-03
Bi-214	1.00E+00	0	0.9	0	9.00E-01
Bi-210	1.00E+00	0	0.9	0	9.00E-01
Total	1.40+01			7.6	13.2013

Table 3. U-238 Decay Chain Stochastic Derived Air Concentration Values

Isotope	SDAC, 10-Micron AMAD, µCi/ml
U238	8.7E-11
Th234	1.4E-07
Pa234	6.1E-06
U234	7.8E-11
Th230	2.8E-11
Ra226	8.0E-10
Pb210	1.3E-10
Bi210	5.5E-08
Po210	4.6E-10

The mixture DAC for the uranium-238 decay chain (UDAC) is calculated from the data in Tables 2 and 3 as follows:

(Equation 1)

$$UDAC = 1/(\frac{1}{U238} + \frac{1}{Pa234} + \frac{1}{Th234} + \frac{1}{U234} + \frac{1}{Th230} + \frac{1}{Ra226} + \frac{0.9}{Po210} + \frac{0.9}{Pb210} + \frac{0.9}{Bi210}))$$

In this equation, the concentrations of uranium-238, uranium-234, thorium-230, radium-226 and protactinium-234m are equal. The concentrations of polonium-210, bismuth-210 and lead-210 are equal to 0.9 times the concentration of uranium-238. The isotope values in the denominator are the DAC values for the respective isotopes and particle sizes given in Table 3.

When the values for 10-micron AMAD particles are substituted into Equation 1, a mixture DAC of 1.4 E-11 μCi/ml uranium-238 is obtained. From Table 2 the number of alpha decays per decay of uranium-238 is 7.6. The corresponding gross alpha DAC for the uranium-238 decay chain is 1.1 E-10 μCi/ml.

2.4 DAC VALUES FOR THE THORIUM-232 DECAY CHAIN (ORE PROCESSING)

The thorium-232 decay chain is shown in Figure 5. The mixture DAC for the thorium-232 decay chain is calculated from the data in Tables 4 and 5 as shown in Equation 2.

The second column of Table 5 provides SDAC values for the thorium-232 decay chain based on a 1-micron activity median aerodynamic diameter (AMAD). These values are calculated to 2 significant figures based on data provided in the supplements to ICRP 30 and are used in a later section of this report.

The third column of Table 5 provides the SDAC values for the thorium-232 decay chain based on a 10-micron AMAD. The DAC values for 10-micron aerosols were calculated using equations 5.8 and 2.1 of ICRP publication 30 along with data provided in the supplements to ICRP publication 30. Additional detail on the calculation for the 10-micron DAC values is provided in a technical calculation provided to CSM (Weston Solutions, 2003a).

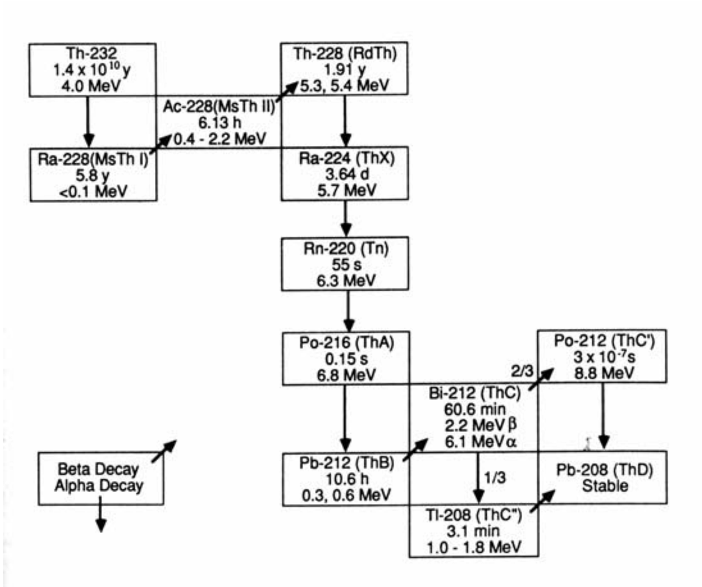

Figure 5. Thorium-232 Decay Chain (after NCRP 1988).

Table 4. Thorium-232 Decay Chain and Equilibrium Assumptions

Isotope	Equilibrium pCi per pCi Th-232	Number of Alphas per Decay	Fraction of Equilibrium Expected	pCi Alpha Activity per pCi Th-232	pCi Activity per pCi of Th-232
Tl-208	3.61E-01	0	0.9	0.00E+00	3.25E-01
Pb-212	1.00E+00	0	0.9	0.00E+00	9.00E-01
Bi-212	1.00E+00	0.36	0.9	3.24E-01	9.00E-01
Po-212	6.43E-01	1	0.9	5.79E-01	5.79E-01
Po-216	1.00E+00	1	0.9	9.00E-01	9.00E-01
Rn-220	1.00E+00	1	0.9	9.00E-01	9.00E-01
Ra-224	1.00E+00	1	1	1.00E+00	1.00E+00
Ra-228	1.00E+00	0	1	0.00E+00	1.00E+00
Ac-228	1.00E+00	0	1	0.00E+00	1.00E+00
Th-228	1.00E+00	1	1	1.00E+00	1.00E+00
Th-232	1.00E+00	1	1	1.00E+00	1.00E+00
Total	1.00E+01	---	---	5.70E+00	9.50E+00

Table 5. Thorium-232 Decay Chain Stochastic DAC Values.

Isotope	SDAC, 1-Micron AMAD, μCi/ml	SDAC, 10-Micron AMAD, μCi/ml
Th232	1.8E-12	5.8E-12
Ra228	4.9E-10	9.4E-10
Ac228	1.9E-08	9.4E-08
Th2228	6.8E-12	3.4E-11
Ra224	7.1E-10	3.4E-09
Pb212	1.3E-08	1.6E-08

(Equation 2)

$$ThDAC = \frac{1}{\left(\frac{1}{Th232} + \frac{1}{Th228} + \frac{1}{Ra228} + \frac{1}{Ra224} + \frac{1}{Ac228} + \frac{0.9}{Pb212}\right)}$$

All isotopes above radon-220 in the decay chain are assumed to be in equilibrium in the thorium-232 chain. Radon-220 and progeny below it in the decay chain are assumed to be present at 90% of the equilibrium values. This leads to 5.7 alpha decays per thorium-232 decay, as given in Table 4. The isotope values in the denominator are the DAC values for the respective isotopes given in Table 5. When these values for 10-micron AMAD aerosols are substituted into Equation 2, one DAC for the thorium-232 chain corresponds to 4.9E-12 μCi/ml thorium-232 and the corresponding gross alpha DAC is 2.8E-11 μCi/ml.

2.5 DAC VALUES FOR MIXTURES OF URANIUM-238 AND THORIUM-232 DECAY CHAIN ISOTOPES

Equation 3 gives the DAC for mixtures of the two decay chains. The factor ThtoU is one-third for a mixture that has the activity ratio (ThtoU) of 1 thorium: 3 uranium, which is equivalent to the activity ratio of 25% thorium to 75% uranium, as explained in Section 2.1 of this report.

(Equation 3)

$$MixDAC = 1/\{ThtoU\{\frac{1}{Th232} + \frac{1}{Th228} + \frac{1}{Ra228} + \frac{1}{Ra224} + \frac{1}{Ac228} + \frac{0.9}{Pb212}\} + \{\frac{1}{U238} + \frac{1}{U234} + \frac{1}{Th230} + \frac{1}{Ra226} + \frac{1}{Pa234} + \frac{0.9}{Po210} + \frac{0.9}{Bi210} + \frac{0.9}{Pb210}\}\}$$

The same assumptions about degree of equilibrium from Tables 2 and 4 are made. This leads to 9.5 alpha decays per uranium-238 decay for this mixture. Substituting the DAC values from Tables 3 and 5 into Equation 3, one DAC (10-micron AMAD) corresponds to 7.2E-12 μCi/ml as uranium-238. One DAC of gross alpha activity (10-micron AMAD) corresponds to 6.9E-11 μCi/ml.

2.6 COMPARISON WITH PREVIOUS DAC FOR ORE PROCESSING

Table 6 provides a comparison of the proposed DAC and the DAC derived in 1995. The previous DAC was based on the assumption that only U-nat (uranium-238, thorium-234, protactinium-234m, uranium-234, thorium-234, and radium-226) and thorium-232 were present in the ore.

The DAC for U-nat given in Title 10 CFR Part 20, Appendix B was used to derive the 1995 DAC. It is based on the assumption that the AMAD of the material is 10 microns and that uranium-238 is in equilibrium with thorium-234, protactinium-234m, uranium-234, thorium-230, and radium-226. Other DAC values used in 1995 for other radionuclides were based on 1-micron AMAD aerosols despite a lack of justification for that value in the CSM operations. The proposed DAC values developed herein are entirely based on 10-micron AMAD aerosols in accordance with the Title 10 CFR Part 20, Appendix B values for grinding and milling of natural uranium ores. As explained in Section 2.1, the uranium to thorium activity ratio that is used in this report is based on a rigorous analysis of all ore materials received in 2001. It was chosen with the objective of having a gross alpha DAC that over-estimates dose 90 percent of the time.

Table 6. Comparison of the Proposed and Previous DAC Values for Ore Processing

Factor	Proposed DAC	DAC Derived in 1995
Isotopes considered	All isotopes in U-238 and Th-232 decay chains.	Unat (U-238, Th-234, Pa-234m, U-234, Th-230 and Ra-226) and Th-232.
Assumed Particle size	10-micron AMAD	Mixed: 1-micron AMAD Th-232 + 10-micron Unat
Number of Alphas in U-238 decay chain	7.6	4
Number of Alphas in Th-232 decay chain	5.7	3
Activity ratio	25 % Th-232: 75% U-238	60% Th-232: 40% U-238
Gross Alpha DAC	6.9 E-11 μCi/ml	5.4E-12 μCi/ml

2.7 COMPARISON OF PERSONAL AND AREA AIR SAMPLE DATA IN BUILDING 73

Personal breathing zone and area air samples have been collected simultaneously in Building 73 work areas at CSM. In general, each breathing zone sample was collected over a work shift. Area air samplers are usually allowed to operate continuously, and the air filter media are replaced once a week. All area air and breathing zone sample results to date have been collected as total dust samples.

Most breathing zone air samples were collected during ore dumping and grinding operations. These area and breathing zone sample results are provided in Table 7 for the time period of April 22, 2002 to June 10, 2002. The breathing zone and area air samples were collected as total dust samples. Based on Table 7, the breathing zone concentrations during ore dumping averaged 4.1% of the DAC (10-micron AMAD). The average airborne concentrations translate to a concentration of less than 10% of the SDAC for the mixture so it is not necessary to demonstrate that the air sampled by area samplers is representative of air in the breathing zones of workers, in accordance with guidance in Regulatory Guide 8.25.

Table 7. Comparison of Breathing Zone and Area Air samples for Ore Dumping and Grinding Activities.

SampleEndDate	Area Gross Alpha Concentration, uCi/ml	Date	Breathing Zone Gross Alpha Concentration, uCi/ml
8-Jan-02	7.7E-13		
14-Jan-02	1.6E-13		
21-Jan-02	1.9E-13		
28-Jan-02	5.5E-13		
4-Feb-02	1.8E-13		
11-Feb-02	2.6E-13		
18-Feb-02	2.4E-13		
25-Feb-02	1.3E-13		
6-Mar-02	1.8E-13		
12-Mar-02	1.2E-13		
19-Mar-02	9.8E-14		
25-Mar-02	1.9E-13		
2-Apr-02	1.8E-13		
8-Apr-02	2.8E-13		
		11-Apr-02	5.3E-12
12-Apr-02	2.9E-13	12-Apr-02	2.0E-12

SampleEndDate	Area Gross Alpha Concentration, uCi/ml	Date	Breathing Zone Gross Alpha Concentration, uCi/ml
		16-Apr-02	4.3E-12
		18-Apr-02	6.8E-13
		19-Apr-02	3.3E-12
22-Apr-02	2.0E-13	22-Apr-02	3.7E-13
29-Apr-02	2.3E-13	24-Apr-02	3.6E-13
		30-Apr-02	4.3E-13
		30-Apr-02	2.2E-12
		01-May-02	1.5E-12
		04-May-02	7.1E-13
6-May-02	2.3E-13	06-May-02	9.9E-13
		08-May-02	1.1E-12
		09-May-02	5.9E-13
		09-May-02	1.6E-12
		10-May-02	9.2E-13
		10-May-02	5.9E-14
13-May-02	1.1E-13	13-May-02	4.2E-12
		14-May-02	7.7E-13
		15-May-02	2.2E-12
		17-May-02	2.3E-12
20-May-02	6.3E-13	20-May-02	4.9E-14
		21-May-02	6.4E-12
		21-May-02	1.1E-12
		22-May-02	7.1E-13
		22-May-02	3.9E-13
28-May-02	3.2E-13	23-May-02	2.5E-12
		30-May-02	1.6E-12
		31-May-02	1.0E-11
3-Jun-02	2.2E-13	31-May-02	1.1E-12
		06-Jun-02	1.8E-13
		06-Jun-02	1.7E-12
		07-Jun-02	3.4E-14
		10-Jun-02	4.0E-12
10-Jun-02	6.1E-13	10-Jun-02	1.8E-12
		11-Jun-02	7.4E-13
		12-Jun-02	2.2E-12
		13-Jun-02	1.5E-12
17-Jun-02	1.0E-13	17-Jun-02	5.8E-13
24-Jun-02	1.4E-13		
1-Jul-02	2.1E-13		
8-Jul-02	2.2E-13	02-Jul-02	1.3E-12

SampleEndDate	Area Gross Alpha Concentration, uCi/ml	Date	Breathing Zone Gross Alpha Concentration, uCi/ml
		10-Jul-02	3.0E-12
		11-Jul-02	0.0E+00
		15-Jul-02	4.4E-13
15-Jul-02	3.5E-13	15-Jul-02	1.6E-12
		17-Jul-02	6.1E-13
		17-Jul-02	6.1E-13
		19-Jul-02	2.9E-12
22-Jul-02	2.7E-13	22-Jul-02	3.4E-12
		23-Jul-02	1.3E-12
		24-Jul-02	1.1E-12
		25-Jul-02	4.1E-12
		25-Jul-02	9.2E-12
29-Jul-02	5.5E-13	29-Jul-02	4.1E-13
		30-Jul-02	2.9E-12
		30-Jul-02	1.5E-12
		30-Jul-02	4.7E-13
		01-Aug-02	4.8E-13
		01-Aug-02	4.0E-13
		02-Aug-02	6.9E-13
		02-Aug-02	2.4E-12
5-Aug-02	7.1E-13	05-Aug-02	1.6E-12
		06-Aug-02	2.3E-12
		06-Aug-02	3.1E-13
		09-Aug-02	3.7E-12
		13-Aug-02	2.3E-12
		14-Aug-02	8.7E-13
		15-Aug-02	4.3E-13
		21-Aug-02	4.6E-13
		22-Aug-02	2.7E-13
		26-Aug-02	7.8E-13
		28-Aug-02	9.9E-14
		29-Aug-02	7.3E-13
		17-Sep-02	1.6E-12
		17-Sep-02	3.4E-12
		18-Sep-02	4.4E-13
		20-Sep-02	3.1E-13
		24-Sep-02	7.2E-12
		24-Sep-02	3.9E-13
		24-Sep-02	8.5E-13
		25-Sep-02	2.8E-12

SampleEndDate	Area Gross Alpha Concentration, uCi/ml	Date	Breathing Zone Gross Alpha Concentration, uCi/ml
		30-Sep-02	1.4E-12
		01-Oct-02	3.2E-13
		01-Oct-02	4.2E-13
		02-Oct-02	4.6E-12
		02-Oct-02	3.7E-13
		03-Oct-02	4.3E-13
		04-Oct-02	1.4E-13
		07-Oct-02	1.7E-11
		09-Oct-02	2.7E-12
		10-Oct-02	7.8E-11
		Breathing Zone Average	2.8E-12
		Breathing Zone Maximum	7.8E-11

Only two breathing zone sample results were obtained for ore screening activities; these results are presented in Table 8. The average breathing zone concentration during this activity was 3.2E-12 µCi/ml. This is 4.6% of the DAC (10-micron AMAD), which is generally consistent with the levels documented by the area air sample results. At these concentrations, it is not necessary to demonstrate under Regulatory Guide 8.25 that area air samples are representative of the air inhaled by workers.

Table 8. Air Sample Results for Ore Screening Activities.

Sample End Date	Area Sample (µCi/ml)	Breathing Zone Sample Date	Breathing Zone Concentrations, (µCi/ml)
13-May-02	1.1 E-13	10-May-02	1.2E-12
28-May-02	3.2E-13	16-May-02	5.3E-12
		Average	3.2E-12

2.8 THORIUM DOPING ACTIVITIES

Thorium is added to tantalum powder in the Thorium Doping Room located in building 29. This process involves a number of steps. First, thorium nitrate is weighed on a balance and dissolved in water. The thorium nitrate solution is poured onto a layer of tantalum powder that has been spread in a layer on a drying table. A steam heating system heats the tabletop to drive off the water. The material is then collected into a drum using a HEPA vacuum system. Finally it is mixed using a shaker.

The Thorium Doping Room is the size of a walk-in closet, about 7 feet wide by 10 feet long. The layout is provided in Figure 6. There are two local exhaust ventilation devices in the room. A slot hood is located adjacent to drying table, and a canopy exhaust hood is located on the opposite side of the room adjacent to the weighing table. Figure 7 provides a view of the end of the room where the steam table is located. The HEPA vacuum is located on the weighing table under the canopy hood. The air sampler head is located at breathing zone height near the HEPA vacuum, as shown in Figure 8. Makeup air comes into the room via the entrance, which has no door.

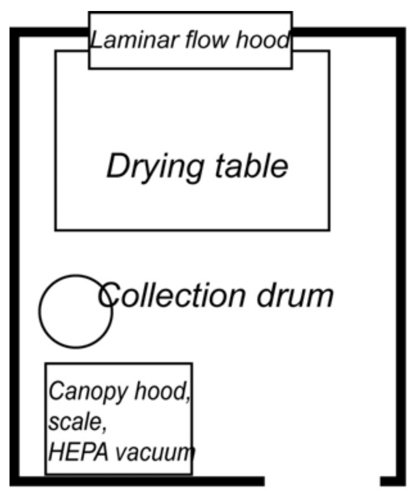

Figure 6. Thorium Doping Room Layout

Figure 7. Slot hood, steam table and drum into which thorium-doped powder is collected.

Figure 8. Canopy hood, weighing table and area sampler head (blue)

2.8.1 Derivation of Mixture and Gross Alpha DAC for Thorium Doping

The basis for a DAC for thorium doping activities is provided in this section. The detailed derivation is provided in a technical calculation provided to CSM (Weston Solutions, 2003a). The radioactive material is in the form of a thorium nitrate. Thorium nitrate has been assigned to lung clearance class W material under the ICRP Publication 30 system of dosimetry.

The Th-232 and Th-228 SDACs given in Table 9 were calculated from data in Federal Guidance Report 11. The remaining values used to calculate the mixture DAC were taken from column 2 of Table 5 of this document.

Table 9. Stochastic DAC values for class W thorium isotopes.

Isotope	SDAC, μCi/ml
Th-232	1.3E-12
Th-228	8.3E-12

Freshly prepared thorium nitrate is assumed to initially contain equal activities of thorium-232 and thorium-228. The progeny of thorium 232 and thorium-228 are not assumed to be present in the freshly produced thorium nitrate because the chemical separation used to generate the thorium would likely isolate these other metals or nuclides. The thorium nitrate reagent used by CSM is assumed to have aged for some time prior to use. This results in ingrowth and decay of radium-228 as well as thorium-228 and its progeny, which would result in a DAC that is less restrictive than the one that is used herein. The minimum possible activity ratio of thorium-228 to thorium-232 is 0.424 (Weston Solutions, 2003a). Based on this ratio the minimum number of alphas emitted per decay of thorium-232 is 3.52. The most restrictive possible stochastic gross alpha DAC for thorium nitrate occurs at an effective age of 4.5 years. The minimum gross alpha DAC for thorium doping is 4.2E-12 μCi/ml. This corresponds to a thorium-232 concentration of 1.2E-12 μCi/ml if no thorium-230 is present.

The gross alpha DAC for thorium nitrate varies by almost a factor of two with age. The most restrictive DAC values are used as long as the age is not known. If the actinium-228 to thorium-232 ratio has been determined by alpha and gamma spectroscopy, then the appropriate DAC value from Figure 9 can be used for dose calculations. Some thorium-230 may also be present in the thorium nitrate reagent. As the amount of thorium-230 increases, the minimum gross alpha DAC proposed for thorium doping (4.2E-12 μCi/ml) becomes increasingly conservative.

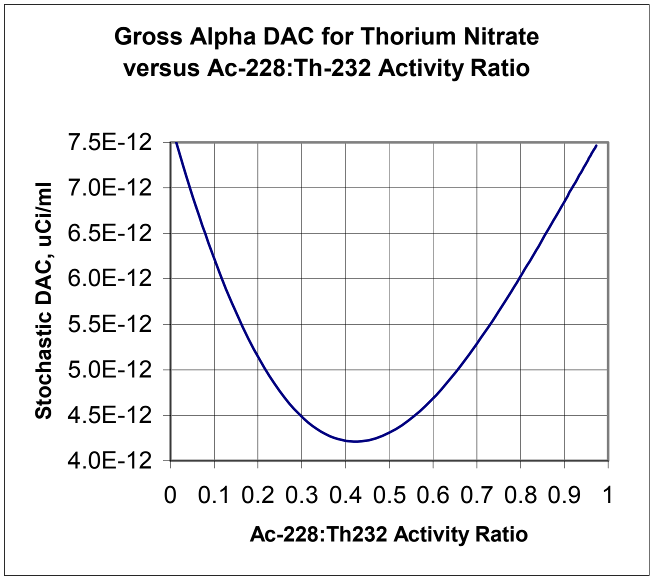

Figure 9. Dependence of thorium nitrate gross alpha DAC on the ratio of Ac-228 to Th-232.

2.8.2 Breathing Zone Air Sample Data during Thorium Doping Activities

Table 10 provides workshift breathing zone gross alpha concentrations during thorium doping operations. The reference time period was January through April 2003. Out of the 29 workshift breathing zone samples, the maximum gross alpha concentration was 6.3 E-13 μCi/ml, which was 9% of the thorium nitrate gross alpha SDAC of 4.2 E-12 μCi/ml. The average concentration was 2.3E-13 μCi/ml, or 5.5% of the SDAC. Since thorium doping only occurs 2 to 3 days per week, annual intakes of thorium nitrate by workers will be well below 10% of the stochastic ALI per year.

Table 10. Breathing Zone Sample Results for Thorium Doping Operations.

Date	Gross Alpha Concentration, μCi/ml
1/24/2003	7.2E-14
2/6/2003	1.2E-13
2/7/2003	7.2E-14
2/8/2003	2.7E-13
2/19/2003	4.6E-13

Date	Gross Alpha Concentration, µCi/ml
2/21/2003	2.3E-13
2/22/2003	1.7E-13
2/24/2003	1.2E-13
2/25/2003	1.2E-13
2/26/2003	1.6E-13
2/27/2003	2.3E-13
2/28/2003	1.2E-13
3/1/2003	1.4E-13
3/3/2003	9.9E-14
3/4/2003	3.1E-13
3/5/2003	1.3E-13
3/6/2003	2.1E-13
3/7/2003	3.0E-13
3/17/2003	4.6E-14
3/18/2003	4.7E-13
3/19/2003	4.3E-13
3/20/2003	4.1E-13
3/21/2003	6.3E-13
3/25/2003	1.5E-13
3/26/2003	1.8E-13
4/2/2003	2.4E-13
4/3/2003	1.8E-13
4/4/2003	3.5E-13
4/5/2003	3.4E-13

3. RECOMMENDATIONS AND CONCLUSIONS CONCERNING THE AIR SAMPLING PROGRAM

The following recommendations are based on observations from the air sampling program review.

3.1 ORE PROCESSING OPERATIONS AND GENERAL RECOMMENDATIONS

1. The gross alpha SDAC values for ore materials and thorium doping presented herein are suitable for calculating the committed effective dose equivalent (CEDE) from inhalation. If the CEDE exceeds 1 rem in a year, then the committed dose equivalent to the bone surface will also need to be calculated and reported.

2. Respirator use during routine ore-processing activities should not be necessary to maintain doses as low as reasonably achievable.

3. Use an activity ratio of 3 uranium-238 : 1 thorium-232. The 3:1 activity is expected to overestimate inhalation doses from airborne material 90% of the time. This ratio is based on a rigorous statistical evaluation of data from 207 lots of ore material processed during 2001.

4. Use the 10-micron AMAD gross alpha DAC of 6.9E-11 μCi/ml to obtain an initial estimate of the inhalation exposures from airborne ore dust at CSM.[2] All area sample filters should be saved after gross activity has been counted and they should be submitted as 3-month composite samples for each location and analyzed for isotopic uranium and isotopic thorium. The gross alpha DAC that is calculated from the actual thorium to uranium isotopic ratio for the quarter should be used to determine the DAC hours that are recorded on a person's official exposure record. On average, it is expected that the quarterly gross alpha isotopic data will reduce the initial DAC-hour estimate by 30%.

5. Enough data have been collected to demonstrate that gross alpha air concentrations during routine ore-processing activities will, on average, be well below 10% of the DAC (10-micron AMAD). Area air samplers are located at the ore dumping stations and should be representative of the dustier routine operations. However, Regulatory Guide 8.25 does not require that area samples be representative of the air inhaled by workers for such low concentrations.

6. Breathing zone air sampling during routine ore-processing activities can be curtailed. Archive past breathing zone filters and maintain the chain of custody once gross counting has occurred. The radiation safety officer should decide when the filters are no longer useful and can be discarded.

3.2 THORIUM DOPNG AND NON-ROUTINE OPERATIONS

1. Data have been collected from enough breathing zone samples in the thorium doping room to demonstrate that gross alpha air concentrations during routine thorium doping activities will, on average, be well below 10% of the SDAC. The thorium doping room is small and an area air sampler is used to monitor conditions in the work area. In accordance with Regulatory

[2] Unless NRC has an objection to the 10-micron AMAD assumption.

Guide 8.25, area samples are not required to be representative of the air inhaled by worker for such low concentrations.

2. Non-routine operations that create dusty conditions can produce elevated airborne radionuclide concentrations. Fixed location area air samplers probably cannot give results that are representative of non-routine activities that involve contact with licensed materials. Workers should wear breathing zone air samplers whenever these non-routine activities occur. Non-routine activities, which involve the use of temporary engineering controls or respiratory protection, should be managed under activity-specific work control document, such as radiation work permits.

4. REFERENCES

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APPENDIX A

URANIUM AND THORIUM CONTENT OF FEED MATERIALS PROCESSED BY CSM IN 2001

Cabot Lot No	% Th	% U	Activity % U-238	Rank by %U-238 Activity
4987	0.015	0.522	99	207
4985	0.015	0.446	99	206
4954	0.015	0.420	99	205
228628004	0.015	0.416	99	204
4969	0.015	0.395	99	203
4995	0.015	0.380	99	202
4933	0.015	0.369	99	201
1008	0.015	0.318	98	200
4967	0.015	0.299	98	199
4955	0.015	0.287	98	198
1006	0.015	0.264	98	197
228624003	0.015	0.237	98	196
4986	0.015	0.206	98	195
4921	0.015	0.198	98	194
4932	0.015	0.194	98	193
5027	0.015	0.192	98	192
4945	0.015	0.191	98	191
224035003	0.015	0.191	98	191
4988	0.015	0.189	97	189
4992	0.015	0.188	97	188
4907	0.015	0.182	97	187
224035005	0.015	0.178	97	186
	0.015	0.177	97	185
5019	0.015	0.175	97	184
4976	0.015	0.172	97	183
5127	0.015	0.172	97	183
5127a	0.015	0.172	97	183
1012	0.015	0.171	97	180
4993	0.015	0.170	97	179
4943	0.015	0.166	97	178
5204	0.015	0.163	97	177
224035006	0.016	0.171	97	176
228623001	0.015	0.159	97	175
228623002	0.015	0.158	97	174
228623004	0.015	0.156	97	173
5129	0.015	0.151	97	172
5154	0.015	0.151	97	172
5154A	0.015	0.151	97	172
228624002	0.015	0.149	97	169

Cabot Lot No	% Th	% U	Activity % U-238	Rank by %U-238 Activity
4904	0.015	0.148	97	168
5063	0.015	0.148	97	167
5074	0.015	0.148	97	167
4946	0.015	0.145	97	165
224035007	0.015	0.144	97	164
5098	0.015	0.143	97	163
1005	0.015	0.140	97	162
5064	0.015	0.138	97	161
5219	0.022	0.200	97	160
4944	0.015	0.134	96	159
4968	0.015	0.131	96	158
228623003	0.015	0.131	96	157
4960	0.015	0.130	96	156
5025	0.015	0.129	96	155
4903	0.015	0.128	96	154
228618001	0.031	0.262	96	153
5048	0.015	0.126	96	152
4949	0.015	0.125	96	151
228623005	0.015	0.123	96	150
228624008	0.018	0.144	96	149
4916	0.015	0.120	96	148
228624007	0.015	0.119	96	147
228624011	0.015	0.119	96	147
4913	0.015	0.118	96	145
5107	0.017	0.131	96	144
4964	0.015	0.116	96	143
5128	0.015	0.114	96	142
4953	0.015	0.114	96	141
4991	0.015	0.113	96	140
4994	0.015	0.112	96	139
5061	0.015	0.112	96	139
228625004	0.015	0.112	96	139
228623009	0.015	0.111	96	136
4947	0.015	0.109	96	135
5184	0.021	0.153	96	134
5014A	0.015	0.108	96	133
5046	0.015	0.108	96	133
4905	0.015	0.106	96	131
4958	0.015	0.104	96	130

Cabot Lot No	% Th	% U	Activity % U-238	Rank by %U-238 Activity
4959	0.015	0.104	96	130
228623008	0.015	0.104	96	130
228623010	0.015	0.103	95	127
228608002	0.026	0.180	95	126
4931	0.015	0.102	95	125
228623015	0.015	0.102	95	125
228626003	0.062	0.416	95	123
228625007	0.018	0.119	95	122
1009	0.015	0.100	95	121
228623011	0.015	0.100	95	121
228627001	0.097	0.647	95	119
5055	0.021	0.141	95	118
5011	0.015	0.099	95	117
228623006	0.015	0.099	95	117
1007	0.015	0.098	95	115
4984	0.015	0.098	95	115
228620002	0.015	0.098	95	115
5024	0.015	0.097	95	112
228627002	0.088	0.568	95	111
228625002	0.018	0.117	95	110
4971	0.015	0.094	95	109
228623007	0.015	0.094	95	109
4952	0.021	0.132	95	107
228625006	0.015	0.093	95	106
228624006	0.015	0.093	95	106
228628001	0.056	0.349	95	104
4972	0.015	0.092	95	103
228628003	0.088	0.534	95	102
228626002	0.070	0.424	95	101
4961	0.015	0.090	95	100
4996	0.015	0.090	95	100
4948	0.015	0.089	95	98
5177	0.023	0.135	95	97
4906	0.059	0.346	95	96
228626001	0.068	0.397	95	95
224035004	0.031	0.179	95	94
4983	0.015	0.086	95	93
228625008	0.018	0.102	95	92
4930	0.015	0.086	95	91
5049	0.015	0.086	95	91
228628002	0.084	0.481	95	89
228628002	0.084	0.481	95	89
5108	0.069	0.390	95	87
231006002	0.015	0.085	95	86
228625003	0.015	0.083	94	85
5056	0.020	0.112	94	84
	0.015	0.081	94	83

Cabot Lot No	% Th	% U	Activity % U-238	Rank by %U-238 Activity
4918	0.015	0.080	94	82
4920	0.015	0.080	94	82
4970	0.015	0.080	94	82
5051	0.015	0.080	94	82
4915	0.015	0.079	94	78
5013	0.015	0.079	94	78
5186	0.018	0.092	94	76
5149	0.018	0.092	94	75
228623014	0.015	0.076	94	74
228625001	0.018	0.094	94	73
228618003	0.016	0.081	94	72
228608001	0.035	0.178	94	71
5218	0.018	0.093	94	70
4902	0.015	0.075	94	69
5053	0.112	0.549	94	68
4919	0.015	0.073	94	67
5054	0.035	0.170	94	66
228618002	0.038	0.176	93	65
228619001	0.015	0.070	93	64
228623012	0.015	0.069	93	63
226594001	0.015	0.068	93	62
228623018	0.015	0.068	93	62
226599001	0.015	0.068	93	62
226600001	0.015	0.068	93	62
228625005	0.018	0.083	93	58
	0.015	0.067	93	57
228614004	0.015	0.066	93	56
5007	0.046	0.199	93	55
5012A	0.015	0.063	93	54
4957	0.015	0.062	93	53
228623013	0.015	0.059	92	52
228623016	0.015	0.059	92	52
228623017	0.015	0.059	92	52
228646001	0.097	0.382	92	49
4914	0.015	0.059	92	48
4917	0.015	0.058	92	47
5073	0.015	0.053	92	46
5050	0.024	0.075	91	45
228615005	0.149	0.458	90	44
5020	0.015	0.042	90	43
228646003	0.016	0.044	89	42
5028	0.062	0.168	89	41
228621001	0.098	0.257	89	40
1011	0.015	0.035	88	39
5176	0.030	0.065	87	38
228614005	0.161	0.338	87	37
5047	0.027	0.057	86	36

Cabot Lot No	% Th	% U	Activity % U-238	Rank by %U-238 Activity
4963	0.015	0.027	85	35
228614003	0.225	0.375	84	34
4965	0.118	0.193	83	33
5052	0.157	0.243	82	32
5058	0.082	0.126	82	31
5057	0.233	0.336	81	30
4962	0.015	0.021	81	29
228614001	0.263	0.370	81	28
228622001	0.158	0.220	81	27
228621003	0.156	0.215	81	26
5060	0.112	0.140	79	25
228615004	0.185	0.229	79	24
5125	0.120	0.146	79	23
5185	0.015	0.018	78	22
5178	0.032	0.036	**78**	**21**
226589001	0.103	0.118	78	20
5006	0.129	0.147	78	19
5023	0.483	0.543	77	18
228621002	0.172	0.192	77	17
5005	0.120	0.126	76	16
231006001	0.193	0.195	75	15
5059	0.158	0.157	75	14
1010	0.054	0.050	74	13
228615003	0.176	0.153	73	12
228646002	0.176	0.136	70	11
4966	0.160	0.120	70	10
1013	0.172	0.128	69	9
5021	0.129	0.081	66	8
5022	0.049	0.031	65	7
228615001	0.253	0.153	65	6
5124	0.319	0.165	61	5
1004	0.232	0.058	43	4
4956	1.128	0.251	40	3
4922	0.607	0.086	30	2
5192-ORE	0.962	0.086	22	1
Total				