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SC&A REVIEW OF PROPOSED NIOSH DOSE RECONSTRUCTION METHODS FOR URANIUM AND THORIUM AT PANTEX PLANT DURING 1951–1957 AND 1984–1991

Contract No. 200-2009-28555
Revision 2

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June 2013

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S. Cohen & Associates: ***Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program***	Document No.: Review of NIOSH Proposed DR Methods for Pantex, Rev. 2 Effective Date: Draft – June 26, 2013
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Project Manager: _____ Date: _____ John Stiver, MS, CHP	Reviewer: John Stiver

Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	06/07/2013	Initial issue.
1 (Draft)	06/13/2013	Includes clarification of the basis for the review of potential travel by W28 workers to other sites and what monitoring data was used in the ER and Ruhter reports for thorium dose estimation.
2 (Draft)	06/26/2013	Minor text changes made for consistency with Ruhter et al. reference

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ABBREVIATIONS AND ACRONYMS

ABRWH	Advisory Board on Radiation and Worker Health
BWXT	BWX Technologies
CATI	Computer-Assisted Telephone Interview
DAC-hr	derived air concentration per hour
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
dpm	disintegrations per minute
DU	depleted uranium
ER	evaluation report
ESH and EP	Environmental Safety and Health and Emergency Procedures (or Preparedness)
EU	enriched uranium
GM	geometric mean
GDS	geometric standard deviation
HEU	highly enriched uranium
HHS	Health and Human Services
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
L	liter
LLNL	Lawrence Livermore National Laboratory
m^2	square meter
m^3	cubic meter
NCRP	National Council on Radiation Protection and Measurements
MDA	minimum detectable activity
MDL	minimum detectable level
NIOSH	National Institute for Occupational Safety and Health
pCi	picocuries
SC&A	S. Cohen and Associates (SC&A, Inc.)
SEC	Special Exposure Cohort
SEM	Scanning Electron Microscopy
SRDB	Site Research Database
TBD	technical basis document

1.0 EXECUTIVE SUMMARY

At the request of the Pantex Plant Work Group, SC&A addressed remaining issues relevant to the Special Exposure Cohort (SEC) consideration for the Work Group's review of the National Institute for Occupational Safety and Health's (NIOSH's) Evaluation Report (ER) for SEC-00068 (NIOSH 2007) for the years 1951–1957 and 1984–1991. These issues involved dose estimation for potential uranium exposures in the early period and for uranium and thorium in the latter period.

1.1 URANIUM, 1984–1989

The NIOSH white paper, *Analysis of Pantex 1990 Uranium Bioassay Results for Workers Identified as Being Production Technicians on the W28 Program*, Rev. 2 (Bihl and LaBone 2012), presents a set of assumed intakes derived from excretion values from a lognormal analysis of the 1990 uranium urinalyses that were taken following a major W28 disassembly contamination incident in 1989. Five different intake timing assumptions are used to define exposure scenarios from which a bounding intake can be postulated. While the mathematical modeling itself is valid, all of the scenarios presented are, by necessity, hypothetical, given that the time periods of individual worker exposures (i.e., starting points) are unknown for most of the workers in question.

As shown in SC&A's review, depending on the exposure scenario (e.g., specific start year of exposure or a specific length of time of exposure), intake rates may vary by more than **two** orders of magnitude for Type M uranium. As the dose varies in the same proportion as the intake, the uncertainty associated with the assigned doses from this approach, using the proposed set of bioassay results, would be considerable and, therefore, the bounding estimates derived would not be "sufficiently accurate."

In addition, the paper assumes that all bioassay results from the W28 program technicians are related to depleted uranium (DU) exposures. As explained in Section 3.0, the activity rate ratios of U-234 to U-238 observed in the samples of urine excretion that were collected from a number of W28 workers are not consistent with exposure to DU alone. The clear presence of other uranium isotopes, notably U-235, would confound use of the single 1990 bioassay set, as currently proposed, to bound DU exposures for W28 disassembly workers in 1984–1989. It appears that some of the W28 technicians were, in fact, exposed to varying concentrations of different isotopic sources of uranium at varying enrichment levels from different workplace activities at the Pantex Plant. This issue has not been addressed by the proposed NIOSH method outlined in Bihl and LaBone 2012.

This was further verified during an onsite visit at Pantex,[1] during which a review of more contemporary bioassay results from 2009 was conducted. This review showed similarly elevated (albeit, relatively low) levels of enriched uranium (EU) for which Pantex's longtime health physics staff could not offer a clear explanation. Without knowing what these exposure

[1] Conducted by SC&A (accompanied by a Work Group member and NIOSH personnel) on April 16–18, 2013.

contributions consisted of and how they varied over time, it is not clear how this single dataset could be applied retrospectively for this purpose. Further discussion is warranted by the Work Group.

1.2 THORIUM, 1984–1991

For thorium, NIOSH has proposed a different approach (Ruhter et al. 2011) than that provided in the ER, with a "chronic" intake of thorium pegged at 2% of the DU intake for times when thorium was present in disassemblies. The basis for this mass ratio intake value was an analysis of air sampling samples taken during work on the W55 program (which contained both DU and thorium) in June 1996. SC&A is concerned that both the newer 2011 approach and the earlier ER/Technical Basis Document (TBD) approach (Hickey et al. 2007) rely on post-1991 thorium sampling data (swipes, bioassay, or air) to benchmark NIOSH's bounding estimate.[2] From NIOSH's research, it is clear that the W55 weapons system was the worst one from the standpoint of potential thorium oxidation and contamination potential (Rolfes 2011b). It is also clear from site expert interviews (notably, [**Worker FF**] 2013a, [**Worker FF**] 2013b, and [**Worker II**] 2011) regarding the W55, that Pantex was concerned enough about DU and thorium contamination during disassembly in the late 1980s to move all W55 disassembly operations into a down-drafted glovebox beginning in late 1991. Use of any bioassay or air sampling data taken after this engineering upgrade as a means to characterize, benchmark, or validate thorium dose estimates, pre-1991, is highly questionable. The proposed approach in Ruhter et al. 2011 applies a mass ratio of DU to Th-232 based on 1996 air sampling data. Without having similar data for the 1984–1991 period, during a period of at least comparable W55 thorium contamination, and substantially less stringent handling practices, contamination controls, and workplace monitoring, these later data and ratio comparisons cannot be considered representative or bounding of this earlier period.

1.3 URANIUM, 1951–1957

SC&A confirmed that no weapons system dismantlement involving DU took place at Pantex until the gravel gerties were constructed and operable in 1958. While DU was handled onsite starting in 1951, these were fresh forms from Y-12 with no available evidence or accounts of loose contamination during handling;[3] the first accounts of such contamination were made with respect to the dismantlement of weapons systems that had been in the stockpile for some time. While DU was burned along with high explosives in the burn pits and DU figured in hydroshots beginning in the late-1950s, SC&A reviewed NIOSH's proposed dose estimation models for bounding potential intakes of uranium for these onsite activities, based on available air sampling results of that era, and found them feasible and sufficiently accurate. Therefore, for the 1951–1957 SEC-relevant time period, as it pertains to uranium exposure at Pantex, SC&A

[2] Ruhter et al. 2011 indicates that "thorium was monitored in workers via nasal swabs, urine and fecal samples, as well as via direct bioassay during 1983 through 1998 as documented in the following SRDB documents: 12319, 17084, 20768, 25373 and 25388." However, these referenced documents only provide data for 1991 and later, with the exception of **one** identified bioassay result and one unidentified, handwritten result, both in 1983.

[3] While there has been an account regarding prompt oxidation of DU following fabrication (Fitzgerald 2011), no accounts or documentation have been found regarding removable contamination being an issue during early handling of DU forms at Pantex in the 1950s.

recommends Work Group acceptance of NIOSH's conclusion that it has sufficient data to perform dose reconstruction with sufficient accuracy.

1.4 URANIUM, 1990–1991

Following the 1989 contamination event, Pantex and DOE management significantly expanded the uranium bioassay program, such that there is considerably more data beginning in 1990 from which dose estimation can be accomplished and a uranium coworker model constructed, as necessary. In its SEC ER, NIOSH showed in Table 5-1 that the number of workers bioassayed for uranium was 46 in 1990, with a routine, comprehensive program instituted for 431 and 239 workers, respectively, in 1991 and 1992. The conduct of a workplace radiological characterization program at Pantex, following significant upgrades in contamination control and monitoring, led to reliance on an event-driven bioassay program after 1992. SC&A validated the ER finding of adequate bioassay data for uranium dose estimation as part of its April 16–18, 2013, onsite review at Pantex through document review and interviews with site health physicists who oversaw these upgrades and expanded personnel monitoring. For the 1990–1991 SEC-relevant time period as it pertains to uranium exposure at Pantex, SC&A recommends Work Group acceptance of NIOSH's conclusion that it has sufficient data to perform dose reconstruction with sufficient accuracy.

2.0 INTRODUCTION

On October 20, 2011, the Advisory Board on Radiation and Worker Health (ABRWH) voted to recommend that SEC status be accorded to "All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Pantex Plant in Amarillo, Texas, during the period from January 1, 1958 through December 31, 1983…" A key part of the basis for the recommendation [and subsequent approval by the Secretary of Health and Human Services (HHS)] was that "NIOSH lacked adequate information necessary to complete individual dose reconstructions with sufficient accuracy for internal radiological exposures due to uranium during the time period in question" (ABRWH 2011a). The NIOSH ER proposed to retrospectively apply, over 30 years, the 1990 bioassay results of 305 Pantex workers taken following a 1989 DU contamination incident during the disassembly of the W28 weapons system. However, the ABRWH accepted the Work Group's findings that operations during that period were neither sufficiently static (i.e., could not be normalized), nor was the 1988 contamination incident necessarily the worse (or "bounding") DU exposure from which dose reconstruction could be based for workers potentially exposed to DU contamination.

For uranium exposures in 1984–1989, NIOSH indicated during Work Group proceedings that it was likely that operations would have been more static during this shorter and more recent operational time period, and it would be more likely that bioassays taken in 1990 could be the basis for dose reconstruction for what was seen as a contiguous W28 disassembly (for retirement) operation over the 5 years in question. To provide a clear bounding method for applying the 1990 bioassay data for 1984–1989, NIOSH issued its *Analysis of Pantex 1990 Uranium Bioassay Results for Workers Identified as Being Production Technicians on the W28 Program*" Rev. 2, on January 17, 2012 (Bihl and LaBone 2012). Recognizing that establishing a start date for those W28 workers with bioassay records would provide "a more precise estimate"

than was possible using this particular bounding method alone, NIOSH sought to locate access records for these workers at Pantex, but the site was unable to locate them (Hinnefeld 2012a and 2012b).

SC&A's analysis reviews this report and its technical basis as to whether it provides a "sufficiently accurate" means to bound uranium doses for workers at Pantex for 1984–1989, and also reviews the proposed mass ratio-based approach by which thorium doses would be estimated, as provided in Ruhter et al. 2011. For completeness sake, SC&A also has reviewed other references cited in the Bihl and LaBone 2012 and Ruhter et al. 2011 reports.

For potential thorium exposures, NIOSH's ER assumed that the methods for assigning intakes of thorium are the same as for plutonium because of similar working conditions. For workers who had the highest possibility of intake (Category 1), a single acute intake of 40 DAC-hr (48 pCi) of Th-232 is assumed for each year from 1980 to 1991. In a new approach (Ruhter et al. 2011) for estimating thorium intakes that supersedes the one given in the ER and TBD, NIOSH proposes to base its estimate of a now "chronic" intake of thorium at 2% of the DU intake for times when thorium was present in disassemblies, based on an analysis of air monitoring samples taken in 1996 during work on the W55 program. It was decided in Work Group discussions to defer any response or action on this new proposed approach for thorium dose estimation until the SEC question of dose estimation for DU for the W28 disassembly workers was resolved; the basis for this deferral was the possibility that the W28 SEC determination would subsume the thorium issue in terms of scope and time period (ABRWH 2011b). The ABRWH has since voted to recommend, and the HHS Secretary has approved, an SEC class for all Pantex workers for 1958–1983 in that regard (ABRWH 2011a, HHS 2011). This SEC period covers some, but not all, of the thorium-related system disassemblies, leaving the 1984–1991 petition period for Work Group disposition. Some technical questions were addressed by the Work Group in a preliminary manner, but none were resolved prior to deferring further deliberations regarding thorium. This review focuses on those issues.

For uranium exposure during the 1951–1957 SEC-relevant time period, SC&A focused on whether any weapons system dismantlement involving DU took place at Pantex during this time period. While DU was handled onsite starting in 1951, these were fresh forms from Y-12 with no available evidence or accounts of loose contamination during handling; the first accounts of such contamination were made with respect to the dismantlement of the Mark 6[4] weapons system, which had been in the stockpile for some time. For DU that was burned along with high explosives in the burn pits and DU that figured in hydroshots beginning in the 1950s, SC&A reviewed the adequacy of NIOSH's proposed dose estimation models for bounding intakes of uranium, and the completeness of available air sampling results of that era upon which they are based.

For uranium exposure during the 1990–1991 SEC-relevant time period, SC&A focused on the availability and adequacy of bioassay data to support dose reconstruction with sufficient accuracy. Following the 1989 contamination event, Pantex and DOE management significantly

[4] While the Mark 6, 7, and 18 weapons systems of that time period contained DU, it was determined that only the Mark 6 had clear accounts of loose contamination during dismantlement at Pantex in the 1950s–1960s.

expanded the uranium bioassay program, such that there is considerably more data beginning in 1990, with the number of workers bioassayed for uranium increasing to 46 in 1990 with a routine, comprehensive program instituted for 431 and 239 workers, respectively, in 1990 and 1991.

3.0 URANIUM EXPOSURES, 1984–1989: REVIEW OF "ANALYSIS OF PANTEX 1990 URANIUM BIOASSAY RESULTS FOR WORKERS IDENTIFIED AS BEING PRODUCTION TECHNICIANS ON THE W28 PROGRAM, REV. 2"

The NIOSH white paper, *Analysis of Pantex 1990 Uranium Bioassay Results for Workers Identified as Being Production Technicians on the W28 Program*, Rev. 2 (Bihl and LaBone 2012), presents a set of assumed intakes derived from excretion values from a lognormal analysis of the 1990 uranium urinalysis from the W28 disassembly contamination incident. Five different intake timing assumptions are used to define exposure scenarios from which a bounding intake can be postulated. While the mathematical modeling itself is valid, all of the scenarios presented are, by necessity, hypothetical given that the time period of individual worker exposures (i.e., start date) is unknown for most of the workers in question.[5] Depending on the exposure scenario, e.g., selection of the specific year of exposure or a specific length of time of exposure, the intake rates may vary more than **two** orders of magnitude for Type M uranium (as illustrated in Table 5 of Bihl and LaBone 2012). As the dose varies in the same proportion as the intake, the uncertainty associated with the assigned doses from this approach, using the proposed set of bioassay results, would be very high and would not be "sufficiently accurate" in the context of dose reconstruction.

There is also uncertainty regarding the completeness of the "Cooley" memorandum (Cooley 1989) regarding the identity of the W28 workers whose bioassays form the basis for the Bihl and LaBone 2012 analysis. From interviews conducted in 2013 with former production technicians, it is clear that those workers "certified" to work on the W28 disassembly represented a larger number than those who happened to be working on that line in 1989. Workers were certified to work on a number of different weapons systems assembly and disassembly operations, and moved around as work priorities dictated ([**Worker BB**] 2013).

[5] An ultimately unsuccessful effort was undertaken by NIOSH to obtain operational access records for the W28 workers in question as a means to determine their respective start dates for the W28 disassembly process in order to make these bounding doses "more realistic and accurate" (Hinnefeld 2012a and b). During a technical conference call between SC&A and NIOSH on February 20, 2013, NIOSH clarified that a January 1, 1984, "start date" would be assumed for purposes of uranium intake modeling for any workers with potential W28 exposure who began employment during the post-SEC period in question, 1984–1989, with December 31, 1983, being the end of the approved SEC class and December 1989 being the timeframe during which the 305 urinalyses were taken. Other W28 workers with pre-1984 start dates would be covered by the existing SEC class under this approach, assuming they have 250 days of employment.

3.1 MINIMUM DETECTABLE ACTIVITY FOR URANIUM

In ORAUT-TKBS-0013-5 (Hickey et al. 2007), it is stated that in 1990, the minimum detectable activity (MDA) for uranium at the Y-12 Bioassay Laboratory was 0.03 pCi/sample (0.066 dpm/sample). The 305 samples were analyzed at the Y-12 Plant Laboratory.

3.2 BACKGROUND URANIUM CONCENTRATIONS IN URINARY EXCRETION OF NON-OCCUPATIONALLY EXPOSED PERSONNEL AND RATIO OF U-234/U-238 ACTIVITIES IN URINE SAMPLES

Long and Carbaugh (1994) have analyzed the results of 75 urine samples obtained over a 3-year period from Pantex Plant personnel not occupationally exposed to uranium. The samples were analyzed for their U-234 and U-238 content. The authors concluded that the activity of U-238 in a sample and its ratio relative to U-234 were independent variables. The 95th percentile for these two parameters were 0.16 dpm/day and 1.2, respectively (in the paper, it is stated as 1.2 dpm/d, but the units are probably a mistake). The authors suggest that these two values should be used as screening levels to initiate dose assessment actions. If the U-238 result is below 0.16 dpm/d, any observed activity is considered to be associated with environmental background. Results above 0.16 dpm/d are reviewed in light of the U-234/U-238 ratio; if the ratio exceeds 1.2, then occupational intake is concluded, and a dose assessment performed.

The paper referenced in *Pantex Bounding Uranium and Thorium Intakes* (Ruhter et al. 2011), *Analysis of 1990 Uranium Urinalysis Data* (Author and date unknown, SRDB 14187), cites the document *Internal Dosimetry Technical Basis and Quality Assurance Document* (Pantex 2001), in which an analysis of urine samples of workers who were not occupationally exposed to uranium is given. It states that the recent data are representative of past environmental exposures and excretion profiles, as dietary and drinking water intakes of natural uranium have not changed over the history of the Pantex site.

The environmental results include a U-238:U-234 ratio of 1.2. Uranium-238 was observed to have a 95th percentile of 0.12 dpm/L (0.052 pCi/L) and a mean value of 0.031 dpm/L (0.014 pCi/L). The results for U-238 + U-234 are consistent with a lognormal distribution with a geometric median (GM) of 0.0226, an arithmetic mean of 0.0570, and a standard deviation of 0.131dpml/L, with a geometric standard deviation (GSD) 3.896. The same paper gives a table of activity ratios of uranium isotopes in various mixtures, including for Pantex workers.

Table 1. Activity Ratios of Uranium Isotopes

Nuclide	DU	Natural	Recycled	2.96% EU	301 workers	Unusual Case	93% HEU
U-234	11.176%	48.8749%	56.32%	82.4758%	67.8839%	73%	96.8101%

These data are pertinent to the analysis that follows regarding the implications of observed uranium isotopic diversity in urinalyses results.

3.3 REVIEW OF THE URINARY EXCRETION RATES OF THE 305 WORKERS TAKEN IN FEBRUARY AND MARCH 1990 REGARDING URANIUM ISOTOPIC DIVERSITY

Analyses of the results from the 305 workers show that:

(A) The highest U-234 result, 1.03 dpm/d, is from a W28 worker. The ratio of U-234/U-238 activities in the urine sample of this worker is 11.45, much higher than expected for a worker exposed to DU, as can be seen in Table 1 above. The concentrations of both U-234 and U-238 in urine are higher than the limit of detection, pointing to measurable uranium excretion in urine. The excretion rate of U-238 is 0.16 dpm/d, on the borderline of the 95th percentile of the Long and Carbaugh 1994 paper and of the one listed for environmental exposure rates in the document *Internal Dosimetry Technical Basis and Quality Assurance Document* (Pantex 2001). The ratio of U-234/U-238 activities in urine is 10 times higher than 1.2, indicating occupational exposure to EU. The amounts of U-235 and U-236 are higher than the minimum detectable level (MDL) and are not expected if a worker is exposed only to DU. This worker was likely exposed to EU. If this worker was not exposed to EU, than the laboratory results cannot be considered reliable.

(B) Among the 10 highest U-234 results, there are 2 other W28 workers. They had U-234/U-238 ratios of 4.9 and 6.8 and measurable U-235 and U-236 concentrations in urine. Those results are characteristic of exposures to EU only, and not of exposures to DU.

(C) Among the highest U-238 excretion rates ($\geq$ 0.16 dpm/d), there are five W28 workers. The ratios of U-234/U-238 activities in urine from four of those workers are on the order of 1.5 (1.44 to 1.75), which may be attributable to occupational exposures to natural uranium or to EU, or a mix of them. One of these four workers is a claimant and was alive at the time of the Computer-Assisted Telephone Interview (CATI). This individual reported working with natural uranium and EU, and sometimes using respirators and working in fumehoods. The excretion rate for U-235 and U-236 for this worker was zero. The fifth worker had a U-234/U-238 rate of 0.53, which may be due to exposures to DU, or to a mix of natural uranium and DU.

(D) The mean value of 0.03 dpm/L (0.042 dpm/d) for U-238 excretion rate for people not occupationally exposed is below the listed MDA. On the other hand, there are a large number of results reported below the 0.066 dpm/d MDA. There are 46 W28 workers with excretion rates of U-238 above or at the mean background levels. The ratios of U-234 to U-238 activities in urine vary considerably: four workers presented ratios above 5, four workers between 4 and 5, seven between 3 and 4. Among the workers with U-238 excretion rates above the mean environmental excretion rate, there are 7 W28 workers with U-234/U-238 ratios between 2 and 3, 19 workers with ratios between 1 and 2, and 6 workers with ratios smaller than 1.

(E) There are six W28 workers with high excretion rates of U-235 (>0.06 dpm/d). For five of those workers, the ratio of U-234 to U-238 excretion rates are higher than 2, as illustrated in Figure 1.

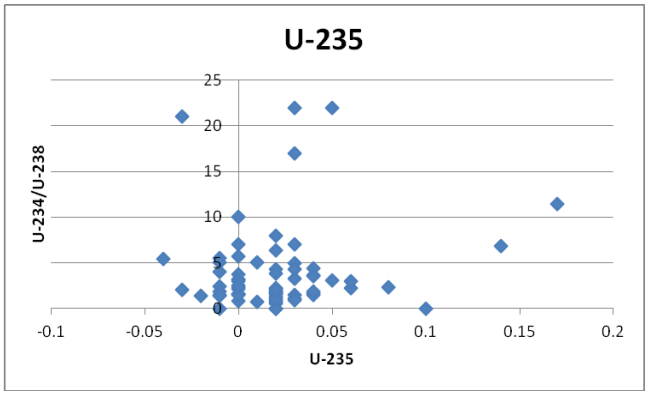

Figure 1. ^{235}U Excretion Rates (dpm/d) versus $^{234}U/^{238}U$ Ratios in Urine Bioassays of W28 Workers

The measurable concentration of U-235 in urine and the high U-234/U-238 ratios of activity in urine are all signs of EU exposure.

(F) There are five W28 workers with U-234 results below 0.06 dpm/d, but only one with a "negative" reported result.

(G) Figure 2 shows the U-234/U-238 ratio versus U-234 results. It can be seen that workers had exposures to EU and natural uranium, besides DU, if laboratory results are considered reliable.

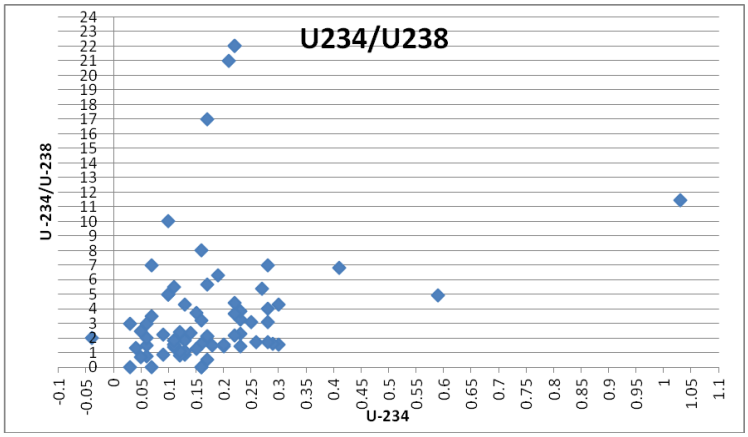

Figure 2. $^{234}U/^{238}U$ Activity Ratio in Urine of W28 Workers versus ^{234}U Results in dpm/d

(H) The six claimant workers that were alive at the time of the CATI reported having worked with EU.

During a technical conference call between NIOSH, SC&A and ORAUT on February 20, 2013, NIOSH staff indicated that the presence of EU isotopes in the bioassay results could be explained by the travel of the affected W28 workers to other DOE sites, notably the Nevada Test Site. It is known that Pantex workers supported radiological activities at this and other DOE sites. To test this hypothesis, SC&A searched available sources for evidence of non-Pantex radiological exposures for the W28 workers who showed EU in their bioassay results. Computer Assisted Telephone Interviews (CATIs) and DOE response files were consulted as sources of worker travel histories, but these sources were of limited value because only one of the affected employees was an EEOICPA claimant at the time of this review. SC&A's primary source of information regarding work at other DOE sites is identified in the SRDB as *Occupational Radiation Exposure Record of Pantex Employees – Non-Pantex Exposure* (Pantex 1990). Data reported in this document includes worker identities, dates, locations, and monitoring results for non-Pantex radiological work spanning a range of years from 1961 to 1988. As can be seen in Table 2, within the limits of available data, travel to other DOE sites can only explain a relatively small fraction of those bioassays found elevated in EU.[6]

Table 2. Comparison of W28 Workers with Elevated Bioassay Results for HEU with Past Work at other DOE or DoD Sites with Potential Exposure

Worker ID	Elevated Activity (Feb–Mar 1990)		Evidence of Work at Other DOE Sites [from Pantex 1990 unless noted]
	U-235 > 0.06 dpm	U-234 > U-238	
A	X	—	None identified
B	X	X	None identified
C	X	—	One other DOE site (no dose reported)
D	X	—	None identified
E	X	—	One other DOE site (no dose reported)
F	X	—	None identified
G	X	X	None identified
H	X	—	One DoD site and one other DOE site identified
I	X	—	None identified
J	X	X	None identified
K	X	—	None identified
L	X	—	None identified
M	X	—	None identified
N	X	—	None identified
O	X	—	None identified
P	X	—	None identified
Q	X	X	None identified
R	X	—	Two other DOE sites identified

The presence of EU in routine Pantex bioassay results was further verified during an onsite visit at Pantex in April 2013, during which a review of more contemporary bioassay results[7] from the late-1990s was conducted. This review showed similarly elevated (albeit, relatively low) levels

[6] Actual names, activity levels, and specific work locations have been redacted for privacy reasons, but are available for Work Group and NIOSH review.

[7] Contained in two 2009 bioassay results, which showed elevated alpha spectroscopy activity readings for U-235 (GEL 2009a and b).

of EU for which Pantex health physics staff could not offer a clear explanation.[8] Interviews with former workers identified possible sources of low levels of EU that may have resulted from certain handling procedures involving specific weapons systems containing EU ([**Worker HH**] 2013). An interview with a former health physics manager at Pantex indicated the possibility of an "uncladded" EU source in a weapons system being dismantled in the 1970s ([**Worker AA**] 2008). Without knowing what these exposure contributions consisted of and how they varied over time, it is not clear how this single dataset could be applied retrospectively for this purpose. Further discussion is warranted before the Work Group.

It can be concluded that the W28 uranium urine results are diversified in terms of U-234 concentrations that indicated exposure to EU. Assuming that the laboratory results were quality controlled, the results show exposures to other forms of uranium besides DU and natural uranium. Given this isotopic diversity, this dataset cannot be used to characterize the exposures of W28 workers or to characterize exposures at Pantex based on the prevailing assumption that DU was the only source of internal exposures to uranium.

Conclusion: The proposed approach, to back-estimate maximum intake of DU, is not valid, due to presence of enriched uranium and inherent methodological uncertainties involved.

The high U-234 urinary excretion rates, together with high U-234/U-238 ratios, show that the W28 workers, and also other Pantex Plant workers that had bioassay monitoring in February and March 1990, had been exposed to EU. The W28 workers' urine excretion results are not characteristic of exposures to DU only. There is no information on where and what jobs these workers may have done at Pantex, and the presence of EU cannot be explained by travel to other DOE sites or confirmed as trace contaminants in the DU received by Pantex. We do not know how many workers were not monitored and may have had elevated U-234 results. For the workers with U-234 results between 0.2 and 0.3 dpm/d, the ratio of U-234/U-238 varies considerably, with two workers showing a ratio of **22**. This could be an indication of poor laboratory results, although the recovery can be considered plausible in this case, i.e., above 77%. It could also be an indication of EU exposure. Based on the U-234/U-238 ratio, it is reasonable to assume that W28 workers have been exposed to different isotopic sources of uranium and not only to DU. Conversely, if these exposures were deemed to be only due to DU, then the laboratory results should not be considered reliable and applied to dose reconstruction. Based on acknowledgments by a number of W28 workers that they had also handled EU, it is more likely that this worker population was subject to various isotopic forms of uranium.

In addition, the use of the dataset taken in 1990 to determine maximum intakes in some hypothetical time period under various intake assumptions is not seen as scientifically valid. NIOSH has shown in their white paper, *Analysis of Pantex 1990 Uranium Bioassay Results for Workers Identified as Being Production Technicians on the W28 Program*, Rev. 2 (Bihl and LaBone 2012), that the intake rates can vary two orders of magnitude depending on the chosen scenario. The uncertainty on the reconstructed dose from such a calculated estimate is not

[8] After being shown these more recent results, it was speculated by the Pantex health physicists that such low-level contamination could have come from DU that originated at Y-12, where EU was also handled; however, no substantiating data are available at this time ([**Worker CC**] 2013).

sufficiently accurate and would not be suitable as a bounding dose for a source of uranium with unknown enrichment.

The Work Group held in abeyance a review of these issues awaiting what was an ultimately unsuccessful effort by NIOSH to obtain operational access records for W28 workers as a means to determine their respective start dates of potential uranium exposure in the W28 disassembly process in order to make these bounding doses more realistic and accurate (Hinnefeld 2012a and 2012b). During a technical conference call between SC&A and NIOSH on February 20, 2013, NIOSH indicated for the first time that a January 1, 1984, "start date" would be assumed for purposes of uranium intake modeling for only "new" workers who began employment during the post-SEC period in question, 1984–1989, with December 31, 1983, being the end of the approved SEC class, and December 1989 being the timeframe during which the 305 urinalyses were taken. Other W28 workers with pre-1984 start dates would be covered by the existing SEC class. SC&A believes the Work Group should review the construct of this "hypothetical" start date for only W28 workers beginning employment in 1984–1989 in the context of how plausible it would be to restrict exposure modeling to only new workers not in the existing SEC cohort class and whether it would be "sufficiently accurate" to do so.

4.0 URANIUM EXPOSURES, 1951–1957, 1990–1991: REVIEW OF EVALUATION REPORT ANALYSIS AND CONCLUSIONS

The following two "bookend" operational time periods addressed in the ER remained for Work Group review following approval of the SEC class for all Pantex employees for 1958–1983.

4.1 1951–1957

Disassembly of Mark 6

Depleted uranium (DU) began to arrive at the Pantex Plant as "new, bare metal forms" as early as late 1951 ([**Worker GG**] 2003). New parts were received, including those for the Mark 6, 7, and 18 weapon systems, and these parts were actively handled at Pantex during the 1953–1958 time period ([**Worker GG**] 2011a). Depleted uranium was mated with explosive material in subassemblies, but apparently not machined for shaping purposes until 1960 ([**Worker EE**] 2008). Before "gravel gerties" were constructed and used in about mid-1958, no assembly or disassembly of fissile devices for these subassemblies was performed at Pantex ([**Worker EE**] 2008).

While former workers interviewed indicated that newly received DU "was very clean" ([**Worker EE**] 2008) and "bright, shiny metal with no oxidation" ([**Worker GG**] 2011a), there is some contradiction with its conditions in somewhat later years. While it was said that the "Mark 6 never showed problems with DU contamination" ([**Worker GG**] 2011a), others had observed "spallation of uranium from the Mark 6" with "a fine powder … sometimes on the floor" ([**Worker EE**] 2010). Another statement indicated that the "Mark 6 units tended to have

considerable DU oxidation… [but that] the Mark 6 wasn't ever as bad as the W28" ([**Worker GG**] 2011b).[9]

However, assuming a potential exposure pathway existed during disassembly of the Mark 6 during the 1950s at Pantex, it is clear that such exposure would have only been likely during disassembly activities, which did not begin until 1958.

Burn Pits

Burning of high explosives and DU parts was done approximately once a week at Pantex, beginning in 1952, with operators located about 100 yards from the burn pad, with other workers at least 300 yards away (Hickey et al. 2007). The basis for determining exposure to uranium from burning activities was air sampling activity for the period of 1960–1967 [no air sampling data were available for 1952–1959 and 1963 (Hickey et al. 2007)], for which inhalation dose models were developed based on 95th percentile values for claimant favorability. Two categories of results are provided: *during burning* and *during cleanup*. With 50 total air samples taken, the highest value recorded, 112 dpm/m^2, is assumed to represent the 95th percentile or higher of air concentrations at the pad. Applying NCRP Report 123 (NCRP 1996) modeling for a ground-level release, NIOSH estimated an air concentration of DU during burning at 4.8×10^{-2} dpm/m^3, which combined with conservative assumptions for breathing rate and exposure time (about 1 to 2 hours), generated an intake of 0.052 pCi DU per burn. For cleanup at the burn site, the 95th percentile intake was estimated to be 130 pCi/day.[10] With the latter cleanup intake being considerably higher than the burn intake, it becomes the default intake value used by NIOSH.

SC&A reviewed the standard methods used to model worker intakes and found them to be plausible and technically feasible for dose reconstruction with sufficient accuracy. The air sampling data themselves are incomplete for the period in question (1951–1957), but their application retrospectively appears to be sound based on first-hand accounts of how the burns were conducted in the 1950s compared with the early 1960s (Bihl and Martin 2004); i.e., there is no evident difference in potential source term or practice that would preclude back-application of the bounding intakes calculated. Therefore, SC&A finds no issue of SEC concern.

Hydroshots

Hydroshots were conducted at Firing Sites 4, 5, and 10, using DU as a surrogate material resulting in uranium contamination at the firing sites. Significant quantities of DU were used in test fire shots during the late 1960s and early 1970s. Operators conducting test firings were located in a bunker, with a self-enclosed ventilation system that was sealed before each detonation. After detonations, the operators would walk to ground zero to retrieve their instruments (Hickey et al. 2007). As the TBD notes, the prevailing winds carried the detonation cloud northward away from most Pantex buildings and worker locations. The TBD analysis uses

[9] This statement is apparently at odds with another statement made by the same individual in [**Worker GG**] 2011a (SRDB #104948) regarding oxidation of the Mark 6. The interviewee may be making a value judgment regarding the lack of a "problem" with the Mark 6 compared with other systems, e.g., the W28.

[10] A former manager for the burn site who was interviewed stated that cleanup personnel wore half-mask respirators, but NIOSH did not take credit for such protection in its modeling calculations.

air concentration measurements inside (94 samples) and outside (79 samples) the bunker at Firing Site 4 for October 1959 to January 1962, with 85% of the measurements recorded as 0 dpm/m^3. The dose distribution model has a 95th percentile value for inside air concentration of uranium of 6.2 pCi/m^3 and an outside value of 24 pCi/m^3.

As part of an earlier review of the TBD (SC&A 2007), SC&A reviewed available air sampling data from Firing Station 4 starting October 27, 1959, and ending December 22, 1961, and compared these data with information presented in Figures 5-1 and 5-2 of the TBD (Hickey et al. 2007). The raw data SC&A reviewed do not support use of the 95th percentile of the 1960s outside air concentration of 24 pCi/m^3 as appropriate or necessarily claimant favorable, given the likelihood of a large variance due to highly variable conditions during firings.[11] It would seem consideration of a 98th or 99th percentile value in this case may be warranted. However, this is clearly of "site profile" consequence, not an issue of feasibility of dose estimation. Furthermore, a former supervisor of the firing sites in that era indicated that the first DU-laden hydroshot was not conducted until 1959, which is within the current SEC class approved for 1958–1983. Therefore, SC&A finds that the proposed method for dose reconstructing hydroshot exposures to uranium is feasible, albeit with some questions regarding its conservatism.

4.2 1990–1991

Following the 1989 W28 disassembly contamination event noted above (and the baseline uranium bioassays conducted in early 1990 for 305 workers), Pantex instituted a comprehensive bioassay program for uranium exposures to be performed at Y-12 under prescribed procedures and quality assurance. The bioassay program initially included 46 workers in 1990, with a routine bioassay program later implemented in 1991–1992 for any worker showing a net activity greater than or equal to a 0.15 dpm environmental screening level (this became an event-driven bioassay program after 1992). This program included 431 workers in 1991 and 239 workers in 1992 (Griffis 1990; Hemphill 1990; Hickey et al. 2007). Given the large number of bioassays taken during the 1990–1991 time period, there are sufficient data to support dose reconstruction with sufficient accuracy and the development of a coworker model for any data gaps, as needed.

Conclusion:

From SC&A's review of sources of potential exposure to uranium in the early period of 1951–1957, it was determined that no records or former worker accounts identify such exposure from any weapons component handling prior to the commencement of disassembly activities in 1958. Although some exposure potential to DU existed for the burn pits and hydroshots, sufficient measurement data exist to permit dose estimation as described in the ER. SC&A recommends Work Group acceptance of NIOSH's stated ability to reconstruct uranium dose with sufficient accuracy for 1951–1957, as well as for 1990–1991, for the reasons stated above.

[11] For example, the TBD cites differing masses of DU or HEU, location of samplers in relation to cloud, and varying particle sizes, which are just a few of the major variables involved.

5.0 THORIUM EXPOSURES, 1984–1991: REVIEW OF THORIUM INTAKE ESTIMATION IN "PANTEX BOUNDING URANIUM AND THORIUM INTAKES"

As noted in the Work Group's presentation before the full ABRWH at its August 2011 meeting, thorium was a contamination concern at Pantex for at least four weapons systems dating back to the 1960s. Thorium was directly handled by workers during assembly, modification, surveillance, and disassembly of these particular weapons during the later SEC period in question (1984–1991). Older components containing DU and thorium were unencapsulated and subject to oxidation over time, creating a source of potential internal intakes, particularly during later disassembly operations, in the 1980s–1990s.[12]

Thorium-232 (and its decay products, particularly Th-228) is substantially more radiologically hazardous than DU, with larger organ doses for certain target organs [e.g., the ratio between thorium and uranium dose per unit of mass intake for Th-232: U-238 (Type M), would be 200:1 for bone surface, 83:1 for bone marrow, and 23:1 for the liver]; the ratio of effective dose for Class S materials per unit of radioactivity intake would be three times as large (EPA 2002). While the ER states that, "because of the relative hazard of thorium, Pantex has used and continues to use strict workplace monitoring practices, such as smear checks of components, to verify the integrity of the thorium components," SC&A finds that this was only the case after 1991 for disassembly operations.

Before 1991 (as with the W28 weapons system before 1990), the W55 and other thorium systems were handled without the benefit of respirators, reliable smear checks, engineered contamination control, and routine bioassay programs. Site experts recalled contamination concerns associated with oxidized thorium components (e.g., [**Worker FF**] 2013a, [**Worker II**] 2011, [**Worker AA**] 2011, [**Worker HH**] 2013). With the disassembly of the W55, vacuum cleaners could not keep up with the amount of depleted uranium and thorium dust (SC&A 2011). It was noted that thorium contamination was typically associated with direct handling or contact with these components during disassembly, as compared with the extensive "spallation" of DU during the disassembly of the W28 system ([**Worker BB**] 2013, [**Worker AA**] 2011). One former production technician noted that his routine use of a screwdriver to separate thorium components was eventually observed by a supervisor and disallowed in the late 1980s because by then, it was generally recognized that such practices would dislodge more oxidized thorium and increase contamination during disassembly ([**Worker HH**] 2013). As an interim measure to limit the spread of such contamination, vacuuming of loose contamination and other similar control measures were instituted in the late-1980s (SC&A 2011).

After the W28, the W55 was considered to be one of the worst weapons systems for disassembly contamination (ABRWH 2011b). From NIOSH's research, it is clear that the W55 weapons system was the worst one from the standpoint of potential thorium oxidation and contamination potential (Rolfes 2011b). After disassembly of the W55 was restricted to a gloveboxed

[12] Further characterization of the thorium source term is restricted. As noted in the NIOSH site profile for Pantex (ORAUT-TKBS-0013-5), "information on source terms of weapons containing thorium is classified, as is the number or percentage of weapons that contain thorium" (Hickey et al. 2007).

downdraft table in the fall of 1991 ([**Worker FF**] 2012a, [**Worker FF**] 2013b, [**Worker CC**] 2013, and [**Worker II**] 2011),[13] one account noted that a "teaspoonful" of loose thorium oxide contamination was found to be typical of what was encountered in disassembly of a unit ([**Worker II**] 2011). A supervisor on the W55 disassembly line during the late 1980s recalled that he could even "smell" thorium contamination in the workplace when present due to its distinct metallic odor ([**Worker FF**] 2013a).

In its ER, NIOSH assumed that the methods for assigning intakes of thorium are the same as for plutonium because of similar working conditions. For workers who had the highest possibility of intakes (Category 1), a single acute intake of 40 DAC-hr (48 pCi) of Th-232 is assumed for each year from 1980 to 1991. For Category 2 workers, 0.1 times the intake was assumed. These intakes are modes of triangular distributions with a "minimum of zero and a maximum of 10 times the mode" to provide some margin for more than 1 intake a year and less representative air sampling results (NIOSH 2007). A check on the "reasonableness" of these estimates was made through an analysis of the 284 urinalyses and 154 fecal samples taken for 1992–1996 and 1996–2000, respectively (Pantex 2005), with "reasonable" agreement found between the excretion rate associated with the assumed acute intake of 48 pCi and the fecal data.

In a new approach (in Ruhter et al. 2011) for estimating thorium intakes that supersedes the one in the ER and TBD (Hickey et al. 2007), NIOSH proposes to base its estimate of a now "chronic" intake of thorium at 2% of the DU intake for times when thorium was present in disassemblies. The basis for this assumed intake value was an analysis of air monitoring samples taken during work on the W55 program (which contained both DU and thorium) in June 1996 using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Scanning Electron Microscopy (SEM) (Pederson 1996). A mass ratio of thorium to uranium was calculated to be 0.071 to 1, based on the air monitoring samples taken, and assuming the uranium mass was from DU and the thorium mass was from Th-232. The activity ratio was found to be 0.018 to 1, which was rounded to 2%.

SC&A is concerned that both the newer 2011 approach (Ruhter et al. 2011) and the earlier ER/TBD approach rely on post-1991 thorium sampling (swipe, bioassay, or air) data to benchmark NIOSH's bounding estimate.[14] It is clear from site expert interviews (notably, [**Worker FF**] 2013b and [**Worker II**] 2011) regarding the W55, that Pantex was concerned enough about DU and thorium contamination during disassembly in the late 1980s to move all W55 disassembly operations into a downdrafted glovebox beginning in late-1991. In [**Worker II**]'s[15] interview, she noted that a "maximum of approximately one half cup of DU-oxide and perhaps a teaspoon worth of Th-oxide" were observed inside of the downdraft table, with "none" or "extremely low level of contamination" found on the exterior…" Based on contamination

[13] This was a source of some disagreement at the Pantex Work Group meeting on August 10, 2011 (see ABRWH 2011b, pp. 230–231); the installation of the gloveboxed downdraft table for W55 disassembly in the fall of 1991 was confirmed through these sources.

[14] Ruhter et al. 2011, cites "direct bioassay" data being available from 1980–1996; however, only one identified (and one unidentified, handwritten) bioassay was taken before 1990, the event-driven one taken in 1983.

[15] [**Worker II**] was the LLNL health physicist responsible for the radiological safety aspects of the LLNL weapons programs (which included the W55); she assumed that role in February 1991.

surveys conducted for 10 W55 disassembly runs in 1991, using the new downdraft glovebox table, no routine bioassays were deemed necessary for subsequent disassemblies ([**Worker II**] 2011).

From these accounts, it is clear that loose thorium oxide contamination had been an issue (along with DU) for the W55 in the 1980s, and that routine bioassays and air sampling for thorium and DU had not been performed.[16] NIOSH's position that, "these bioassay data and lapel sample results from the 1990s can be used to bound historical exposures given that the source term was cleaner and lower in the earlier days (due to fewer disassemblies and less time since fabrication), and because engineering safeguards were largely unchanged" (NIOSH 2010), is neither accurate, likely, or even capable of being validated for the 1984–1991 period in question. The source term (i.e., W55 disassembly) was not necessarily "cleaner" in the late 1980s, and a radically improved engineered safeguard, the downdraft table (essentially a large glovebox, see Figures 3 and 4 below), was put in place in late 1991 as a contamination control measure. While W55 units disassembled in the 1990s may have been in service somewhat longer than those disassembled in the late 1980s, it is not clear that the oxidation rate of the thorium would remain linear over time (i.e., that it would not have leveled off at some point in time following fabrication) or that, ultimately, it would make any substantial difference in the availability of loose contamination. However, what is clear is that **how** workers handled these components (i.e., directly, without respiratory protection, before 1991) and **whether** such handling was done in a glovebox downdraft table under negative pressure (i.e., after 1991) would have had the most significant bearing on the likelihood and degree of potential intake by the W55 disassembly workers involved.

Use of any swipe, bioassay, or air sampling data taken after this engineering upgrade in 1991 as a means to characterize, benchmark, or validate thorium dose estimates, pre-1991, is highly questionable. The proposed approach in Ruhter et al. 2011 applies a mass ratio of DU to Th-232 based on 1996 air sampling data. Without having similar data for the 1984–1990 period, during a period of at least comparable W55 contamination and radically different handling practices and contamination controls, these later data and ratio comparisons cannot be considered representative of this earlier period. In particular, certain worker practices, such as using screwdrivers to separate thorium-containing components, along with other direct handling techniques to loosen and clean components later discontinued in the late 1980s, would have exacerbated the release and resuspension of thorium oxide particulates during W55 disassembly ([**Worker HH**] 2013).

NIOSH states that "no airborne contamination problems [were] associated with the material [thorium] due to the large particles observed" (Ruhter et al. 2011), and that LANL had conducted an industrial hygiene analysis in 1976 that found "no airborne contamination problem associated with this material due to the large size [of particulates]" (Rolfes 2011a). However, no definitive and representative sampling was conducted of particulate sizes in the breathing zone of workers dismantling thorium-bearing weapons systems in the 1980s, and of those conducted in the 1990s, one in 1996 found that the "uranium particles are in the order of three time [sic] larger than the thorium we have identified…" (Coleman 1996). This same analysis questioned how

[16] While gross alpha and beta smears were performed, no definitive analysis for thorium contamination was performed; such contamination could only be deduced by comparing alpha and beta readings for a given locaton (Rolfes 2013).

representative such particle sizing could be for thorium, given that what was sized were the particles actually found and not a representative sample, because "there were not enough [thorium] particles to perform particle size analysis" (Coleman 1996). This comment underscores the difficulty and complexity of sizing breathing zone particulates in a representative manner under realistic workplace conditions, e.g., W55 disassembly as practiced in the 1980s.[17]

For the mass ratios being proposed by NIOSH, the differences between pre- and post-1991 W55 disassembly practices, and the advent of glovebox containment negative pressurization and filtration, and improved workplace contamination smearing and air sampling, would have likely led to differing ratios of thorium oxide to DU found in the 1980s than those found in 1996 and beyond. Confirmation of this difference would require analysis of contamination surveys for both uranium and thorium from this earlier period, which are not available.[18]

Conclusion: The proposed approach to back-estimate maximum intake of thorium based on 1990's air sampling measurements is not valid.

Loose thorium contamination presented an airborne pathway for potential intakes for W55 disassembly workers and other workers disassembling thorium-containing weapons systems at Pantex before the 1990s. The use of a mass ratio-based intake value for thorium (i.e., 2%) based on air sampling data from 1996 is not valid for the SEC period in question, 1984–1990, because such a parameter would not be necessarily representative of, or bounding for, that operational time period due to significant differences in worker handling practices, contamination controls, and workplace and personnel monitoring. In particular, in 1990–1991, a gloveboxed downdraft table was installed as an engineered contamination barrier for workers disassembling the W55 system, virtually eliminating airborne contamination outside of the box, and likely changing the ratio of thorium to DU contamination that was found on workplace air samples in 1996.

[17] A similar argument (i.e., "not easily dispersible nor respirable") was made previously by NIOSH for minimal DU airborne resuspension during W28 disassemblies (for example, response #2 to SC&A in Rich and Rolfes 2011); it was SC&A's position during subsequent Work Group discussions that worker interviews, as confirmed by the 1990 bioassay results, indicated otherwise.

[18] The contamination smears and bioassays conducted for the W55 program were done in the mid to late-1990s, following the introduction of a downdraft glovebox table; not in the 1980s, when neither engineered nor procedural practices existed to minimize exposures during dismantlement of these systems.

Figure 3. Gloveboxed Downdraft Table, Installed late-1991, for W55 Dismantlement
Source: [**Worker II**] 2011

Figure 4. Closeup of Downdraft Table used for W55 Dismantlement
Source: [**Worker II**] 2011

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