

## *Disclaimer*

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## **6.0 INTERNAL DOSE ISSUES**

The following are issues raised by SC&A's review of the NIOSH evaluation report for Rocky Flats Plant (April 7, 2006) as they pertained selected internal dose estimation issues including the issued coworker model, evaluation of dose reconstruction examples, and its treatment of the dose reconstruction of radiation exposures to americium, thorium, and radionuclides other than uranium (natural, enriched, or depleted) and plutonium that were present in historic operations. We use the term "other radionuclides" to denote these radionuclides as a group.

### **6.1 "OTHER RADIONUCLIDES"**

The Rocky Flats TBD described the overall situation as regards internal exposure potential for radionuclides present at Rocky Flats as follows:

*Workers at Rocky Flats had the potential to receive intakes of plutonium, americium, enriched uranium, depleted uranium, and tritium, as well as miscellaneous other radionuclides. Section 5.2 describes the available source term information, including isotopic composition, solubility, and particle size. Site-specific internal dosimetry information for other radionuclides, such as thorium, curium and neptunium, is rare or not available. [TBD, Vol. 5, pp. 7-8]*

The Rocky Flats SEC Evaluation Report (ER) makes the following statement about radionuclides other than DU, EU, Pu, and tritium:

*Lastly, there have been a number of special projects involving small quantities of other radionuclides. Small quantities of thorium-232 were used in the fabrication of metal parts as early as 1952, as mold-coating compounds, and in analytical procedures. Thorium-228 was noted as being removed from uranium-233 metal in thorium "strikes" during the mid- to late-1960s. Limited amounts of neptunium-237, curium-244, americium-241, and plutonium-238 were employed as tracers into the make-up of Special Order pits to assist research taking place at other facilities, for plutonium-238 as Zero Power Reactor fuel elements, and extraction of americium-241 for special applications. None of these other*

*radionuclides were present at Rocky Flats in high enough quantities to contribute significantly to internal dose potential. [ER, p. 44]*

The ER does not provide an analysis of the conclusion based on source terms that these radionuclides could not contribute “significantly to internal dose potential.” The issue of the dose potential of “other radionuclides” was raised in SC&A’s TBD review and in the matrix (Item 29 of the March 27, 2006 matrix for Rocky Flats) developed from that review. Since the publication of the ER, NIOSH and its contractors (collectively referred to as NIOSH below) have done a considerable amount of work on the issues relating to these radionuclides, mainly in response to concerns raised by the Working Group and SC&A regarding the adequacy of the data and dose reconstruction methods proposed for these radionuclides.

## 6.2 DOSIMETRY AREAS AND BIOASSAY DATA

Rocky Flats internal dosimetry areas were divided into four areas, A, B, C, and D, each characterized by certain radionuclides. These were, in fact, the original names of the plants given according to the kind of materials processed there. Later the areas were given building numbers. According to the TBD, the kind of bioassay done was specific to the various areas:

*In the beginning of operations (1952), the Rocky Flats Plant was divided into four distinct sub-plants, plus a general support area. The sub-plants were named A Plant, B Plant, C Plant, and D Plant. The designations A, B, C, and D are significant because they are also the code names for the materials processed in those plants as well for the urinalysis procedures used to analyze those materials. The records of the 1950s do not contain the words: depleted uranium, enriched uranium, and plutonium. Instead, depleted uranium is A material processed in A Plant (buildings numbered 4##, mainly Building 444); enriched uranium is B material processed in B Plant (buildings numbered 8##, mainly Building 881); and plutonium is C material processed in C Plant (buildings numbered 7##, mainly Building 771). D Plant (buildings numbered 9##, mainly Building 991) handled all materials. A nonspecific gross alpha urinalysis method was used for workers in D Plant. (TBD, Vol. 5, p. 38)*

Table 6.1 The TBD describes the methods of analysis as follows (Vol. 5, p. 38)

A	Fluorimeter, reported in micrograms/liter (1952-1956); reported in micrograms/24-hr (1957-1964)
B1	Electroplating, reported in disintegrations per minute per 24-hr (dpm/24-hr). (Note: electroplating, in Rocky Flats records, more properly should be called electrodeposition.)
B2	Ether extraction, reported in dpm/24-hr
B3	Tributyl phosphate (TBP) extraction (hand written on some cards)
C1	Carrier precipitation, reported in dpm/24-hr
C2	Thenoyl trifluoro acetone (TTA) extraction, reported in dpm/24-hr. (Note: On the header of cards for the period 1961-1965, the code C2 is “Pu by Radio Autography.” There is no indication that this method was implemented at Rocky

	Flats.)
D	TBP extraction

The radionuclides and areas associated with the various types of analysis described in the above table are stated to be as follows (TBD, Vol. 5, p. 38):

- A = DU
- B1 = DU and EU
- C1 and C2 = Pu
- B2, B3, D = Gross Alpha. .

In discussions of Rocky Flats issues, NIOSH initially stated that when radionuclide-specific data are lacking, it would use gross alpha bioassay data and interpret it according to the most claimant favorable radionuclide present at the facility in question. This is also stated in the ER (p. 51-52, exposure scenarios 4, 8, 12, and 16.). While the above Table 6-1, taken from the TBD, indicates that gross alpha data appear to be only available for certain Plants (B and D, with methods B1 and B2 used in the former case), Roger Falk, NIOSH's site expert stated that this routine designation of where gross alpha samples were taken did not preclude such samples from being taken in other areas in "special situations" [26 July 2006 Working Group meeting transcript, p. 27]. The approach of using gross alpha data has not been ruled out. It is to be noted here, however, that eventually, NIOSH developed other dose reconstruction approaches for Th-232 and for Th-228 associated with U-233 as a decay product of trace contaminant U-232

The depth and breadth of the debate that occurred on these various issues and the turns that they took are documented in the transcripts of Working Group meetings and the associated documents (both those produced by NIOSH and its contractor and by SC&A). We will assess the final dose reconstruction approaches proposed by NIOSH here rather than recount the details of the technical history of the development of the issues.

It should be noted that a significant amount of work done by NIOSH on issues relating to other radionuclides was based on review of classified documents. SC&A pointed this out to the Working Group.<sup>1</sup> SC&A did not undertake any classified reviews as none were authorized by the Board. This is noted, when relevant, in the following discussion for clarity and as a statement of fact, where there is a material review issue involved.

### 6.3 AMERICIUM-241

The americium-241 discussion is divided into two parts:

1. *Americium-241 intake estimation*: Process streams where americium-241 was abnormally concentrated relative to plutonium or was in pure form.
2. *Plutonium depleted in americium-241*: The reliability of using of americium-241 in-vivo counts in areas where the plutonium being processed was depleted in americium-241.

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<sup>1</sup> See for instance, the memorandum on other radionuclides from Joe Fitzgerald to the Working Group, October 27, 2006.

### 6.3.1 Americium-241 Intake Estimation

Am-241 purification began at Rocky Flats in 1957 in Building 771. It was recovered for resale, which went on until the late 1970s. From then on, Am-241 removed from Pu was sent to the radioactive waste streams in Building 774. (Chem Risk 1992, p. 69 and TBD, Vol. 2, p. 11). In 1967, the ammonium thiocyanate process was replaced by a molten salt extraction process.

In response to the concerns about the gap in Am-241 monitoring in regard to operations involving separating and purification of Am-241, NIOSH stated that the initial attempts to extract Am-241 were not successful, as there was very little of it present in the plutonium sent to Rocky Flats. This was due to the short time that had elapsed after initial plutonium production. This NIOSH conclusion was based on expert interviews. This was stated during the Working Group meeting of July 26, 2006 by Mel Chew, who led the NIOSH research on other radionuclides:

*If you think about it, the plutonium that showed up at Rocky Flats in the early years and in the '50's, prior to '63, was fairly fresh plutonium that came in from Hanford. The --the plutonium that didn't come in for the -- with the americium content was basically out of the recycled plutonium that was in the weapons that was in the '50s here, and really didn't come back out of the stockpile until '62, '63. All right? And so therefore where we were looking for americium in the early years at Rocky Flats, Wanda said it wasn't there. Right? So you know, I think we were all obviously looking and said -- well, assuming it was there. And matter of fact, we confirmed this with a discussion with Ed Vejvoda, and he was responsible for developing the process to start -- to start to thinking about separating the americium from the weapons returned. He made a comment very clearly in this document from this discussion with him that they even had a tough time with the metallurgist even finding americium to validate the process. Right? And I happen to know some parts per million contents that I think the specs that came in from Hanford, and Wanda would know this, you know, of her early years, they were very, very low. For deliberate purposes. Right? And so clearly the americium, I think I can say with a fair amount of confidence that the -- where we were looking for bioassay, just wasn't there in -- in enough significant quantities or a few -- I'd hate to say a few atoms, to be humorous here -- that was enough to cause any concern, even -- especially they even tried to look for it here. Right? But clearly when the weapons returned -- did come back in the -- in the '63, '64 time period -- which makes sense when you really think about it. Okay? When the time period, when we put into the stockpile. Okay? It stays there for a certain amount of years, I think all of you know that, and then we got the return. That's when the americium content really -- really start to come up and the americium was separated out, you know, to refresh the plutonium and make better -- to make weapons grade plutonium back -- to go back into the system again. And also the americium was now concentrated in a form like the molten salt extraction, both to sell the -- and sent back to Oak Ridge. And as you know, your americium is widely used, you know, throughout the system for many, many other purposes, even more*

*than the weapons complex. So I'd like to just make that comment is that we cannot see the americium prior to '63, Mark, because it just wasn't there. And that makes a lot of sense. [July 26, 2006, Working Group meeting transcript, pp. 19-21]*

This statement stands as the last definitive NIOSH statement on the subject of Am-241 monitoring in the 1957-1962 period. While it appears to be reasonable as a technical hypothesis, SC&A notes that it did not do further verification of weapons returns to Rocky Flats, which is mainly in the classified arena, and its associated implications for the 1957 to 1962 period for Am-241.

Am-241 bioassay began in 1963 (TBD, Vol. 5, p. 42). However, the TBD advises dose reconstructors not to use these data in dose reconstruction due to interference from Th-228-related alpha particles:

*The dose reconstructor should use the plutonium urine data instead of the <sup>241</sup>Am urine data to assess intakes of weapons grade plutonium. The intake of the <sup>241</sup>Am is then calculated from the value of the initial parts per million of <sup>241</sup>Am measured or assumed for the plutonium mixture involved in the intake. [TBD, Vol. 5, p. 14]*

SC&A raised this issue with NIOSH during the July 26, 2006 Working Group meeting. NIOSH site expert Roger Falk pointed out that any interference from Th-228 present would result in a higher value of estimated intake and therefore the result would be claimant favorable July 26, 2006, Working Group meeting transcript, pp. 28-29. SC&A agrees with this conclusion.

SC&A did a brief review of the HIS-20 database to check the availability of Am-241 bioassay data. The number of samples increased steadily from 1963 to 1967. This could be due to a ramping up of work and an increasing number of workers involved or a sparseness of sampling in the initial period that coincided with an aqueous Am-241 production process. The process was changed to a molten salt extraction process in 1967. [July 26, 2006, Working Group meeting transcript, pg. 22-23.] SC&A raised this issue in its October 27, 2006 memorandum on other radionuclides. NIOSH's response was as follows:

*Presumably, SC&A is referring to the number of Am bioassay results in HIS20. By our count, there are 475 Am bioassay results in 1963, 1299 results in 1964, 1227 results in 1965, 1406 in 1966, and 2939 results in 1967. This is consistent with Rocky Flats beginning to handle Pu (with ingrown Am) from weapons returned from the field beginning in 1963. SC&A has presented no evidence that there are gaps in Am monitoring, nor is NIOSH aware of any gaps. [NIOSH Evaluation of SC&A's: Thorium-232 and other "exotic" radionuclides at Rocky Flats – review of NIOSH papers, November 3, 2006]*

This NIOSH explanation quoted in full is plausible on its face, but offered without documentation as to the increasing scale of Am-241 processing. It is to be noted that the Am-241 production process changed in 1967 from an aqueous to a molten salt process. Hence, dose reconstruction would require sufficient records for the period up the change in process, since the

later, post-1967, data may not be applicable to the earlier period. It is to be noted that the TBD explicitly notes the exposure potential for early americium operations to 1967 as follows:

*The process ...was cumbersome, resulted in a disproportionate quantity of waste solutions, and created personnel alpha-contamination exposure problems due to required manual operations and maintenance. [TBD, Vol. 2, p. 11]*

It should also be noted that NIOSH's statement that SC&A did not find gaps in the Am-241 monitoring is true. However, SC&A did not do the classified review that would be necessary to establish the production-related issues associated with such an investigation.

Lung counting began at Rocky Flats in 1964 (TBD, Vol. 5, p. 19). However, meaningful results were not obtained until after the 1965 fire. There are some quality issues with some of the data, notably those susceptible to interference from the 63 KeV gamma from thorium-234. Neither the NaI detectors, used until 1973 nor the phoswich detectors (used until 1976) would be able to adequately discriminate between the Th-234 and the Am-241 signals. However, as Roger Falk pointed out during the July 26, 2006 Working Group meeting, any Th-234 interference would yield a higher *in vivo* count and a claimant favorable result. [July 26, 2006 Working Group meeting transcript, pp. 28-29] SC&A agrees with this interpretation so long as Th-234 was not also being used for measuring uranium-238 lung burden.

**Conclusion regarding Am-241 processing:** In the final analysis, given the significant amount of data available even in the 1963-1966 period (inclusive), and in the period after that, the Am-241 issue does not appear to be an SEC issue; especially as lung counting data whose results are likely to be claimant favorable are also available to supplement bioassay data, if needed.

### **6.3.2 Plutonium Depleted in Americium-241**

SC&A has raised the question of how in-vivo counts of Am-241 are to be interpreted in areas where the incoming plutonium might itself have had low Pu-241 content to begin with. In that case, the relatively low Pu-241 content would result in relatively low Am-241 content in returned weapons plutonium. Purification of such plutonium could lead to removal of americium-241 to very low levels. This may make assumptions about Am-241 to Pu ratios in interpreting in-vivo count estimates questionable.

During Working Group meetings, NIOSH has responded by stating that specifications for weapons plutonium by weapons designers required Rocky Flats to maintain a certain isotopic composition of plutonium, including a specified level of plutonium-241. The practice at Rocky Flats was therefore to mix aged plutonium depleted in Pu-241 with sufficient fresh weapons plutonium to maintain the specified requirement. As a result, the situation of very low Pu-241 content in outgoing plutonium would not arise.

This explanation with regard to Am-241 levels to be expected in returned plutonium was made on behalf of NIOSH by site expert, Roger Falk. NIOSH also presented some documentary evidence to this effect.

SC&A concurs with NIOSH regarding the effort made by Rocky Flats to maintain plutonium-241 levels in plutonium. However, according to site expert Bob Bistline, “there were exposures exposure cases to very low ppm of americium, less than 50 to 100 ppm of americium, in Building 771 in the chemical processing area prior to the mixing with the aged plutonium.” While in-vivo lung counts were not possible under such circumstances, he noted that “this occurred in the area where the plutonium was in a soluble form which made it possible to monitor them with urine bioassay.” (Personal e-mail communication, 2 January 2007). Since Am-241 bioassay data are available, this would not be an SEC issue.

#### 6.4 THORIUM-232

Thorium-232 was present and processed at Rocky Flats. According to the TBD, only small quantities were present:

*Beginning in 1952, thorium was used onsite in quantities small enough that effluents were not routinely analyzed for Th. Thorium quantities varied from as little as none to as much as 238 kg in a given month. The principal use was fabrication of metal parts from natural thorium metal (<sup>232</sup>thorium) and from various thorium alloys. Thorium oxide might have been used as a mold-coating compound in limited experiments. Thorium compounds were used in analytical procedures. In addition, twice between 1964 and 1969, thorium “strikes” were performed to remove gamma-emitting <sup>228</sup>thorium from uranium-233 metal needed for fabrication of test devices. The strikes involved a fluoride precipitation and filtration process using natural thorium. Photon radiation from <sup>228</sup>Th decay products would have been monitored by standard gamma dosimetry badges in use at the plant. In addition, thorium was used as a stand-in for plutonium or uranium components in development programs (ChemRisk 1992). [TBD, Vol. 2, pp. 9-10]*

This statement reflects a 1976 paper entitled *Thorium Use at Rocky Flats* (no author) that was discussed by the NIOSH, the Working Group and SC&A. Thorium-related production matters are still classified and SC&A has not done a review of the classified documents. However, the unclassified 1976 document, as well as compilations of unclassified data from classified sources by NIOSH on the thorium issue, seem to substantiate that the largest total inventory of thorium present at Rocky Flats until 1976 appears to have been in the ~250 kilograms.

The development of the issues relating to Th-232 dose reconstruction has run a rather complex course. Since there are still outstanding issues, SC&A is including the key papers as attachments:

Attachment 15: NIOSH, *Potential for Thorium Intake at Rocky Flats*, no date, published in October 2006.

Attachment 16: Brant Ulsh, Bryce Rich, and Melton Chew, *Summary of NIOSH’s Investigation of Thorium Handling at Rocky Flats*, December 27, 2006

Attachment 17: SC&A Memorandum to the Rocky Flats Working Group, *Thorium-232 and other “exotic” radionuclides at Rocky Flats – review of NIOSH papers*, October 27, 2006

Attachment 18: *NIOSH Evaluation of SC&A’s: Thorium-232 and other “exotic” radionuclides at Rocky Flats – review of NIOSH papers*, November 3, 2006

#### **6.4.1 Thorium-232 Source Term**

In its October 2006 paper on the subject (Attachment 15), NIOSH provided data on thorium - 232-related work at Rocky Flats. The main source term for potential thorium air contamination was stated as “Fabrication of metal weapons parts from natural Th and Th alloys – machining, shearing, grinding” (Table 1, p. 1). NIOSH has stated that the parts from Oak Ridge were “trimmed and lightly machine” at Rocky Flats (Attachment 15, p. 2). The maximum amount of thorium-232 in such metal parts was estimated at 60 kilograms per year, with a potential for “unsealed or loose contaminants from large metal parts is 10% or less,” (p. 4), yielding a source term of at most 6 kilograms per year. NIOSH then applied NUREG-1400, a Nuclear Regulatory Guidance document, to this source term to develop an estimate of potential intake for thorium-232 exposure at Rocky Flats (see below for NUREG-1400 discussion).

SC&A raised two basic questions relating to the source term aspect of NIOSH’s analysis. The first related to the magnitude of the thorium processed and the second to the 10% factor used.

Thorium-232-related documents had been destroyed at DOE’s Fernald plant in the 1970s. The question arose, therefore, as to whether this had been a wider policy or whether the examined documents represented a complete review of the thorium work at Rocky Flats. Further, a closer examination of thorium documents at Y-12 had yielded data indicating far more thorium processing than NIOSH initially believed. SC&A therefore sought some clarity as to the completeness of the thorium source term data, that were central to NIOSH’s conclusion that upper bound doses were very low – so low in fact that they could be ignored (since they were less than 1 millirem in the worst case). (Working Group Meeting, November 6, 2006, transcript, pp. 213-214)

A 1976 Rocky Flats assessment of thorium (initiated due to a complaint from a Rocky Flats neighbor that was judged to be without merit in reference to potential harm from thorium) indicated that cumulative “Normal Operating Losses” amounted to 32 kilograms of thorium-232 (*Thorium Use at Rocky Flats*, 1976, p. 2). SC&A raised the question as to whether this estimate of cumulative normal operating losses was compatible with the NIOSH assertion that thorium metal processing was limited to very light work to smooth out irregularities in some parts that did not fit.

NIOSH has since revisited the source term question with regard to the amount of thorium metal processed. In its December 27, 2006 report, NIOSH stated that three thorium metal parts, each weighing about 80 kilograms, were rolled from 12”x12”x 3” ingots to metal bars between May and September 1960, with a total working time of 25 hours. Canning of the ingots in mild steel was also done. Only 12 workers are said to have been involved. There was an incident during

hot rolling of the third ingot in September 1960 and the ingot was cut with a torch and eventually scrapped (see Attachment 16). This was new information about thorium processing presented in the December 27, 2006 report (Attachment 16). While this new information did not change NIOSH's October 2006 estimate of the maximum inventory of thorium-232 at Rocky Flats in any year (Attachment 15), it did increase the maximum amount estimated to be processed in any year from ~60 kilograms (plus small amounts in various processes) to 240 kilograms for canning and rolling, up to 60 kilograms for light machining of thorium metal from Oak Ridge, plus small amounts of other thorium uses.

NIOSH has also reviewed a number of other potential sources of thorium exposure. In its December 27, 2006 report, NIOSH also reviewed whether Rocky Flats received thorium from the Dow Madison plant and concluded that no pure thorium shipments occurred between these two sites. However, NIOSH also found that magnesium alloy containing up to three percent thorium was shipped from Dow Madison to Rocky Flats:

*A review of transcripts of the interviews of Dow Madison workers upon which this question is based<sup>(50-52)</sup> reveals that the Dow Madison workers were clearly speaking of shipments of magnesium alloy, of which thorium is a minor component (up to three percent according to the workers). NIOSH further verified this with a follow-up interview of the worker who spoke of shipments of material between the Dow Madison Site and Rocky Flats. In this follow-up interview<sup>(53)</sup>, the worker recalled frequent shipments to Rocky Flats, and he stated unambiguously that the material was magnesium alloy, not thorium metal. He did not recall the Madison Site ever shipping pure thorium metal to Rocky Flats or anywhere else. [Attachment 16, NIOSH December 27, 2006 report, p. 7]*

The December 27, 2006 NIOSH report does not explore the amounts of alloy that were shipped, or whether the alloys were processed in a way that could have exposure potential. During the January 9, 2007 Working Group teleconference call, NIOSH stated that the worker interviewed on this topic remembered that alloys were shipped by the truckload. The frequency of such shipments is unknown. SC&A notes here that a single truckload with ~10 metric tons of 3% thorium alloy would contain 300 kilograms of thorium. This material is not included in the Rocky Flats thorium inventory records. Yet, it could exceed the amounts that NIOSH has discussed to date. It is unknown at the time of this writing (January 9, 2007) whether and how this material was processed. NIOSH is investigating the issue. (A reference to the January 9, 2007 Working Group call transcript will be added for this paragraph when the transcript becomes available.)

SC&A is cognizant of the large effort, including document reviews, that NIOSH has undertaken to compile the history of thorium processing at Rocky Flats. We also have taken note of the various interviews that NIOSH has conducted and documented. Based on this research, NIOSH has concluded that "thorium activities at Rocky Flats were minor, and involved few workers (a dozen, at most)." (NIOSH December 27, 2006 thorium report, Attachment 16, p. 7).

However, SC&A lacks confidence that NIOSH's December 27, 2006 report is the last word on this SEC-related issue. This lack of confidence arises from several factors:

1. NIOSH's earlier confidence that the thorium source term and upper bound intake estimates (see below) were properly described in the paper discussed at the November 6, 2006 meeting (Attachment 15) are shown to be incorrect by new processing information NIOSH's December 27, 2006 report. The continual emergence of new information in response to questions leaves a residual uncertainty as to whether there are other parts of the source term that have not yet come to light.
2. Further intensive work has revealed that earlier (October 2006) NIOSH assertions regarding the largest amount of thorium metal processed in any one year were incorrect.
3. New and far more major metal processing activities have been revealed by the new NIOSH research. SC&A had been of the opinion that "light" work of the nature described by NIOSH during the November 6, 2006 Working Group meeting did not appear to be compatible with the description of thorium work in at Rocky Flats in the 1976 paper, *Thorium Use at Rocky Flats*, which states:

*The major Rocky Flats use of thorium has involved the fabrication of metal parts. Such fabrication has involved natural Thorium metal as well as the various alloys of Thorium with other metals specified by our customers...It should be emphasized that **this has been the principal role of Thorium at Rocky Flats.**" (emphasis added)*

4. Given that 240 kilograms of thorium were canned and rolled (with the hot rolling of the last 80 being unsuccessful) in a total of 25 hours of work by at most a dozen people, Rocky Flats clearly had the capability to handle considerably larger amounts of thorium (without exceeding the idea that the thorium was a "minor" material there).
5. A new source for thorium metal supply to Rocky Flats was discovered – the ingots in question came from W.R. Grace and not from Oak Ridge. This is also compatible with the 1976 description quoted above, since Oak Ridge parts did not undergo significant manufacturing work at Rocky Flats, according to NIOSH.
6. A new source term for thorium was discovered in the form of shipments in the form of magnesium-thorium alloy from Dow Madison. The scale of these shipments is unknown, but as discussed above it is possible that the amount of thorium could be comparable to, and possibly even greater than, the scale of other thorium-related inventories at Rocky Flats. It is unknown at this time what was done with this alloy. NIOSH is investigating the issue, following the Working Group discussion during the January 9, 2007 teleconference call.
7. Thorium-related documents have been destroyed at Fernald. Some documents at Rocky Flats have also been destroyed. These facts also raise questions about completeness of data regarding thorium processing.

The new NIOSH findings came to light about eight months after NIOSH completed its Evaluation Report, more than one year after SC&A raised the issue of thorium-related dose reconstruction in its TBD review SC&A Rocky Flats TBD review, p. 53), and after many questions were raised about the thorium issue during the arduous process of discussion of the ER. The magnitude of the new revelations regarding thorium metal working processes as well as two previously undisclosed and undiscovered sources of thorium supply to Rocky Flats is

uncomfortably reminiscent of the discussions at Y-12, where repeated questions raised about data relating to thorium yielded a final source term picture that was very different from the initial assertions.

Further, NIOSH's analytical approach relies on material stocks, which do not reveal how much was actually processed in any one year. SC&A agrees with NIOSH that there is documentation indicating that the largest stock of thorium-232 at Rocky Flats at any time appears to have been ~250 kilograms (excluding any quantities present in magnesium-thorium alloy). Therefore, SC&A would also agree that, by this criterion of material stocks, thorium-232 was a minor material at Rocky Flats, relative to plutonium and uranium. It also appears to have been processed sporadically.

However, the data on the stocks of thorium do not allow any conclusions as to the amounts processed in any one year, which could, in theory, be much larger or smaller than the maximum stock in any given year. Examination of logbooks and monthly reports by NIOSH in the latest phase of its thorium investigation had yielded data on the processing of three 80 kilogram ingots from W.R. Grace and Company. Based on an initial review, SC&A also would agree with NIOSH that the processing of the three thorium ingots appears to have been well-documented (though it should be noted that SC&A has not yet had an opportunity to examine the source documents in detail). But this does not settle the issue of whether the most recent NIOSH review represents a complete picture of thorium metal processing at Rocky Flats.

**Finding regarding thorium-232 metal source term:** New components of the thorium source term have emerged in research done by NIOSH in response to questions raised by SC&A and the working group. This new source term information does not relate one way or another to NIOSH's ability to reconstruct dose if more historic thorium processing is uncovered. However, SC&A lacks confidence that the thorium-232 metal source term is necessarily complete due to the various factors stated above. It is to be noted SC&A has not carried out an independent review of this source term, which SC&A has pointed out would involve a classified investigation.

**Finding regarding Dow Madison magnesium-thorium alloy source term:** No quantitative data are available so far in NIOSH reports on the amounts of thorium contained in the magnesium-thorium alloy shipped from Dow Madison to Rocky Flats. A worker description that the alloy was shipped by the truckload indicates that the amounts may have been substantial. NIOSH has not presented an analysis indicating how dose from exposure to this alloy would be reconstructed if any processing was done at Rocky Flats. Implications of magnesium alloyed with thorium for NIOSH's ability to dose reconstruction are unknown at this time since the scope of the source term and knowledge about processing remains unknown (see below for some preliminary remarks on this topic).

#### **6.4.2 Estimating Thorium-232 Intakes**

NIOSH has outlined its dose reconstruction approach for Th-232 as follows:

*As indicated above thorium was present and handled at Rocky Flats primarily in short duration special projects in a general research and development mode. Quantities were relatively small in the gram to 250 kg levels. Few personnel were involved, the tasks involved unusual isotopes and exposure potential, thus attracted heightened attention and controls. The tasks were well monitored for air, personnel, and surface contamination, and included urine samples for verification of low exposure potential from the field monitoring data. However, thorium was recognized as unusual in metabolic characteristics, thus urine analysis was not only technologically difficult in the early years, but was recognized as questionable in terms providing the means of definitive quantitative intake analysis.*

*For this reason the following intake analyses are provided to demonstrate "bounding" of the internal dose potential from the major identified internal sources. Where available, bioassay data is preferred for dose reconstruction. When only field monitoring data (primarily air sampling data) is available, this can be used with appropriate conservative assumptions to derive the maximum bounding dose. The bounding assumptions outlined in NUREG-1400 can be used to derive intake and/or confirm the estimates provided by data based analyses. [Attachment 16, NIOSH December 27, 2006 thorium paper, pp. 9-10]*

#### **6.4.2.1 1960 Thorium Ingot Operations**

Leaving aside the reservations about the source term discussed above, SC&A tentatively concurs with the first two parts of NIOSH's proposed dose reconstruction approach for thorium-232 ingots. Some bioassay data are available, and the Minimum Detectable Amount is known. Logbooks examined by NIOSH (but not yet in detail) by SC&A, indicate that monitoring of the rolling of the thorium ingots was carried out. Air concentration data are also available for 1960, though, again, SC&A notes that it has not examined the issue of the adequacy of this data for dose reconstruction. However, in principle, the data available in the monthly reports and log books should allow dose reconstruction for the workers identified as having been involved in the major thorium project in 1960.

NIOSH has presented its approach to estimating doses from the operations conducted with the 80 kilogram ingots using air concentration data, which include four samples taken during the September 1960 incident. SC&A has not verified the details of the calculations, or examined the underlying documents due to the brief time available.

#### **Conclusion regarding ingot-related thorium operations during May-September 1960:**

Based on the documents that SC&A has reviewed in a preliminary way and the data presented in the NIOSH issue paper, SC&A tends to agree that dose reconstruction using thorium air samples appears to be feasible for the ingot-related operations in 1960.

#### **6.4.2.2 Machining of Thorium Parts from Oak Ridge**

NIOSH has not so far presented data for the machining of parts from Oak Ridge that would be comparable to the data available for the ingot operations conducted in 1960 for the thorium metal received from W.R. Grace and Company. The December 27, 2006 paper (Attachment 16) is not clear on whether NIOSH intends to rely on NUREG-1400 or whether it intends to use some uranium air concentration data on machining and grinding from other sites presented in the paper.

SC&A has expressed some skepticism regarding the very low doses derived from the application of NUREG-1400 to the situation at hand (Attachment 17). At the November 6, 2006 meeting, NIOSH asserted that the intakes and doses estimated were bounding estimates. NIOSH further stated that the 10% estimate for loose material was conservative, given that only light machining occurred on some components. SC&A agreed that the time of processing might have been short due to the limited work, but that the bounding nature of the estimate claimed by NIOSH needed to be established in a more reliable fashion related to metal working operations. NIOSH agreed to examine some metal working processes, including centerless grinding to evaluate whether the proposed application of NUREG-1400 was bounding. November 6, 2006 Working Group meeting transcript, pp. 219-220.) NIOSH's December 27, 2006 paper provides some analysis of this issue.

The committed and effective doses estimated for light machining of 60 kilograms of thorium parts per year, using a 10% loose material factor, Type S thorium, and the application of NUREG-1400 according to NIOSH's interpretation, were:

*Effective dose – 9E-5 rem, (<1 mrem)*  
*Bone dose – 4E-4 rem, (0.4 mrem)*  
*Lung dose – 7 E-4 rem, (0.7 mrem)* [Attachment 16, p. 11]

For comparison actual operations, NIOSH used the following approach:

*A study of air activity measured from similar machining and/or grinding operations was conducted to validate the estimate derived using NUREG-1400 approach. Thus an extensive study by scientists of the AEC Health and Safety Laboratory prior to 1958<sup>(57)</sup> was referenced which presents air sampling data from a number of facilities in which a variety of processes were used in the early 1960s time period for processing of uranium. This study was with uranium being processed in large quantities for extended time period of production operations and present a much greater contamination release potential than the light machining or grinding of relatively small pieces of thorium metal during relatively short time periods, but can be used in a high bounding comparison. The releases from similar processes, i.e. milling, grinding, etc. on uranium as compared to thorium is also conservative/bounding based upon the differences in the physical characteristics. The melting point for uranium metal is 1690 C and for thorium metal 1845 C. The boiling point is 3500 C for uranium and 5200 C for thorium. Thus values derived for thorium air activity based upon the direct comparison with uranium results below will be higher than those anticipated for thorium.*

*The air activity levels for the machining and grinding operations, which were performed on the uranium metal parts, were converted to mass concentrations, which were then converted to thorium activity concentrations. This is based upon the assumption that equal mass quantities of thorium to those of uranium would be released. Since thorium metal, oxides and hydroxides are considered insoluble, solubility class S dose conversion factors were used.*

*Since the work with thorium metal parts was performed on equipment designed for enriched uranium at the Rocky facilities, the machines were shrouded/hooded and were considered in the “vented” category listed in the reference study.*

[Attachment 16, NIOSH December 27, 2006 study, p. 12]

The results obtained are shown in the table below, which is reproduced from the NIOSH report for convenience:

Table 6-2. Calculation of CDE and annual DE Dose in mrem

Operation	dpm/m <sup>3</sup> U	µgU/m <sup>3</sup>	dpm/m <sup>3</sup> Th	hr/yr	Bq intake	mrem	DE mrem	
						CDE	1 <sup>st</sup> yr	20 <sup>th</sup> yr
Machining	50	64	16	10	3.1	44 bs	0.25 bs	6.5 bs
						24 lung	5 lung	0.3 lung
Grinding	200	257	63	10	12.6	176 bs	1.0 bs	27 bs
						97 lung	21 lung	1.6 lung

Key: bs = bone surfaces, lung = lung as the organ of reference. For reference the annual dose equivalent in mrem is given for the 1<sup>st</sup> year after intake and the 20<sup>th</sup>. CDE = Cumulative dose equivalent is derived by multiplication of the intake by the dose conversion factor from ICRP 68 in Table 3.

Source: This is a reproduction of Table 6-1 in the NIOSH December 27, 2006 paper (see Attachment 16).

From this analysis, NIOSH concluded as follows:

*Based upon a conservative bounding of the doses based upon assumed intakes from comparative air sampling data, organ dose does not appear to be limiting, even though intakes using this comparison analyses is a couple orders of magnitude larger than that calculated using NUREG 1400. [p. 12]*

SC&A is unclear as to the meaning of the phrase “does not appear to be limiting” in the above context. But it is clear that the intakes estimated from actual production operations are much greater (“a couple orders of magnitude larger”) than those obtained using NUREG-1400. SC&A concludes that the use of NUREG-1400 is clearly not bounding according to this check performed by NIOSH. Further, during the November 6, 2006 Working Group meeting, NIOSH claimed that (i) NUREG-1400 was designed to be “grossly conservative” and (ii) the light machining operations carried out at Rocky Flats, without chemical processing or involvement of powders would result in an estimate that was “bounding on the high side.” (November 6, 2006 Working Group meeting transcript, pp. 215-216.). Compared to these claims, the bone surface dose estimate provided by the examination of operational processes by NIOSH in its December 27, 2006 paper is well over two orders of magnitude greater for some organs than the claim made

by NIOSH in its October 2006 paper and at the November 6, 2006 Working Group meeting (committed dose comparisons).

Moreover, SC&A does not concur that the approach taken by NIOSH above in examining uranium operations is bounding for Rocky Flats thorium operations. Light machining would reduce the time for an operation, but not necessarily the dust generated during the machining. The small amount of time for light machining does not provide any element of conservatism in NIOSH's calculations. Moreover, NIOSH has already taken the small amount of time per year into account in its estimate derived from operational processes by assuming that these are in operation for only 10 hours per year (Attachment 16, Table 1, reproduced above as Table 6-2). Similarly, NIOSH used data from vented operations in its operational dose estimate. This may correspond to realistic conditions for thorium processing at Rocky Flats, but it does not provide an element of conservatism that could lead to a description of the intake result as bounding.

Further, the relative melting point and boiling points of thorium and uranium are not very relevant to the problem of air concentrations in this context. Machining would create oxidation processes that would result in solid oxides becoming air borne, in addition to fine solid metal particles. The centerless grinding daily averages cited in the paper referenced by NIOSH are between 50 and 300 dpm/m<sup>3</sup>. Since this is a range of daily *averages*, it would not be claimant favorable to use a value of less than 300 dpm/m<sup>3</sup> (NIOSH used 200 dpm/m<sup>3</sup>). Given that NIOSH assumes a small number of workers who did the job over short periods of time, the use of averages may not be claimant favorable, since 42 CFR 83 requires that a suitably bounding dose be developed for all members of the class. Finally, there is a large amount of data from other facilities, including from thorium operations that NIOSH might have referenced, so it is not clear that the comparison provided is definitive enough to sustain a claim of conservatism in the result. (SC&A has not attempted to verify the details of NIOSH's calculations, since these are not relevant to the SEC-related question).

**Finding regarding machining of thorium metal from Oak Ridge:** NUREG-1400 does not provide a bounding approach to estimation of thorium doses from machining operations relating to the 6-kilogram pieces machined on occasion at Rocky Flats. NIOSH has not yet established an approach to dose reconstruction relating to these operations that meets the criteria for estimation of dose with sufficient accuracy under 42 CFR 83 for these operations. This is not to say that such an approach could not be established (with the proviso of a firm source term) using data from Rocky Flats and other facilities for comparable operations. This may be possible. SC&A's finding is that the methods proposed by NIOSH to date do not meet the test required by dose reconstruction with sufficient accuracy 42 CFR 83.

#### ***6.4.2.3 Magnesium-thorium alloy***

During the January 9, 2007 Working Group teleconference call NIOSH stated that a worker interview indicated that magnesium-thorium alloy may have been shipped by the truckload from Dow Madison to Rocky Flats. SC&A did a very preliminary review whether the processing or use of such material might have implications for dose reconstruction.

The Nuclear Regulatory Commission produced a detailed assessment of circumstances in which by-product and source materials might be exempted from regulation (*Systematic Radiological Assessment of Exemptions for Source and Byproduct Materials*, NUREG-1717, June 2001). NUREG-1717 includes dose assessments that indicate that doses from metal-thorium alloys could produce doses that are in excess of those estimated by NIOSH using NUREG-1400 for pure thorium.

In the case of tungsten-thorium welding rods with 4% thorium, NUREG-1717 cites a German study whose findings were as follows:

*Ludwig et al. (1999) reported that in a room with volume of about 100 m<sup>3</sup>, and without any ventilation or suction system, 35 electrodes (45 by weight thorium) were ground in 15 minutes. Their graph indicates an activity concentration for <sup>232</sup>Th during the grinding of about 180 mBq/m<sup>3</sup> ( $5 \times 10^{-6}$  Ci/m<sup>3</sup>) with the airborne activity concentration decreasing soon after the end of grinding. The only case from the Ludwig et al. (1999) study that involved local exhaust ventilation indicated a reduction factor of 100.*

*The study estimated levels of <sup>232</sup>Th intakes for welders from less than 0.1 to 144 Bq/yr ( $< 2.7 \times 10^{-3}$  to 3.9 nCi/yr) during welding and from 0.02 to 30.2 Bq/yr ( $5.4 \times 10^{-4}$  to 0.82 nCi/yr) during grinding. In six cases the estimated total intake was estimated to exceed the annual limit for intake to the public of thorium in oxide form, as derived from ICRP Publication 71 (ICRP 71), based on the projections from limited sample data. Four of the six cases involved welders, working with alternating current, where the main exposure was caused by the welding process. The other two welders used direct current welding with the grinding causing the estimated intake to exceed the intake limit. [NUREG-1717, p. 3-105]*

It is to be noted that an intake at the high end of the cited range, 144 Bq of Th-232, would produce a committed bone surface dose of ~30 rem, if Type M solubility is assumed. This is almost five orders of magnitude greater than the bone surface dose calculated for the light machining of thorium using NUREG-1400. For Type S the committed dose would be ~4 rem, about four orders of magnitude greater than the dose that NIOSH calculated for light machining.

NUREG-1717 also explicitly discusses magnesium-thorium alloy:

*In 10 CFR 40.13(c)(4), persons who receive, possess, use, or transfer any finished product or part fabricated of, or containing, tungsten- or magnesium-thorium alloys are exempted from licensing requirements for source material, provided the thorium content of the alloy does not exceed 4% by weight. The exemption does not authorize the chemical, physical, or metallurgical treatment or processing of any such finished product or part. An exemption for thoriated tungsten containing not more than 3% by weight of thorium, and without any other conditions on treatment or processing of the material, was first established on March 15, 1949 (14 FR 1156). The exemption in*

*its present form was proposed on September 7, 1960 (25 FR 8619), and issued as a final rule on January 14, 1961 (26 FR 284). [NUREG-1717, Section 3.16]*

Note that under present day standards, in force since 1961, the “physical, or metallurgical treatment or processing” of magnesium-thorium alloys is **not** exempt from regulation. Even when alloy is not processed, the annual external doses alone in NUREG-1717 are far greater than the effective dose calculated by NIOSH for light machining. NUREG -1717 estimates that average annual external dose to a maintenance worker handling and working on aircraft parts EDE for 1040 hours per year to be about 50 mrem (p. 3-243) .

**Finding regarding magnesium-thorium alloy:** It is clear from NUREG-1717 and the other considerations presented above that knowledge of the approximate quantities, periods, and processing status of the magnesium-thorium alloy is needed before any reliable conclusions can be arrived at regarding doses to Rocky Flats workers from this material.

#### ***6.4.2.4 Intakes from other Thorium-232 Operations***

There were also other thorium operations at Rocky Flats. Some of these involved less than 500 grams of material. Such uses of thorium were regarded as small and were not reported in materials accounting records. Such uses of less than 500 grams included (*Thorium Use at Rocky Flats*, 1976, p. 1 and pp. 3-4):

- Coating molds with thorium oxide;
- Use “in analytical procedures...as well as in development programs... [on numerous occasions....”]
- Use of thorium “as a stand-in or replacements for the more expensive Uranium or Plutonium components in certain phases of development programs. Usually these needs involved small amounts of material, but it nevertheless involved handling Thorium. This type of operation occurred frequently in the past and is occurring at the present time. Each individual use is too small for record keeping but, in the aggregate, it would approach 7 kg of Thorium in a variety of forms at the present moment.”

The term “in the aggregate” in the last bullet point appears to refer to all then-current thorium development programs during 1976; however, SC&A notes that the statement is ambiguous and may refer to a cumulative amount of thorium use in development applications.

NIOSH implicitly proposes to use NUREG-1400 for these small uses as well. In its October 2006 paper on thorium intakes, NIOSH stated:

*Other uses and operations involving thorium at RFP are listed in Table 1. The highest calculated potential internal intakes result from the fabrication of large metal weapons parts for which intakes are estimated above. Smaller quantities assumed for most of the other uses and operations are offset by the thorium being in the form of powders or other more dispersible materials, but still resulting in fractional mrem estimated doses. [Attachment 15, p.5]*

However, the argument that doses would be in the “fractional mrem” has not been well established. The source term for these small uses is not individually documented in material control records due to the then-prevailing policy regarding thorium accounts. It should be noted that the higher dose conversion factors for thorium for some organs make one gram of thorium-232 radiologically comparable to a far larger amount of uranium (~100 times larger in case of bone surface dose, in the worst-case, for the same solubility, using dose conversion factors for committed dose in Federal Guidance Report 13 as the basis for the comparison). Hence, small amounts of thorium-232 would represent doses that would correspond to those delivered by much larger amounts of uranium for bone surface and several other organs. Further, given that NIOSH has not established that NUREG-1400 yields a bounding dose – on the contrary the one test against operational air concentrations for machining operations yielded a contrary result.

NIOSH stated during the January 9, 2007 call that the cumulative amounts from small uses are in the material accounts. Hence, it may be possible to establish a source term for these small uses. However, given that the use of NUREG-1400 to Rocky Flats thorium operations has not been demonstrated to be in conformity with 42 CFR 83 in the one case in which a comparison was done with operational processes, it is not clear how NIOSH would proceed to estimate doses from the repeated small uses of thorium.

**Finding regarding small uses of thorium-232:** Small uses of thorium-232, each less than 500 grams, were not part of Rocky Flats materials accounts. In view of the inapplicability of NUREG-1400 to Rocky Flats thorium doses under 42 CFR 83, discussed above, it is unclear how NIOSH will estimate doses from the many occasions when thorium was used in small quantities.

## 6.5 URANIUM-233 AND THORIUM STRIKES ON U-233

One basic reference for U-233 processing is:

It is on NIOSH’s Site Query database

U-233 was processed at Rocky Flats between 1965 and 1983. It contained, among other things, up to 50 ppm of U-232. It was processed in the 700-series buildings (771, 774, 777, 777A, 779A), 559 (assay lab) and 881 and 883 at various times in this period, where Pu was also processed. [*History of U-233 (<sup>233</sup>U) Processing at the Rocky Flats Plant*, RS-090-056, April 1, 1999].

Rocky Flats bioassay results for uranium were in dpm rather than in terms of weight. Uranium bioassay data are available, and there is nothing to indicate that U-233 operations were omitted from surveillance that was exercised for less radioactive forms of uranium. SC&A concludes that it should be feasible to estimate U-233 intakes.

The problem regarding Th-228 contamination of U-233, which arose from presence of trace U-232 (50 ppm) in the U-233, is more complex. Rocky Flats conducted operations to remove the Th-228 from U-233 prior to processing of the latter according to customer requirements (“thorium-228 strikes on uranium-233”). NIOSH proposes to use NUREG-1400 to provide an

upper bound estimate for intakes of Th-228 during such operations. Its evaluation of the matter in its December 27, 2006 report states:

*The previous comparison between conservative values above resulted in a value above the NUREG-1400 estimate. In this case the Th<sup>228</sup> extraction with daughters is so grossly overestimated both in terms of total quantity of isotope present and in the demonstrated confinement of the glove box process facilities in which the extraction and waste handling was performed, that the NUREG-1400 estimate is not deemed overly conservative. Air activity that would result in 100 Bq intake would have been cause for a significant release with the subsequent detail in the health physics logs we have reviewed. [Attachment 16, p. 13]*

This is a confusing conclusion. For instance, if NUREG-1400 is not deemed overly conservative” then how is it to be characterized? SC&A asked NIOSH for a clarification and received the following response on 29 December 2006 via an e-mail from Brant Ulsh:

*Joe [Fitzgerald] et al:*

*The following elaboration was provided by Bryce Rich. I hope this clarifies things, but let me know if you have additional questions:*

- *Using the NUREG-1400 approach, we used a confinement factor of 3E-4 (99.7% filtering efficiency of typical HEPA filters for 0.3 micron particles – the least well filtered particle size) instead of the 0.01 used for typical evaluations for the original purposes of the report.*
- *10 Ci of Th-228 is used, but is an overestimate of quantity, since the amount of U-233 is maximized at 20 kg (one time at this level) and 2 years for ingrowth of Th-228 is assumed to achieve 50% equilibrium.*
- *This resulted in a calculated potential intake of 1 Bq.*
- *If we had used the ratio of 100:1 (measured:NUREG-1400) estimates derived in the previous thorium metal parts machining example and upgraded this estimate by a factor of 100, i.e. 100 Bq intake, this would have meant a release of >100 MPC/MPL (3E-10 uCi/cc) air concentrations for 8 hours and no respirators. Considering the routine monitoring capability in Bldg. 771 at the time this would have alarmed all the CAMs immediately and been the cause of a major incident with reports, urine sampling, surface surveys, cleanup, etc.*
- *This was a “special” project with high gamma-emitting radioisotopes. They had a lot of attention by HP professionals and technicians. The 100 Bq intake release didn’t happen. Glove box releases happened due to accidents, glove failures, etc. – not routine releases.*
- *For this reason, using the NUREG-1400 estimating technique was deemed adequate as used and did not predict a major release.*

Even if one accepts without further documentation that air concentrations corresponding to an intake of 100 Bq would cause alarms to go off, it is unclear, why the intake may not have been 5

Bq or 10 Bq or some other number less than 100 Bq but more than 1 Bq. Therefore NIOSH's reasoning does not demonstrate that the intake estimate of 1 Bq is reasonably bounding. Further, NIOSH's reasoning depends on assumptions about monitoring that was operative at the time of Th-228 strikes and is based on general statements about the integrity of and care taken in monitoring. SEC affidavits have, on the contrary, claimed that furtive work practices were ordered and that such unauthorized activities were carried out. In this context, acceptance of a general statement such as the one above, without reference to the specific process in consideration, amounts to endorsing one point of view over the other and placing the burden of proof regarding Th-228 strikes on the petitioners. It is, of course, for the Board to consider, whether and to what degree, this is appropriate.

Finally, the comparison of the application of NUREG-1400 to operational processes above indicates that at least in some circumstances, the use of NUREG-1400 could lead to significant underestimates of intake. Therefore, NUREG-1400 cannot be reasonably regarded as yielding estimates of "sufficient accuracy" under 42 CFR 83 unless a specific demonstration is made that 1 Bq is a bounding estimate. NIOSH has not done this in its analysis. NIOSH's assertion that operations lasted for a short period of time is not really relevant to the application of NUREG-1400. Whether the routine operations are done over 250 days or a single day is not relevant to NUREG-1400. The relevant consideration in NUREG-1400 is that the equation should be applied over operations and times where air concentrations can reasonably be averaged. NUREG-1400 discusses intakes over an annual average, but does not require processes to be operating all the time.

**Finding regarding Th-228 strikes:** NIOSH has provided no analysis to show that NUREG-1400 provides a bounding estimate for dose in the case of Th-228 strikes that would be appropriate under 42 CFR 83. Specifically, SC&A does not concur with NIOSH that its reasoning regarding a 100 Bq intake being essentially impossible demonstrates that a 1 Bq intake estimate is a reasonable upper bound estimate. SC&A concludes that NIOSH's estimates for intakes during thorium-228 strikes using NUREG-1400 do not meet the test of dose estimates with sufficient accuracy under 42 CFR 83. NIOSH has not presented any operational data for this process that would allow such estimates.

## **6.6 REMAINING RADIONUCLIDES**

The rest of the radionuclides that SC&A raised in the context of the TBD review matrix or that NIOSH has mentioned in the TBD are curium-244 and neptunium-237. These appear to have been used as tracers and mixed with plutonium. SC&A had also raised the question of the availability of tritium bioassay data. None of these radionuclides are represented in the bioassay data in the HIS-20 database.

In its November 3, 2006 report (Attachment 18), NIOSH agreed that these three radionuclides are not represented in the HIS-20 database. NIOSH provided references to curium-244 bioassay data and other documentation. Special bioassay results are also available for neptunium-237. NIOSH also stated that tritium bioassay results are available in claimant files.

**SC&A conclusion regarding curium-244, neptunium-237, and tritium:** In view of the availability of bioassay data, SC&A concurs with NIOSH that estimation of curium-244, neptunium-237, and tritium intakes is not an SEC issue.