ISSUE RESOLUTION MATRIX FOR SC&A FINDINGS ON TBD-6000

NIOSH Responses Added on March 6, 2009

SC&A Response to NIOSH Response Added March 9, 2009

Additional Material Added Following the October 14, 2009, Work Group Meeting

Additional Material Added Prior to October 12, 2010, Work Group Meeting

Issue 1: Failure to Discuss Elevated Levels of Th-234 and Pa-234m Close to Surface of Freshly Cast

SC&A Finding: The TBD would benefit from a discussion of the possibility and potential dosimetric significance of uranium metal-working operations involving freshly cast uranium ingots, where there might be elevated levels of Th-234 and Pa-234m close to the surface of the ingot. Furthermore, it is not clear from the TBD whether scrap recovery at any of the covered AWE sites involved melting and casting of uranium. This should be investigated, since it could make a significant difference in the external dose reconstruction protocol.

NIOSH Response: It is agreed that the TBD would benefit from a discussion of uranium progeny concentrations during uranium casting. The issue requires additional research. Also, scrap recovery involves several steps one of which may be remelting the uranium for casting. At facilities that normally cast uranium, this was a viable step to recovering some of the scrap. However, a facility that did not have the recasting equipment would not utilize this step solely to recover uranium. Since most facilities that cast uranium would also have some scrap recovery efforts, both types of work would normally be considered.

SC&A Reply: It appears that NIOSH and SC&A are in agreement on this issue. The work group may want to close the issues or leave it in abeyance until TBD-6000 is revised to accommodate this issue. NIOSH may wish to refer to Putzier 1982 for a discussion of uranium progeny concentrations on the surface of freshly cast (< 100 d) uranium ingots (see list of references).

October 14, 2009, Work Group Meeting: This issue was briefly discussed at the work group meeting and NIOSH agreed to look into how they will address this matter. SC&A recommended that this issue remain in abeyance until the TBD is revised.

December 16, 2009, Work Group Meeting: NIOSH reviewed the just-published Issue 1 White Paper, *Consideration of Recasting Increasing Progeny Concentration* (Allen 2009) (See Attachment 6). There was general agreement between SC&A and NIOSH that the 95th percentile values of beta dose determined using TBD-6000 were conservative and claimant favorable. However, it was not clear whether using the 95th percentile in a deterministic calculation was more or less claimant favorable than using the full lognormal distribution based on a geometric mean and geometric standard deviation. SC&A was requested by the Work Group to include some hypothetical probability of causation (POC) calculations in the paper it was preparing in response to Allen 2009.

Actions Subsequent to December 16, 2009, Work Group Meeting: SC&A delivered a memorandum on December 28, 2009, documenting its comments on Allen 2009 and providing results of some hypothetical POC case studies (SC&A 2009) (See Attachment 7). In one hypothetical case comparing the POC for skin cancer (other than hands and arms), both the full distribution and the deterministic 95th percentile from TBD-6000 resulted in high POCs (82.6% for full distribution and 89.1% for 95th percentile). This comparison is only applicable to skin cancer associated with beta dose. Results were significantly different for photon dose to the lungs.

May 12, 2010, Work Group Meeting: There was extensive discussion on Issue 1, particularly with regard to how the Putzier effect would be addressed in the revision of TBD-6000. Member Griffon was concerned that dose to the hands might not be adequately covered by the existing TBD-6000 approach when the Putzier effect existed. Chairman Ziemer asked if NIOSH could prepare suggested language for a revised TBD-6000 addressing the Putzier effect. NIOSH agreed to do so.

Developments Since May 12, 2010: NIOSH provided a White Paper documenting proposed language to be used in TBD-6000 on the Putzier effect (Allen 2010), which is included here as Attachment 8.

Board Action:

Issue 2: Omission of External Exposure to Skin from Beta Particles Emitted from Contaminated Surfaces

SC&A Finding: The TBD presents generic photon exposure conversion factors for submersion in an airborne plume of uranium (expressed in units of mR/hr per dpm [α]/m^3) and for standing on a contaminated surface (expressed in units of mR/hr per dpm [α]/m^2). However, the TBD does not present similar dose conversion factors addressing external exposure to skin from beta particles emitted from contaminated surfaces. SC&A's calculations of the potential skin exposures from this pathway reveal that this source of exposure is significant relative to photon exposures and should be addressed in the TBD.

NIOSH Response: It is agreed the beta dose should be addressed if the photon is to be addressed. It is however, important to realize the external dose from contaminated surfaces is small compared to that from metal. The dose rates in Table 6-4 indicate that, in the worst case, the photon dose from this source of exposure is less than 1% of that from the metal itself.

SC&A Reply: We agree with the NIOSH observation regarding the relative magnitude of the exposures from contaminated surfaces and metal ingots. However, since TBD-6000 has generic applicability, there may well be cases where a worker had been exposed to contaminated surfaces but not to metal ingots. In such cases, doses to skin and superficial organs would be underestimated. It appears that NIOSH and SC&A are in agreement on this issue. The work group may want to close the issues or leave it in abeyance until TBD-6000 is revised to accommodate this issue.

October 14, 2009, Work Group Meeting: This issue was discussed at the October 14, 2009, work group meeting, and NIOSH agreed to include a table in TBD-6000 addressing external exposures to beta associated with contaminated surfaces. SC&A recommends that this issue be held in abeyance until the TBD is revised.

May 12, 2010, Work Group Meeting: Chairman reaffirmed that Issue 2 remains in abeyance pending revision of TBD-6000.

Board Action:

Issue 3: Questions Regarding Recycled Uranium

SC&A Finding: Based on this review, we conclude that the default concentrations of Pu-239, Np-237, and Tc-99 contained in recycled uranium shipped to AWE facilities for metal working, as presented in TBD-6000, are scientifically valid and claimant favorable. However, we do not understand the reason for including Th-232 and Th-228 in Table 3.2 of TBD-6000. Furthermore, a default assumption that RU was present during and after 1953 is appropriate unless there is specific evidence from an AWE site's own records that only virgin uranium was handled there.

NIOSH Response: The origin of the thorium values is being explored, however, since the values provided represent an activity less than 6 millionths that of the uranium, we consider it a minor issue. Also, the default assumption mentioned in the comment is indeed the default specified in the TBD in the second bullet in section 7.1.3.

SC&A Reply: It appears that NIOSH and SC&A are in agreement on this issue. The work group may want to close the issues or leave it in abeyance until TBD-6000 is revised to accommodate this issue.

October 14, 2009, Work Group Meeting: This issue was discussed at the October 24, 2009, work group meeting. Dr. Poston stated that Th-232 is sometimes associated with RU and therefore it is appropriately included in TBD-6000 as a trace contaminant in RU. SC&A recommends that this issue be designated as closed.

May 12, 2010, Work Group Meeting: Chairman reaffirmed that Issue 3 is closed.

Board Action:

Issue 4: Airborne Uranium Dust Concentrations Recommended in the TBD Might Not Be Claimant Favorable
SC&A Finding: Default airborne dust loadings used in the TBD to derive external exposures and inhalation exposures are based on data provided in Harris and Kingsley (1959). The TBD would benefit from including a review of the time-weighted daily average uranium dust loadings reported in the Adley et al. report, *Study of Atmospheric Contamination in the Metal Melt Building* (AEC 1952), and in the site profile for Simonds Saw and Steel, ORAUT-TKBS-0032 (ORAUT 2005). SC&A's review of these documents revealed that the bounding, default, time-weighted average airborne uranium dust concentrations recommended in the TBD might not be claimant favorable.
NIOSH Response: This comment is not clear. The SC&A report indicates that some of the highest numbers in Adley are higher than the geometric mean in the TBD. The highest values should more appropriately be compared to the 95th percentile of the distribution in the TBD.
SC&A Reply: As indicated on page 17 of SC&A's review of TBD-6000, time weighted average airborne concentrations of uranium in the breathing zone of workers at the Hanford Metal Melt Facility, as cited by Adley et al. (AEC 1952) appear to be about twice the values adopted as default values in TBD-6000. We believe that NIOSH should revise TBD-6000 to explicitly consider the extensive data described in AEC 1952. SC&A recommends that this issue remain open.
October 14, 2009, Work Group Meeting: This issue was discussed at the October 14, 2009, work group meeting. Prior to the meeting, NIOSH distributed a white paper to the work group. This white paper is provided in Attachment 2 to this matrix. Prior to the work group meeting, SC&A performed a review of the white paper in Attachment 2 and distributed its evaluation of NIOSH's white paper to the work group at the time of the meeting. Attachment 3 presents SC&A's review of NIOSH's white paper. Based on SC&A's review of NIOSH's white paper regarding Issue 4, SC&A accepts NIOSH's report and recommends that this issue be designated as resolved.
May 12, 2010, Work Group Meeting: Chairman reaffirmed that Issue 4 had been resolved**.**
Board Action:

Issue 5: Concerns with Method Used to Derive Surface Contamination and Associated External Doses

SC&A Finding: SC&A has several concerns with the method used to derive the surface contamination and associated external doses in Table 6.4 of the TBD. Our primary concerns are the assumptions that the surface contamination levels are directly proportional to the airborne dust loading of respirable particles of uranium, and that the constant of proportionality makes use of a respirable particle deposition velocity of 0.00075 m/sec and an arbitrary time period of deposition of 7 days. The various reports summarized in Attachment 1 to this report reveal that surfaces at uranium metal-working facilities become contaminated primarily from the deposition of relatively large flakes of uranium oxide produced during the rolling, machining, and general handling of uranium metal. These flakes fall directly onto surfaces, rather than slowly becoming deposited, as is the case for smaller particles in the air. The TBD should consider the empirical data regarding surface contamination reported in the Adley et al. report (AEC 1952) and the Simonds Saw and Steel report (ORAUT 2005), which provide information indicating that the default upper-bound uranium dust loading on surfaces, as recommended in the TBD for AWE facilities involved in uranium metal-working operations during the early years, might be underestimated by 1 to 2 orders of magnitude. As a result, default external exposures from contaminated surfaces and internal exposures from the inhalation of resuspended particles of uranium deposited on surfaces might also be underestimated by 1 to 2 orders of magnitude.

NIOSH Response: There appear to be two issues in this comment. First the issue of flakes. Large flakes of uranium that are produced would fairly quickly be ground into dust under foot and forklift traffic typical of operating area. They would then be available for resuspension and contribute to the air concentrations measured. This implies a connection between airborne concentrations and surface contamination often represented by a resuspension factor. If an abundance of large flakes present on the floor are not ground into dust quickly, it would imply a lower resuspension factor than might exist in an area free of large flake contamination. This implies this issue is closely related to the next comment and it is recommended that they be combined.

The second issue indicates that the surface contamination in the TBD may be underestimated by one or two orders of magnitude and recommends considering the data contained in the Adley report. NIOSH performed a cursory review of the empirical data in Adley. The review indicates that the methods utilized in the TBD would overestimate the measured settling rates in Adley.

SC&A Reply: SC&A believes that it is important to separate operational data that characterize the levels of surface contamination at AWE uranium handling facilities and generic literature that addresses indoor resuspension factors. The AWE literature on the buildup of uranium on surfaces, as described in Section 6.1.2 of SC&A's review of TBD-6000, reveals that the default surface contamination recommended in TBD-6000 is not claimant favorable. For example, based on the investigations cited in AEC 1952, it will only require about 3 days of uranium processing before the surface contamination can build up to the default surface contamination level recommended in TBD-6000. We believe that NIOSH should revise TBD-6000 to explicitly consider the extensive data described in AEC 1952. SC&A recommends that this issue remain open.

October 14, 2009, Work Group Meeting: This issue was discussed at the October 14, 2009, work group meeting. Prior to the meeting, NIOSH distributed a white paper to the work group. This white paper is provided in Attachment 4 to this matrix.

Prior to the work group meeting, SC&A performed a review of the white paper in Attachment 4 and distributed its evaluation of NIOSH's white paper to the work group at the time of the meeting. Attachment 5 presents SC&A's review of NIOSH's white paper.

Based on SC&A's review of NIOSH's white paper regarding Issue 5, SC&A accepts NIOSH's report with respect to the methods used to estimate the contamination level on surfaces and recommends that this aspect of this issue be designated as resolved. This conclusion is important, because it is applicable to SC&A comments on numerous procedures and dose reconstruction reviews. SC&A previously believed that the deposition velocity approach adopted by NIOSH would underestimate accumulation of material on surfaces. However, SC&A's review of the data in the Adley report reveals that this approach is scientifically sound.

May 12, 2010, Work Group Meeting: The Chairman noted that this issue had been closed previously**.**

Board Action:

Issue 6: Underestimate of Resuspension Factor

SC&A Finding: In order to derive upper-bound default inhalation exposures due to the resuspension of uranium particles deposited on surfaces, the TBD uses a default resuspension factor of 1×10^{-6} per meter. A review by SC&A of the literature addressing resuspension factors indoors reveals that this value might be low by about an order of magnitude. Considering that the default bounding surface contamination used in the TBD might be low by 1 to 2 orders of magnitude, and that the default bounding resuspension factor might be low by an order of magnitude, the default inhalation rate and associated doses associated with the dust resuspension pathway might be underestimated in the TBD by several orders of magnitude.

NIOSH Response: There is little specific information related to resuspension factors in the SC&A review of this TBD. As such, insufficient detail is provided to allow NIOSH to address the comment. It is suspected that the details appear in the SC&A review of OTIB-70.

SC&A Reply: NRC (2002) recommends the use of a resuspension factor of 1×10^{-6} per meter for screening analyses to determine if a building can be released for unrestricted occupancy. There are two key assumptions that underlie the use of such a value. First, the surface contamination occurred sometime in the past, and no new contaminants are being introduced. Second:

> *It is assumed that surfaces will be cleaned or washed during decommissioning. This will remove most of the loosely bound and some of the more tightly bound particles. Following the above discussion, surfaces that have been cleaned would be expected to have a smaller RF than surfaces that have not been cleaned, given the same levels of surface contamination.* (NRC 2002, p 4)

Clearly, neither of these assumptions apply to an operating facility that performs work on uranium or thorium metals.

Attachment 1 presents an excerpt from previous literature reviews performed by SC&A on behalf of the Board related to resuspension factors. We believe we have demonstrated that 1E-6 per meter is low by a factor of at least 10, especially for facilities that have not been cleaned up, where there is a lot of anthropomorphic activity, and your intention is to be claimant favorable.

May 12, 2010, Work Group Meeting: The chairman stated that this issue had been transferred to the Procedures Work Group.

Board Action:

Issue 7: Use of Deficient Methodology For Estimating Inadvertent Ingestion of Uranium

SC&A Finding: Internal doses associated with the inadvertent ingestion of uranium are derived in the TBD using models and assumptions that have been discussed with NIOSH in the past as part of the review of numerous site profiles and exposure matrices. Based on these discussions, it is our understanding that NIOSH would agree that the basic methodology described in the TBD is deficient and should be revised when the overall revised methodology is developed.

NIOSH Response: As the comment indicates, this methodology is the subject of numerous reviews and has been taken up as an overarching issue. If the methodology is changed as a result, the change will be incorporated into this TBD.

SC&A Reply: SC&A raised this issue in our review of dose reconstructions in December 2004. At that time, NIOSH agreed to consider the inadvertent ingestion rates in EPA 1997 in their response to our comments. We have raised this issue repeatedly over the next 4 years, and it has still not been resolved. The bottom line is NIOSH is effectively assuming a default inadvertent ingestion rate of contaminated residue, soot, etc of 0.5 mg/day. Others (EPA and NCRP) have suggested 50 to 100 mg/day. Notwithstanding whether we assume 0.5 or 50 mg/day, the exposures associated with the inadvertent ingestion pathway are small, relative to the inhalation pathway. Nevertheless, is would be desirable to close out this issue.

October 14, 2009, Work Group Meeting: This subject was discussed at the October 14, 2009, work group meeting. NIOSH agreed that the inadvertent ingestion of "soot" may, in fact, be as high as 50 to 100 mg/day, but it is inappropriate to conclude that this material is entirely composed of the radionuclide of concern. SC&A accepts this position. NIOSH further argued that the 0.2 rule is appropriate, as delineated in OTIB-009. Using this approach, the daily ingestion rate of a radionuclide is derived by multiplying the radionuclide concentration in air (expressed in units of Bq/m^3 or mg/m^3) by 0.2 to obtain the daily ingestion rate of the radionuclide (expressed in units of Bq/day or mg/day, depending on the units that are used to characterize the airborne concentration of the radionuclide). SC&A explained that this approach seemed to be reasonable, especially if the dust loading is high. For example, if a uranium facility has a dust loading of uranium of 100 mg/m^3, the 0.2 rule would result in an ingestion rate of 20 mg/day of uranium. SC&A believes that this is reasonable.

If the dust loading were much lower, let us say 1 mg/m^3 of uranium, the inadvertent ingestion rate would be derived as 0.2 mg/day. SC&A argued that this is a very low ingestion rate. However, NIOSH explained that, any uranium on surfaces at such a facility would mix with non-radioactive soot on surfaces and, as a result, though the inadvertent ingestion rate of "soot" might be as high as 50 to 100 mg/day, it is unlikely that it would be pure uranium. SC&A accepts this position. Hence, SC&A concurs with NIOSH's position on this matter, with one proviso. If a uranium facility is known to have extensive surface contamination, where large quantities of uranium are present on surfaces; i.e., visible quantities, we suggest that NIOSH consider using a default uranium ingestion rate of 50 mg/day under such circumstances.

SC&A recommends that this issue remain open until the work group has an opportunity to discuss the aspect of this issue which deals with uranium facilities where there is heavy contamination of virtually pure uranium (or its various chemical forms) on surfaces.

May 12, 2010, Work Group Meeting: There was extensive discussion on this issue. SC&A felt that when high air concentrations existed, the NIOSH model linking air concentrations to ingestion would result in reasonable ingestion rates. However, SC&A envisioned situations where high uranium surface concentrations existed, which could lead to high ingestion, but concomitant high airborne exposures might not occur, thereby underestimating ingestion exposure with the NIOSH model. NIOSH felt that situations where high surface concentrations were not associated with high airborne concentrations were unlikely to occur. The Chairman concluded that this was a TIB-0009 issue and, accordingly, was outside the scope of the TBD-6000 Work Group.

Board Action:

References

AEC 1952. Adley, F.E., Gill, W.E., and Scott, R.H., "Study of Atmospheric Contamination in the Metal Melt Building," U.S. Atomic Energy Commission, HW-23352 (rev.), April 4, 1952.

Allen, David 2009. "BATTELLE-TBD-6000 ISSUE 1 WHITE PAPER – Consideration of Recasting Increasing Progeny Concentration." NIOSH/OCAS. December 10, 2009.

Allen, David 2010. White Paper TBD-6000 Working Group – Putzier Effect." NIOSH/OCAS. September 2010.

Harris, W.B. and I. Kingsley 1959. "The Industrial Hygiene of Uranium Fabrication," A.M.A. Archives of Industrial Health, Vol. 19, May 1959. pp. 76–101.

ORAUT 2005. ORAUT-TKBS-0032, "Site Profile for Simonds Saw and Steel," Revision 00 PC-1, Oak Ridge Associated Universities Team. July 8, 2005.

Putzier, E.A. 1982. "The Past 30 Years at Rocky Flats: A Summary of Experiences and Observations at Rocky Flats Plant Over the Past 30 Years with Emphasis on Health and Safety."

SC&A 2009. "Review of NIOSH Issue 1 White Paper Dated December 10, 2009." Not PA Cleared. December 28, 2009.

ATTACHMENT 1: RESUSPENSION FACTORS

The resuspension of radioactive material from surfaces can be modeled by the use of an equilibrium resuspension factor (RF) (in units of length^{-1}). The RF is simply a ratio of the air concentration of radioactive material above a surface (Bq/m^3) to the concentration on the surface (Bq/m^2).

Measured RFs vary over very wide ranges. Kennedy and Strenge (1992) reported RFs from approximately 1E-11 to 1E-2 m^{-1}, which suggests that resuspension is a complex process of several parameters, and that the specific conditions present at the time of measurement are critical. For modeling purposes, an RF is a lumped parameter that is used to account for a complex combination of mechanisms that are poorly understood, but whose net effect is observed in the real world.

The RF is affected by a number of physical factors that include the following:

- Type of disturbance
- Intensity of disturbance
- Time since deposition
- Nature of the surface
- Particle size distribution
- Climatic conditions
- Type of deposition
- Chemical properties of the contaminant
- Surface chemistry
- Room geometry and characteristics

A general discussion of these factors is provided in Beyeler et al. (1999).

When choosing an appropriate value for RF, one must consider the nature of contamination on the surface (e.g., how tightly it is bound to the surface), and balancing the driving forces that cause the material on the surface to become airborne with the mechanisms that remove the material from the air. Clearly, the concept of RFs applies to solid particles and does not apply to gases.

The primary force that will resuspend particles in occupancy and reuse scenarios can be expected to be mechanical forces associated with rubbing and abrasion of surfaces. These forces are typically associated with human activity. In buildings, air currents caused by normal ventilation or by vibrations are not expected to be a major cause of resuspension of particles (NUREG-1720). Moreover, RFs determined from mechanical disturbance can be an order of magnitude higher than RFs determined with only air currents (Beyeler et al. 1999). Higher RFs were measured when driving forces were increased and when surface contamination was loose and easily removable (NUREG-1720). It is important to assess the types and intensity of the applied driving forces in order to select appropriate RF values for any dust inhalation exposure scenario.

Although ventilation does not cause significant resuspension, it will cause removal of already resuspended particles in two ways. The first is by outflow of air from a space such as a room or truck cab. The second is by turbulent inertial impaction caused by the change of direction of air streams as the air goes around obstacles. These removal mechanisms are important because they will reduce the airborne concentration and thus the RF. Resuspension factors based on studies with no ventilation will tend to be higher. Conversely, RF values taken from studies with excessive ventilation will be lower.

How the surface radioactivity is bound to the surface will have a major effect on the RF. For particles to become airborne, the bond between the particles and the surface (e.g., floor or wall) must be broken by the driving forces. Particles that are tightly bound to the surface are not easily resuspended, whereas particles that are loosely bound, like freshly deposited material, will be more easily resuspended. Tightly bound particles require greater mechanical force to break the bonds and become resuspended. For the same amount of surface radioactivity, surfaces with a large portion of tightly bound particles will yield smaller RFs.

Consideration of the representativeness of the surface radioactivity is important in selecting appropriate RF values. For the recycle and reuse of contaminated material, it should be assumed that the surfaces are cleaned or washed before release for unrestricted use. This cleaning will remove most of the loosely bound and some of the more tightly bound particles (NUREG-1720).

As discussed in Beyeler et al. (1999), resuspension is greatest for smaller diameter particles. The RF decreases with particle diameter in the range of 1 to 5 microns. The distribution of particle size may also change with time as mechanical forces are applied.

Although larger particles may be resuspended, gravitational settling removes them from the air more rapidly than smaller particles. Nevertheless, larger particles can be important because they can be measured as “removable” by wipe tests, leading to the conclusion that a higher fraction of resuspendable particles may be present that can actually contribute to dose. In this context, significant removable activity as larger particles may cause the RF to be underestimated (NUREG-1720). Since the RF is a ratio, the numerator is set equal to the measured airborne concentration, whereas the denominator is set equal to the measured surface activity.

Unfortunately, there are no experimental data that specifically address resuspension from tools or equipment. The experimental data and recommendations summarized in Table 1 are felt to be the most appropriate available information. The range of RFs cited in Table 1 is 2 E-8 m^{-1} to 4 E-3 m^{-1}. The reported data are generally from experiments that examined resuspension of liquid or powder contaminated material that had been uniformly applied to clean surfaces in a laboratory-like setting. The highest values are typically associated with inefficient ventilation, excessive mechanical disturbance, or dusty conditions. Typically, the purpose of these studies was to help determine radiation protection safety guidelines for loose residual, surface radioactivity.

One recent study performed by the NRC staff (NUREG-1720) used published literature and extensive field measurements at two decommissioning facilities to determine RF values for building occupancy at decommissioned facilities. As a result of their study, an improved basis to

estimate indoor RFs has been established. The staff conducted statistical analysis of RF mean values for five sites deemed applicable to building occupancy after decommissioning. The staff believes that the available data are not perfect and tend to overestimate the likely RFs at decommissioned facilities. Their recommended values for RF should be used for building occupancy, but may be high for equipment reuse scenarios.

Lower-end values for reuse scenarios are considered appropriate because of two key assumptions inherent in the scenario definition: (1) readily removable contamination has been removed from the surface of the recycled equipment or material prior to clearance, and (2) contamination that is not readily removable is the least susceptible to resuspension. This situation represents a key difference between this scenario and the conditions for which resuspension measurements have typically been taken.

Table 1. Representative Reported Indoor Resuspension Data and Recommended Values

Reference	Resuspension factor or range	Comments
Barnes (1959)	4E-5 m^{-1} (confined space) 2E-6 m^{-1} (open air)	Reported for "dusty operations"; 10^{-5} m^{-1} recommended for most laboratory work.
Stewart (1964)	1E-6 m^{-1} (quiescent conditions) 1E-5–1E-4 m^{-1} ("operational" conditions)	Notes that excessively high particulate resuspension values indoors are likely to indicate some degree of inefficiency in the ventilation system.
Brunskill (1964)	2E-4–4E-3 m^{-1}	Measured in small rooms with various types of personnel movement, including introduction of loose contamination on coveralls. Lower recommended values were measured for a large area of "loose" contamination on concrete; "much smaller" values were found for linoleum floor.
Jones and Pond (1964)	2E-8–5E-5 m^{-1} 5E-5 m^{-1} (recommended for worst practical conditions)	Estimated that 10%–20% of total airborne radioactivity was respirable. Suggested that recommended value could be an order of magnitude lower for average conditions.
Dunster (1964)	2E-6–4E-5 m^{-1} 2E-6 m^{-1} (recommended safe value for long-term use)	Highest values from digging through dusty building rubble and in an enclosed and unventilated space.
Spangler and Willis (1964)	4E-5 m^{-1} (derived)	This value is calculated using equation for equilibrium airborne concentration in a small room from a surface concentration and recommended values appropriate for calculating 40-hr maximum permissible concentration (MPC) levels.
Healy (1971)	2.1 E-7–1.0 E-3 m^{-1}(derived)	This value is calculated using the equation for airborne concentration, assuming ventilation rate for a reasonably tight 28 m^2 H 2.4 m room.
Gibson and Wrixom (1979)	2E-6–4E-5 m^{-1}	The lower value was used in original calculation of derived working limits (DWL) for active area surfaces and might be inappropriate for widespread contamination on dusty surfaces. The higher value was obtained from measurements in a confined space and is suggested for general use.
IAEA (1970)	2E-6–3E-3 m^{-1} 5E-5 m^{-1} (recommended)	Recommended value is suggested as appropriate for general conditions of contamination on surfaces. Because of confounding factors, this effectively reduces the recommended value by 2.5H for use in calculating DWL values.
Kennedy et al. (1981)	2.5E-5 m^{-1} (derived)	This value is calculated using the equation for airborne concentration, assuming ventilation rate of an open transport truck and resuspension rate for a 28 m^2 room.

Table 1. Representative Reported Indoor Resuspension Data and Recommended Values		
Reference	**Resuspension factor or range**	**Comments**
Kennedy and Strenge (1992)	1E-6 m^{-1} (recommended)	Based on a review of resuspension literature. Recommended as a reasonably conservative default value to be applied to total surface concentration.
IAEA (1992)	1E-6 m^{-1} (recommended)	This value is recommended for use in assessing reuse of tools and equipment. Used a transfer factor of 0.01 to account for the fraction of the residual surface radioactivity that is available for resuspension.
Chen (1993)	1 E-6 m^{-1}	No justification given (based on use in Kennedy and Strenge 1992)
Draft NUREG-1720 (2002)	Lognormal distribution with mean of 3.7 E-7 m^{-1} and 90th percentile of 9.6 E-7 m^{-1}	NRC staff analyzed literature and recent field data considering realistic assumptions about decommissioned facilities and building occupancy for the DandD code. Resuspension factor values best represent cleaned and aged surfaces.

The use of RFs near the lowest measured value is also justified based on consideration of the respirable fraction of resuspended contamination. In one of the few studies where particle size has been measured, Jones and Pond (1964) reported that measurements of air concentration were often biased by a few highly active large particles. In their study on resuspension of plutonium, they concluded that only 10 to 20 percent of the total airborne radioactivity would be respirable.

Another complicating factor is that the residual surface radioactivity is probably not uniform. Several studies (Dunster 1964, IAEA 1970, Healy 1971) discuss how this issue relates to resuspension values. Healy (1971) points out that in most cases, resuspension has been measured for uniformly contaminated surfaces and uniformly applied resuspension forces. Healy suggests that air concentrations are more strongly related to the total amount of surface contamination present, rather than the amount on any one limited area, and that basing allowable surface contamination limits on the highest surface levels may be too conservative.

There are many other factors that contribute to the uncertainty in resuspension that are not addressed here because of lack of information. These include temperature, humidity, type and roughness of surface material, degree and effectiveness of mechanical disturbance, weathering processes, and chemical state of the contamination. The effect of changes in many of these factors on resuspended air particle concentrations is intuitive (e.g., an increase in the size of the contaminated area would likely result in an increase in the resuspended air concentration); however, the degree and direction of the effect of other factors (e.g., specific surface conditions) is not so clear. Combining all these factors to define a "generic" RF or rate for modeling purposes is difficult. Based on consideration of these factors and good engineering judgment, however, it is reasonable to use a lognormal distribution with geometric mean of the lowest reported RF in the model.

References

Barnes, D.E., 1959. "Basic Criteria in the Control of Air and Surface Contamination," *Symposium on Health Physics in Nuclear Installations*, at Riso, Denmark, 25-28 May 1959. Organization of European and Economic Cooperation/European Nuclear Energy Agency, Paris, 1959.

Beyeler et al. 1999. *Residual Radioactive Contamination from Decommissioning, Parameter analysis*. Draft Report for Comment, NUREG/CR-5512, Vol. 3. U.S. Nuclear Regulatory Commission.

Bond, R.G., Straub, C.P., and Prober, R. 1972. Air Pollution, Vol. 1 of Handbook of Environmental Control. Cleveland, Ohio: CRC press.

Brunskill, R.T., 1964. *The Relationship Between Surface and Airborne Contamination*, Surface Contamination, Proceedings of a Symposium Held at Gatlinburg, Tennessee, June 1964. Pergamon Press, Oxford, 1967.

Chen, S.Y., 1993. *Risk Assessment Bases on Current Release Standards for Radioactive Surface Contamination*, ANL/EAIS/CP-79677. Argonne National Laboratory, Argonne, Illinois, September 1993.

Dennis, R. 1976. Handbook of Aerosols. TID 26608. U.S. ERDA, Washington, DC. U.S. ERDA Dennis, R. 1976. Handbook of Aerosols. TID 26608. U.S. ERDA, Washington, DC. U.S. ERDA.

Dunster, H.J., 1964. "The Concept of Derived Working Limits for Surface Contamination," in *Surface Contamination, Proceedings of a Symposium Held at Gatlinburg, Tennessee, June 1964.* Pergamon Press, Oxford, 1967.

First, M.W. and Drinker, P. 1952. "Concentrations of Particulates Found in Air." *Arch. Ind. Hyg. Occup. Med.* 5:387.

Gilbert, T.L., et al. 1983. "Pathways Analysis and Radiation Dose Estimates for Radioactive Residues at Formerly Utilized MED/AEC Sites. ORO-832 (Rev).

Healy, J.W., 1971. Surface Contamination: Decision Levels, LA-4558-MS. Los Alamos Scientific laboratory, Los Alamos, New Mexico, September 1971.

IAEA 1970. International Atomic Energy Agency. *Monitoring Radioactivity on Surfaces*, Technical Report Series No. 120. International Atomic Energy Agency, Vienna, 1970.

Jones, I.S. and S.F. Pond, 1964. "Some Experiments to Determine the Resuspension of Plutonium from Various Surfaces, " in *Surface Contamination, Proceedings of a Symposium Held at Gatlinburg, Tennessee, June 1964.* Pergamon Press, Oxford, 1967.

Kennedy, W.E. and D.L. Strenge, 1992. *Residual Radioactive Contamination from Decommissioning: Volume 1, Technical Basis for Translating Contamination levels to Annual Total Effective Dose Equivalent*, NUREG/CR-5512. Prepared by Pacific Northwest Laboratory for the U.S. Nuclear Regulatory Commission, Washington DC. December 1992.

Linch 2002., Linch, KD. "Respirable concrete dust-silicosis hazard in the construction industry," *Appl Occup Environ Hyg Mar*; 17(3):209-21, 2002.

Oztunali, O., et al. 1981. *Data Base for Radioactive Waste Management, Impacts Analyses Methodology Report.* NUREG/CR-1759. Washington, DC: U.S. NRC.

Schwendiman, L.C. 1977. *Supporting Information for the Estimation of Plutonium Oxide Leak Rates Through Very Small Apertures*, BNWL-2198. Richland, Washington: Pacific Northwest Laboratory.

Sinclair 1976., Sinclair, P.C. "Vertical Transport of Desert Particulates by Dust Levels and Clear Thermals," *Proceedings of the Atmospheric-Surface Exchange of Particulates and Gaseous Pollutants– 1974 Symposium*, pp 497-527, USERDA, CONF-740921, NTIS, Springfield, VA. 1976.

Spangler, G.W., and C.A. Willis, 1964. "Permissible Concentration Limits," in *Surface Contamination, Proceedings of a Symposium Held at Gatlinburg, Tennessee, June 1964.* Pergamon Press, Oxford, 1967.

Stern, A.C. 1976. "Air Pollution," In: *Air Pollutants, Their Transformation and Transport*. Volume 1. New York: Academic Press.

Stewart, K., 1964. "The Resuspension of Particulate Material from Surfaces," in *Surface Contamination, Proceedings of a Symposium Held at Gatlinburg, Tennessee, June 1964.* Pergamon Press, Oxford, 1967.

Sutter, S.L. 1982. *Accident Generated Particulate Materials and Their Characteristics - A Review of Background Information*, NUREG/CR-2651. Battelle Pacific Northwest Labs., Richland WA.

United Power Association (UPA) 1974. *Final Elk River Reactor Program Report*, COO-651-93. Elk River, Minnesota.

Yu et al. 1993. *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil*. ANL/EAIS-8. Environmental Assessment and Information Division, Argonne National Laboratory.

ATTACHMENT 2: NIOSH COMMENTS ON ISSUE 4

BATTELLE-TBD-6000 ISSUE 4 WHITE PAPER
Comparison to Adley Air Data
Prepared by Dave Allen, OCAS
October 9, 2009

Issue 4 of the Battelle-TBD-6000 review matrix recommended comparing air exposure values in the TBD to time-weighted air exposure values in the report by Adley et al. (1952) and the Simonds Saw Steel site profile. This white paper provides that comparison.

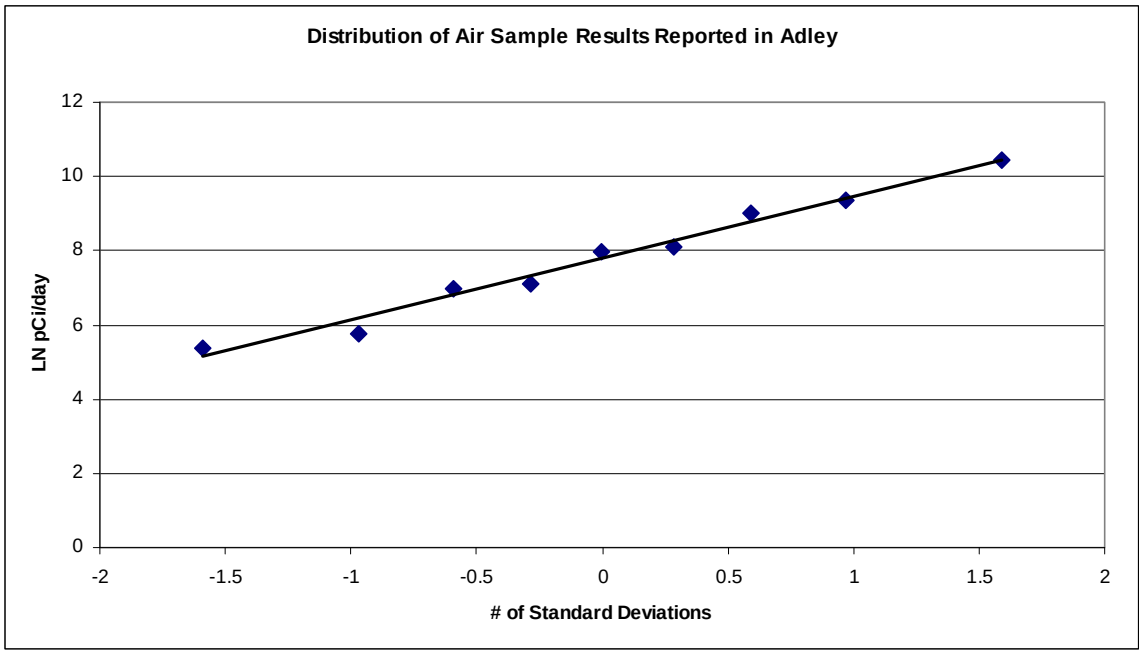
Review of Adley Data

The Adley et al. report provides nine time-weighted average air exposure values in Table IX. The values are presented in units of $x10^{-5}$ ug-hrs/cc. In order to compare these values to TBD-6000, the values were first converted to an average air concentration value by dividing the daily time-weighted value provided in Adley by 8 hours. The values were next converted to units of pCi/m^3, then to annual exposures and finally divided by 365 calendar days. This resulted in units of pCi/calendar day exposure, which are the units used in TBD-6000.

These values are provided in the Table below along with those from TBD-6000.

Job Title	pCi/calendar day
Adley	
Furnace Operator	8221
Furnace Assistant	3354
Saw Room Operator	11574
Oxide Operator	33816
Rod Handler	1047
Autoclave Operator	218
Rod Receiving-unloading	2944
Rod Receiving-weighing	316
Rod Receiving-stacking	1244
Battelle-TBD-6000	
Extrusion Operator	2965
Rolling Operator	10559
Forging Operator	3497
Machining Operator	16379
Slug Production Operator	592
Scrap Recovery Operator	5051

The values in TBD-6000 are the geometric mean (GM) of a lognormal distribution with a geometric standard deviation (GSD) of 5. The values in Adley have no distribution listed so a comparison is difficult. In an attempt to compare the values analytically, a distribution of the Adley values was determined. This resulted in a log normal distribution with a GM of 2420 pCi/day and a GSD of 5.3. The figure below shows the fit of the data.



The table below list values for the six operations from TBD-6000. The GM values from Table 7.8 as well as the 95th percentile are listed. Also the GM and 95th percentile values from the Adley distribution above are listed.

	GM	95th
Adley	2420	37636
Battelle_TBD-6000		
Extrusion Operator	2965	41863
Rolling Operator	10559	149083
Forging Operator	3497	49374
Machining Operator	16379	231256
Slug Production Operator	592	8358
Scrap Recovery Operator	5051	71315

Five of the six GM values from TBD-6000 are higher than the GM of the Adley distribution. Also, the 95th percentile of the same five samples are also larger than the 95th percentile of the Adley distribution.

Simonds Saw and Steel

Simonds Saw and Steel rolled uranium rods for the AEC. The Health and Safety Lab (HASL) visited the site and took air samples on several occasions. As a result of these, HASL made recommendations for improving control of airborne uranium. The first day samples were take was October 27, 1948. Since these were taken before additional controls were put in place, these samples were used in the Bethlehem Steel TBD. An analysis of these samples found they fit a lognormal distribution with a GM of 1177 dpm/m^3 and a GSD of 8.36 which correlated to a 95th percentile of 38,754 dpm/m^3. Putting this in the same units as above, the GM is 3487 pCi/day and the 95th percentile is 114,783 pCi/day. Comparing this to the Rolling Operator values in the

TBD-6000 shows both the GM and the 95th percentile intake rates in TBD-6000 are higher than that derived from Simonds Saw and Steel data.

Reference

Adley, F.E., Gill, W.E., Scott, R.H., *Study of Atmospheric Contamination in the Melt Plant Building*, USAEC report HW-233352(Rev.), April 4, 1952.

Oak Ridge Associated Universities, *Site Profile for Simonds Saw and Steel*, ORAUT-TKBS-0032 Rev. 00 PC-1, July, 8, 2005.

ATTACHMENT 3: SC&A COMMENTS ON ATTACHMENT 2

SC&A REVIEW of NIOSH BATTELLE-TBD-6000 ISSUE 4 WHITE PAPER
October 13, 2009

SC&A conducted a brief review of the NIOSH Issue 4 White Paper dated October 9, 2009. During its review SC&A, spot checked various calculations in the Issue 4 paper and concurred with the results presented.

In the Issue 4 Paper, NIOSH stated that "The values in Adley have no distribution listed so a comparison is difficult." Actually, Adley et al. (1952) provide results of multiple air samples for various operations involving nine different job titles. However, it is not clear from Adley how the average concentrations reported in Table IX of that report were obtained from the individual measurements reported elsewhere in Tables II through VIII.

Consider, for example, the saw room operator, who is assigned an exposure of 11,574 pCi/calendar-day in the Issue 4 Paper. This is based on a weighted daily exposure of 2,233 × 10-^{5} µg-hr/cc from Table IX in Adley et al. 1952. As shown in Table 1 below, the average concentrations reported in Table IX (column 3) often do not agree with the averages of the actual measurements calculated in column 6. We do not know why the results are different. The calculated averages from the individual measurements (column 6) are generally higher than the average values from Table IX of Adley (column 3). Using the averages of the individual measurement would increase the weighted daily exposure from 2,223 × 10^{-5} µg-hr/cc to 4,115 × 10^{-5} µg-hr/cc.

Table 1. Weighted Daily Exposures to Saw Room Operator

Operation	Daily Time for Operation (hr)	Average Concentration per Adley Table IX (10^{-5} µg/cc)	Number of measurements	Measurements per Adley Table III (10^{-5} µg/cc)	Calculated Average from Column 5 (10^{-5} µg/cc)	Weighted Daily Exposure (10^{-5} µg-hr/cc)
stripping billets	0.4	19.1	4	0.9, 15, 22, 43	20.2	7.6
sawing	3.0	67	7	87, 92, 12, 59, 286, 154, 122	116	201
lathing	0.2	37	5	442, 27, 4.3 97, 20	118	7.4
grinding	0.3	5450	2	23,800, 55	11,928	1635
sweeping	0.1	86	1	86	86	8.6
miscellaneous	3.5	4.0	5	5.3, 0.4, 127, 10, 18	32.1	14
furnace room help	0.5	717	6	147, 85, 58, 62, 79, 6.2 (Adley Table II)	72.9	359

Use of the averages of the individual measurements results in higher exposures than the averages cited by Adley et al. in Table IX. However, as shown in the Issue 4 Paper, the results from

Adley et al. based on Table IX are generally lower than those in TBD-6000. Consequently, use of the higher exposure values based on averages of the actual measurements is not inconsistent with those presented in TBD-6000.

Reference

Adley, F.E., Gill, W.E., Scott, R.H., *Study of Atmospheric Contamination in the Melt Plant Building*, USAEC report HW-233352(Rev.), April 4, 1952.

ATTACHMENT 4: NIOSH COMMENTS ON ISSUE 5

BATTELLE-TBD-6000 ISSUE 5 WHITE PAPER
Comparison to Adley Contamination Data
Prepared by Dave Allen, OCAS
October 9, 2009

Issue 5 of the SC&A review of TBD-6000 recommended considering the surface contamination levels reported in the report by Adley et al. (1952) as well as the Simonds Saw and Steel TBD. SC&A's comment questioned the appropriateness of using a 0.00075 m/s settling rate, as well as the use of 7 days deposition time. This white paper provides a review of the data in Adley and Simonds Saw with regard to these issues.

Review of Adley Data

In the study reported in Adley, settling plates were placed in 13 locations throughout the Melt Plant building at Hanford. Uranium settling out of the air was allowed to accumulate for 158 days during the winter. The plates were removed for analysis and replaced with more plates for an additional 117 days during the spring. The winter period represented a time when the doors were kept closed, while the spring period represented a time when the doors were generally left open. The total uranium content of each plate was divided by the area of the plate and the number of days it was exposed to determine a settling rate in mg of uranium per square foot per day.

Four plates from the spring time period were lost due to breakage or other accidental causes. This left 9 plates that were in place during both winter and spring months. Table XIII of the report provides the results for the winter and spring settling samples. Six of the nine samples are higher for the 117 days than the 158 days but generally within a factor of 2. This indicates little difference between the 158 day exposure and the 117 day exposure, which implies a buildup period ends before 117 days even without some of the typical removal factors (foot traffic, house cleaning, etc.).

The lowest settling rate determined in Adley was 0.21 mg/ft^2/day recorded in an office area. The highest rate (5.72 mg/ft^2/day) was recorded in the Burnout Room. The burnout room appears to be one of the higher airborne areas in the facility while the office area is likely one of the lowest. This implies that the amount of contamination settling on the plates is generally correlated with airborne levels.

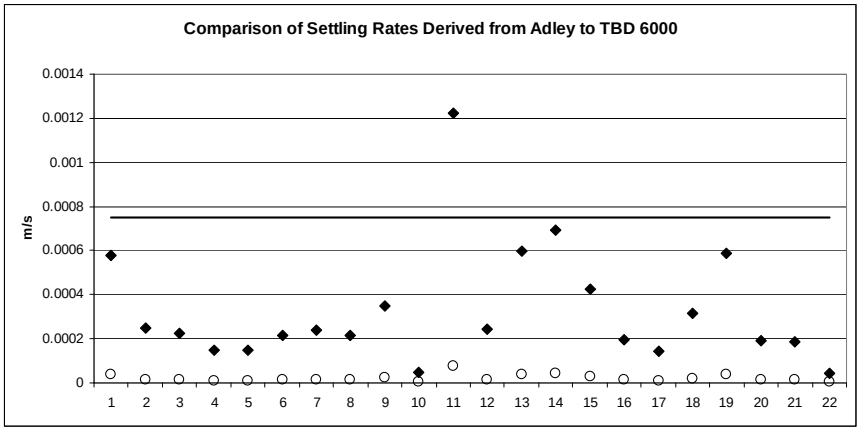
Adley Settling Rate

Adley recorded settling rates in units of mg/ft^2/day. In order to determine a settling rate that can be compared to the 0.00075 m/s rate used in TBD-6000, it is necessary to know the airborne activity. It is difficult to use Adley for this purpose for two reasons. First, Adley measured airborne activity for the purpose of determining exposure to various operators in the facility. This means that the airborne levels during the various tasks were determined but no airborne

concentrations were measured at other times. This is a problem because the settling plates would be collecting uranium at all times whether or not an operation was occurring in the vicinity. This can be illustrated by reviewing the airborne concentrations during the highest two operations in Table IX of Adley. These are grinding in the saw room and loading and unloading oxide furnace trays. These operations occurred for 18 minutes and 30 minutes per day respectively. Even though air concentrations were high during these short evolutions, this airborne activity would contribute to the settling plates for only a limited time.

The use of daily time-weighted exposures can help to resove this issue by accounting for the amount of time the airborne generating operation occured. This, however, creates a second problem, which is that daily time-weighted airborne exposures are based on the operator rather than the areas. Some operators were required to move about the facility throughout the course of the day, so these values are not strictly associated with a specific area. However, much of the equipment in this building was located in an open area (the Main Bay) and 9 of the 13 settling plate locations were in this bay. Also, for the spring measurements, Adley reported that the doors were generally left open. These factors would likely cause a general mixing throughout the building and, therefore, the average air activity in the building was likely affected by all tasks in the building.

To compare settling rates from Adley with those from TBD-6000, the distribution of time-weighted air exposures from Adley was used. The distribution, which was determined in the white paper written for issue 4, was lognormally distributed with a geometric mean (GM) intake rate of 2420 pCi/day and a geometric standard deviation (GSD) of 5.3. The corresponding value, when converted mass, results in a value for the GM of 584 ug/m^3 with a 95th percentile concentration of 9076 ug/m^3. The settling rates from Adley, reported in units of mg/ft^2/day, were converted to ug/m^2/day. These values were then divided by 584 ug/m^3 (the geometric mean of the time-weighted distribution) to determine the settling rates. This value was then converted to m/s so that it could be compared to the value used in TBD-6000. The derived values, represented by diamonds, are shown in the Figure 1 below. A horizontal line is drawn at 0.00075 m/s to show the value used in TBD-6000. The circles represent the same derived values, if the 95th percentile value of the airborne activity is used.



The median value of these settling rates (determined using the Excel "median" function) is 0.00023 m/s.

Contamination Levels – Adley

The settling rate derived above appears to indicate the 0.00075 m/s used in TBD-6000 is a reasonable value. However, contamination levels are determined by the combination of the settling rate and the deposition time.

In Adley, plates were placed for 117 day and 158 days and a settling rate determined by dividing the uranium content by these times. It is therefore a simple matter to determine the actual contamination level on the plates at the end of the settling period. It is also a simple matter to use the airborne exposure values from TBD-6000 to determine the contamination levels associated with the operations (assuming a 7 day deposition and a 0.00075 m/s deposition rate). This analysis was done for both sets of data and lognormal distribution parameters determined for each. The median value for the TBD-6000 derived contamination levels was 3.8 times lower than the contamination levels derived from Adley. A GSD of 5 is applied to the external doses in TBD-6000 therefore this was used to determine a 95th percentile value for the TBD-6000 contamination levels. When compared to the 95th percentile determined from the Adley distribution, it was determined that the Adley values are 1.01 times higher.

Contamination Levels - Simonds Saw and Steel

The SC&A review of TBD-6000 recommended considering values from the Simonds Saw and Steel TBD. During the Working Group meeting on March 11, 2009, twenty film badges that were hung in the Simonds Saw plant were mentioned. The Simonds Saw TBD discusses these badges and indicates that when they were collected they were heavily contaminated. While the radiation dose measured with these badges would include radiation from the contamination, they would also include direct radiation from uranium metal in the facility. There are surface contamination surveys of the Simonds Saw and Steel plant that would be much more appropriate to consider. The Health and Safety lab performed direct measurement contamination surveys at the plant on October 27, 1948 and December 1, 1948 during rolling operations. This is prior to instituting controls recommended by HASL.

The measurements were converted to units of ug/m^2 and the parameters of a lognormal distribution determined from the set of data. When compared to the GM of the TBD-6000 data, it was found that the TBD-6000 data was 2.2 times lower than the Simonds Saw data. A comparison of the 95th percentile values indicates the Simonds Saw data was 82% that of the TBD-6000 values.

Conclusions

TBD-6000 used a 7 day deposition period when determining the surface contamination for external dose from surface contamination. However, section 7.1.5 of TBD-6000 indicates that for the purposes of airborne activity from resuspended surface contamination, a deposition period of one year was used. If the 0.00075 m/s settling rate is used, the necessary deposition time to match the Adley data would be either 27 day or 7.1 days based on the median and 95th

percentile values respectively. The deposition time necessary based on the Simonds Saw data would be 15 day or 5.8 days.

The highest external dose rate from surface contamination in Table 6.4 of TBD-6000 is 0.009177 mr/day. The external dose rate from the uranium metal for the same task is 6.84 mr/day. Therefore, the dose from surface contamination is 0.13% that of the dose from metal. The 3.8 factor derived from the Adley median value increases this to 0.52% while the 95th percentile increases it to 0.14%. If the Simonds Saw values are used, the external dose from surface contamination would became 0.29% or 0.11% of the dose from uranium metal based on the GM and 95th percentile values, respectively.

Reference

Adley, F.E., Gill, W.E., Scott, R.H., *Study of Atmospheric Contamination in the Melt Plant Building*, USAEC report HW-233352(Rev.), April 4, 1952.

Oak Ridge Associated Universities, *Site Profile for Simonds Saw and Steel*, ORAUT-TKBS-0032 Rev. 00 PC-1, July, 8, 2005.

ATTACHMENT 5: SC&A COMMENTS ON ATTACHMENT 4

SC&A Review of NIOSH Issue 5 White Paper
October 13, 2009

This memorandum summarizes SC&A's preliminary review of the NIOSH Issue 5 White Paper dated October 9, 2009.

Use of Adley et al. 1952 to Estimate External Exposures from Contaminated Surfaces.

Per Table 6.4 of TBD-6000, the geometric mean external exposure from contaminated floor surface for an operator working in scrap recovery (prior to 12/31/1950) is 2.83E-03 mR/day. (For perspective, exposures to other operators range from 3.31E-04 for slug production to 9.18E-03 for machining). Per Table 3.10 of TBD-6000, the conversion factor for surface contamination is 4.49E-09 mR/d per dpm/m^2.

Adley et al. (1952, Table XIII) cite measured uranium settling rates for winter and spring samples. The median (geometric mean) value for the winter samples is 1.01 mg U/ft^2/day and for the spring samples is 1.11 mg U/ft^2/day. The winter sampling period was 158 days while the spring sampling period was 117 days. The settling rates in Table XIII are based on the assumption that deposition occurs linearly with time. There is no information in Adley et al. 1952 to support the validity of this assumption. An alternate hypothesis, also unsubstantiated in Adley et al. is that the settling rates are based on a deposition/re-suspension equilibrium where the total quantity of uranium deposited (per unit area) is no longer changing. The total uranium deposited is an experimentally measured quantity with quantifiable uncertainty and can be used as a bounding quantity under the equilibrium assumption.

Based on the above data, the total U deposition for the winter samples is 160 mg/ft^2 and for the spring samples is 130 mg/ft^2. Using the winter sample data and assuming that the specific activity of natural uranium is 6.77E+05 pCi/g, the equivalent surface concentration is 2.83E+06 dpm/m^2 (160 mg/ft^2 × 1 g/1000 mg × 1 ft^2/0.085 m^2 × 6.77E+05 pCi/g × 2.22 dpm/pCi).

Using the dose conversion factor noted above the bounding exposure is 12.7E-03 mR/day (4.49E-09 mR/day per dpm/m^2 × 2.83E+06 dpm/m^2). The exposure value is about 4.5 times higher than the value estimated in TBD-6000. If instead, one had assumed that the operations documented in Adley et.al 1952 were more akin to machining (which was certainly part of the operation) than the difference would be reduced to a factor of 1.4.

Based on this analysis, it appears that the surface concentrations measured by Adley et al. (1952) result is similar, but slightly higher, exposure estimates to those based on TBD-6000.

Note: According to TBD-6000, Section 6.1.3, the deposition period assumed calculating surface exposure is 7 days, and the air concentration experienced by a scrap recovery operator is 1690 dpm/m^3 (TBD-6000, Table 7.7). On this basis, the surface contamination is 7.67E+05

dpm/m^2 (1690 dpm/m^3 × 0.00075 m/s × 604,800 sec). Alternatively, the surface contamination can be calculated based on the exposure of 2.83E-03 mR /day from TBD-6000, Table 6.4 and the surface contamination conversion factor of 4.49E-09 mR/day per dpm/m^2 from Table 3.10 of TBD-6000 which results in a value of 6.3E+06 dpm/m^2. It is not known why the two calculations of surface contamination differ by about 20%. They should be identical.

Other Comments on Issue 5 Paper

In the section entitled **Contamination Levels – Adley**, NIOSH states that "This analysis was done for both sets of data and lognormal distribution parameters determined for each. The median value for the TBD-6000 derived contamination levels was 3.8 times lower than the contamination levels derived from Adley." It is not clear what are the two sets of data to which NIOSH refers. This section requires some elaboration as to the data sets used and the nature of the calculations. Since NIOSH notes earlier in the Issue 5 paper that the median deposition velocity based on Adley et al. is lower than that used in TBD-6000 (i.e, 0.00023 vs. 0.00075 m/s), it would seem that the contamination level based on Adley would also be lower.

ATTACHMENT 6: NIOSH ISSUE 1 WHITE PAPER

BATTELLE-TBD-6000 ISSUE 1 WHITE PAPER
Consideration of Recasting Increasing Progeny Concentration
Prepared by Dave Allen, OCAS
December 10, 2009

Background
Issue 1 of the SC&A review of TBD-6000 indicated that the TBD would benefit from a discussion of the possibility that recasting of uranium metal raises the concentration of Th-234 and Pa-234m close to the surface of the ingots. SC&A referred to Putzier in describing this phenomenon. NIOSH responded in agreement that the TBD would benefit from the discussion. During the October 14, 2009 meeting of the Working Group, it was clarified that SC&A felt the issue was more than simply adding a discussion to the TBD. SC&A felt the phenomenon could cause shallow doses in TBD-6000 to be as much as a factor of ten higher. This white paper explores this issue by comparing the TBD-6000 values with the shallow dose at another facility that recast uranium.

TBD-6000
TBD-6000 provides deep and shallow dose rates for various uranium metal production tasks. The values are provided in Table 6.4 which indicates a deep dose rate of 5.7 mrem per calendar day and a shallow dose rate of 57 mrem per calendar day for a 2000 hour work year. These dose rates are the geometric mean of a lognormal distribution that has a geometric standard deviation of five.

Fernald Data
Dosimeter data from the Fernald plant will be used for the comparison in this white paper. Fernald performed various tasks with several chemical forms of uranium. One of those tasks involved re-melting uranium metal and casting it into molds. The data set consists of annual doses from each employee between 1952 and 2006. A total of 124,113 individual annual doses were reviewed.

Analysis
Since the Fernald data includes operations other than recasting, a distribution of the shallow dose could be reduced by these other operations. Therefore, the maximum doses were compared to the 95th percentile of the TBD-6000 distribution.

The results of these analyses are shown in the Table. The TBD-6000 doses were converted to annual doses. Both the maximum deep and the maximum shallow dose at Fernald are provided in the Table. These represent the maximum from any employee for any year. They are not from the same employee or the same year.

Annual Dose in Rem

	Deep	Shallow
TBD-6000 – 95th	29.375	293.747
Fernald – max	12.300	52.000

Conclusion

The TBD-6000 doses at the 95th percentile exceed the maximum doses recorded at Fernald. While the phenomenon of increased shallow dose rates in recasting areas is well known, it appears other favorable assumptions in TBD-6000 account for this.

Reference

Putzier, E. A. 1982. "The Past 30 Years at Rocky Flats: A Summary of Experiences and Observations at Rocky Flats Plant Over the Past 30 Years with Emphasis on Health and Safety."

ATTACHMENT 7: SC&A WHITE PAPER – REVIEW OF NIOSH ISSUE 1 WHITE PAPER DATED DECEMBER 10, 2009

The version of the report attached here has been reviewed for Privacy Act-protected information and redacted accordingly. This PA-Cleared version was provided to the Work Group on January 14, 2010.

DRAFT WHITE PAPER

REVIEW OF NIOSH ISSUE 1 WHITE PAPER DATED DECEMBER 10, 2009

Contract Number 200-2009-28555

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December 2009

Disclaimer

In its review of Battelle-TBD-6000 (subsequently referred to here as TBD-6000), one of SC&A's findings was as follows (SC&A 2007):

(1) *The TBD would benefit from a discussion of the possibility and potential dosimetric significance of uranium metal-working operations involving freshly cast uranium ingots, where there might be elevated levels of Th-234 and Pa-234m close to the surface of the ingot. Furthermore, it is not clear from the TBD whether scrap recovery at any of the covered AWE sites involved melting and casting of uranium. This should be investigated, since it could make a significant difference in the external dose reconstruction protocol.*

NIOSH responded to this finding in *BATTELLE-TBD-6000 ISSUE 1 WHITE PAPER: Consideration of Recasting Increasing Progeny Concentration,* December 10, 2009 (see Appendix A). During the Work Group meeting held on December 16, 2009, there was extensive discussion regarding the degree to which the annual external exposure distributions adopted as default values in TBD-6000 capture the effect of elevated surface levels of Th-234 and Pa-234m. We also discussed whether, and the degree to which, these elevated levels of surface activity actually occurred at many facilities. This report is provided in response to NIOSH's white paper on this subject, as requested by the TBD-6000 Work Group at its December 16, 2009, meeting.

The discussion presented here is focused on TBD-6000 guidance for uranium fabrication operations. Elevated surface levels of Th-234 and Pa-234m also occurred in some of the uranium refining operations covered in TBD-6001. A different methodology for estimating doses is used in TBD-6000 than is used in TBD-6001. In its review of TBD-6001, SC&A described concerns related to external dose reconstruction used in that document (SC&A 2008). These should be addressed when that review is considered by the Work Group. However, we have provided a brief note at the end of this review comparing, but not reconciling, some of the guidance in TBD-6000 and TBD-6001.

Background

The concern about high beta radiation levels associated with the melting and casting of uranium was based in part on a document authored by Edward Putzier (1982), formerly Health Sciences manager at the Rocky Flats Plant, who observed that the surface beta dose from as-cast uranium ingots was about an order of magnitude greater than from a clean uranium surface in equilibrium with Th-234 and Pa-234m daughters. For convenience, this phenomenon will be referred to as the Putzier effect. As quoted by Putzier (1982):

> *In the earlier years in handling large quantities of depleted uranium, and to some extent this is true in more recent years, we did have a significant beta radiation control problem in Building 444. This was not experienced so much in the machining areas but in the part of the foundry operations we called burnout and breakout. Castings were removed by breaking them out of the molds. This operation and the recovery of the material from the casting and handling the molds themselves resulted in very high beta radiation levels. There was an extremely high level of beta radiation associated with this because the first two*

> *daughters of ^{238}U are beta emitters and during the molten state of the uranium there is a tendency for these two daughters to flow to the top and also to show up at the interface of the uranium and the mold itself thereby enhancing the amount of beta radiation coming off from the chunk of the material. We used to use as a rule of thumb that clean uranium metal in equilibrium with at least its first two daughters would give off on the order of 200 mrad per hour beta radiation at the surface of a piece of the metal. This went up by at least an order of magnitude and probably more than that. We can say that we saw readings as high as 2000 to 3000 mrad/hr on castings of depleted uranium that were in the foundry area. Then, too, the dusts which were generated in the burnout and breakout process settled on various pieces of equipment and from that there were additional beta radiation fields generated.*

The phenomenon was not unique to Rocky Flats operations. Evidence of high surface concentrations of beta emitters has been observed on equipment used in uranium casting operations at Electro-Met and MCW (AEC 1949b, p. 51, 58; ORAUT 2005a). For example, at MCW, it was noted that (ORAUT 2005a, p. 86):

> *Second, in the vacuum recasting of the uranium metal, impurities in the metal volatilized and condensed on the cooler portions of the furnace, creating spot deposits (AEC 1949b; Eisenbud 1975). The impurities contained Th-234 and Pa-234, which were concentrated to a significant degree in the deposits (AEC 1949b; Eisenbud 1975); this deposit residue could have "up to 1000 times the beta activity of natural uranium" (AEC 1949b). Manual contact with these deposits during charging, discharging, cleaning, and repair of the furnaces provided "opportunity for hand irradiation of a greater magnitude than whole body" (AEC 1949b), possibly as much as 2–3 rads/week to exposed skin and perhaps to the eyes when the original ore was pitchblende at 25% average enrichment (Eisenbud 1975). Mallinckrodt (MCW 1949a) observed that 25% of Plant 4 workers received over 500 mrep/week beta and 3–6 workers per week received 2000 mrep or more; AEC (1949g) also observed that the beta values (on film badges) from Plant 4 consistently ranged up to 2.7 rep/week.*

Similarly, the authors of AEC 1949b state the following:

> *A similar separation occurs in the processes at Mallinckrodt Chemical Works Plant 4 and Electro Metallurgical Company. In these plants, uranium metal, with UX_1-UX_2 in approximate equilibrium, is purified by vacuum recasting at a temperature which volatilizes various impurities in the metal, including the UX_1-UX_2. These impurities condense on the cooler surfaces of the furnace interior and this deposit is the source of intense beta exposure during charging, discharging, cleaning and repair of the furnaces.*

Both of these later sources focus on build-up on equipment, rather than on the surface of uranium ingots. Some information on the surface distribution is found in U.S. Statutory Invention

Registration H137, where it is noted that the highest β+γ readings were found on the bottom of the cylindrical casting, where initial solidification occurs. The readings taper off from the bottom to the top of the cylindrical surface, although not in a consistent manner. Radiation readings on the top surface of ingots generally tend to be higher than on upper portions of the cylindrical surface (Briggs et al. 1986). While there is broad evidence for the Putzier effect, the physical mechanisms that underlie the process have not been clearly articulated.

For the Putzier effect to be observed on cast uranium ingots, one of two conditions must exist:

- Either the Th-234 and Pa-234m are not removed from the uranium during refining of the ore to produce metal, allowing the Putzier effect to occur upon the initial vacuum casting of uranium metal

- Or sufficient time has passed after a refining process (i.e., one which successfully removes thorium during the solvent extraction process) to allow in-growth of the short-lived progeny, and then, in subsequent melt-refining steps in the purification process, the Putzier effect occurs

First, let us consider the question of whether or not Th-234 is removed during uranium ore refining. A simplified schematic diagram for uranium ore processing is presented in Figure 1. It should be noted that, after the ore is digested in nitric acid and treated to remove radium, the product liquor is fed to the solvent extraction process. In this process, the uranium containing aqueous product liquor is emulsified with a suitable organic solvent (e.g., ethyl ether or tributyl phosphate in kerosene) in the extraction column. The uranium partitions to the solvent phase and the impurities (such as Th and Pa) are concentrated in the aqueous phase. The immiscible phases are then separated and the aqueous (raffinate) phase with the impurities is treated as a waste stream. The uranium is then stripped from the organic phase and prepared for the next process step. Christofano and Harris (1960) state that, "the material remaining in the aqueous phase contains nitrates of all the undesirable metals including the UX_1 and UX_2 radioactive components." However, Christofano and Harris (1960) do not provide any quantitative information on how effectively Th and Pa are removed from the uranium process stream.

According to the Fernald TBD (ORAUT 2004, p. 71), "Uranium received at the FEMP usually has been through one or more chemical separations at other sites. The separations remove most of the daughter products." Based on these sources, it is reasonable to assume that most, but not all, of the Th-234 and Pa-234m are removed during solvent extraction.

The second necessary condition for the Putzier effect to be observed involves a positive answer to the question, If thorium is quantitatively separated from the uranium during solvent extraction, has sufficient time passed for significant in-growth of Th-234 to have occurred prior to casting of uranium ingots? Th-234 has a 24.1-day half-life, as compared to a 4.47E+09-year half-life for the U-238 parent. Thus, secular equilibrium of Th-234 and U-238 is rapidly approached. Figure 2 shows the build-up of Th-234 in uranium from which all thorium had initially been removed by chemical processing. Th-234 has reached 50% of its equilibrium value after 24 days and 90% after about 80 days.

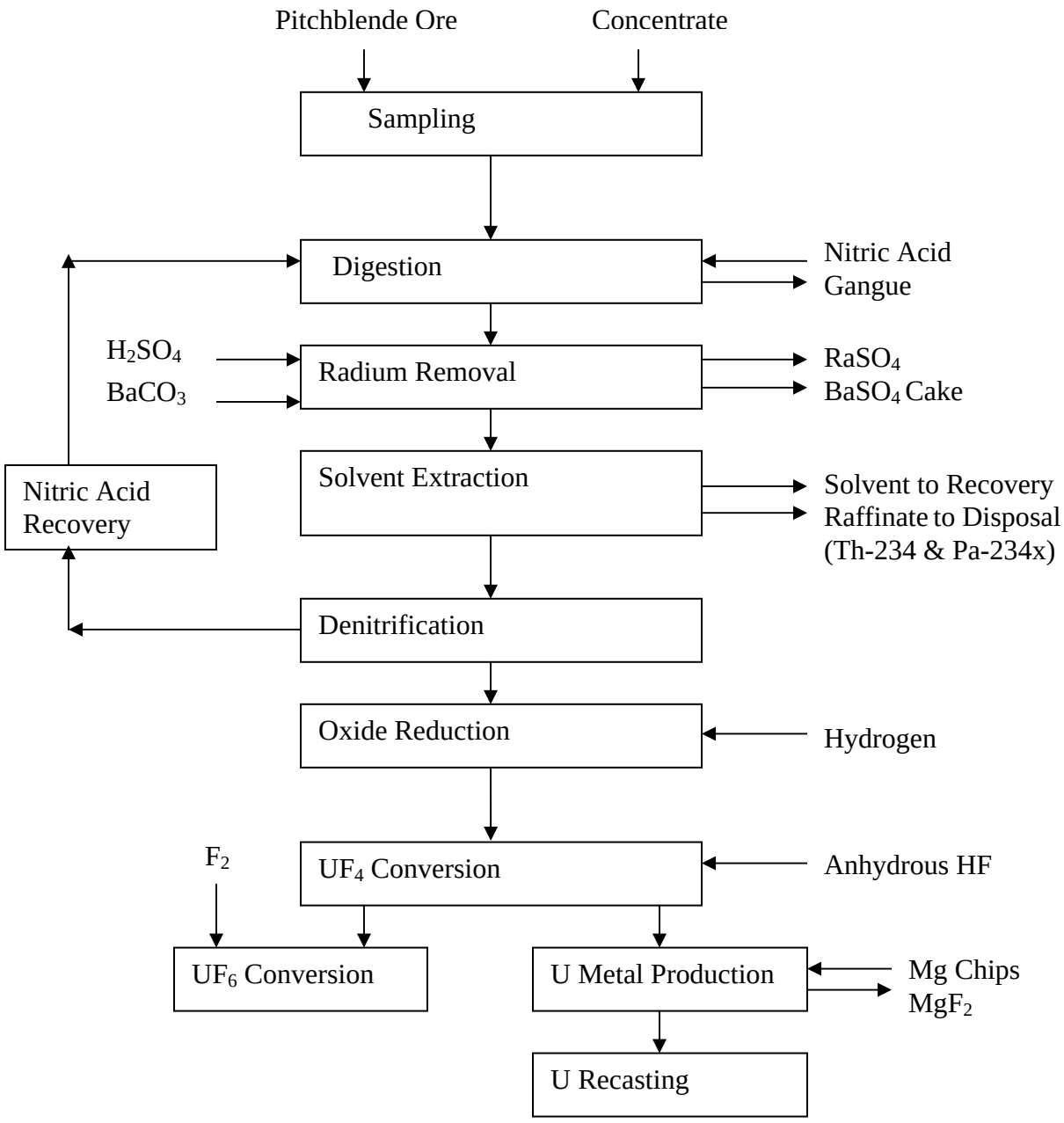

Figure 1. Uranium Refining Flow Diagram
(Based on Christofano and Harris 1960)

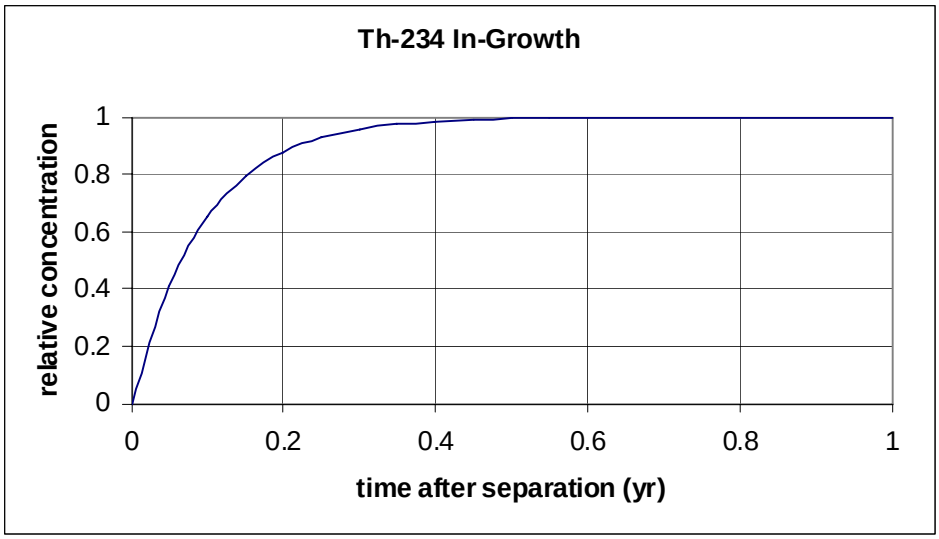

Figure 2. In-Growth of Th-234 into Natural Uranium as a Function of Time after Initial Separation

Assuming that Th-234 is quantitatively removed from uranium during solvent extraction, the question then becomes, what is the elapsed time between completion of solvent extraction and arrival of a uranium billet at a fabricator for rolling, forging, extrusion, etc.? At Atomic Weapons Employer (AWE) sites, many of the unit operations involved in uranium refining were not integrated, but instead were assigned to different facilities. Prior to the start-up of Fernald in late 1951, ore digestion, solvent extraction, denitration, and reduction to brown oxide (UO_2) were performed at MCW in St. Louis, Missouri. The brown oxide was then shipped by rail to Linde in Tonawanda, New York. At Linde, the brown oxide was converted to green salt (UF_4) and shipped by truck to Electro-Met in Niagara Falls, New York. At Electro-Met, the green salt was reduced to uranium metal and cast into billets in vacuum induction furnaces. The billets were then shipped by rail to locations such as Simonds Saw and Steel in Lockport, New York, or Vulcan Crucible Steel in Aliquippa, Pennsylvania, for rolling (AEC 1949b) for fabrication. Thus, the steps required to obtain cast uranium billets suitable for subsequent fabrication involve processing at three locations, one rail shipment, and one truck shipment. It is highly unlikely that this sequence of events could be accomplished in less than 1 month, by which time significant in-growth of uranium daughter would have occurred. Rail shipment to the metal fabricators would involve only decay of surface contamination, not in-growth.

In the context of all metalworking operations examined in TBD-6000 other than scrap remelting, the Putzier effect would be an issue only for those operations where the contamination on the surface of the cast uranium billet was not removed prior to fabrication, or where sufficient time has elapsed after casting for Th-234 on the surface to experience significant radioactive decay. For example, Electro-Met shipped cast billets to Simonds Saw and Steel for rolling (AEC 1949b). There is no evidence that Electro-Met machined the surfaces of the cast billets prior to shipment. Thus, contamination from Th-234 and Pa-243m on the cylindrical surfaces would not have been removed, and workers at Simonds handling the billets could have experienced abnormally high skin doses. However, power hacksaws were used to cut the billets to length at Electro-Met (Dust Sample Results, Nov. 1948–Jan. 1949). During this process, we presume that

the top and perhaps the bottom of the cast billets were removed and scrapped;[1] thus, any excessive surface contamination in those areas would have been removed. If the metal-working operations occurred at least 30 days after casting, the Th-234 on the surface would have decayed to 42% of its initial value.

In the case of scrap recovery, an even longer time would have passed between chemical separation and remelting of the scrap into ingots for refabrication. The resultant ingots would, in all probability, have high surface concentrations of Th-234 and Pa-234m.

In conclusion, it is highly likely that any uranium handled at AWE facilities that worked uranium would have elevated surface concentrations of Th-234 and Pa-234m. Assumptions underlying this conclusion for metal-working operations other than scrap remelting include the following:

- The surfaces of the uranium ingots are not removed by machining prior to shipment to the fabrication shop
- The time between casting of the ingot and fabrication is less than 1 to 2 months

Operators involved in scrap remelting would be highly likely to experience elevated doses from the short-lived uranium progeny.

TBD-6000 Approach to Exposure/Dose Estimation

The approach taken in TBD-6000 to estimate exposure to non-penetrating radiation from uranium surfaces is presented in Section 6.3 of that document. The key assumptions used in calculating operator dose are as follows:

- Workers spend 50% of their time with their hands in contact with a uranium object
- The calculated dose to the skin on the hands and arms from contact with an unshielded slab of uranium metal is 230 mrem/hr (Coleman et al. 1983) which, based on a 40-hr work week, is 630 mrem/calendar-day (0.5 × 230 mrem/hr × 8 hr/work-day × 250 work-days/365 calendar-days)
- The photon dose 1 foot from a uranium slab is 2.08 mrem/hr (Anderson and Hertel 2005)

[1] According to SRDB 8917 (Dust Sample Results, Dec. 1947-May 1948), the saw operator cut a sample from the end of the billet.

- The dose to the skin other than the hands and arms is estimated to be 10 times the photon dose at 1 foot (This factor is apparently based on a review of film badge data in "ORAUT 2005," but we have been unable to trace this assumption to its source.)[2]
- The dose to the skin other than the hands and arms is 57 mrem/calendar-day based on a 40-hour work-week (0.5 × 2.08 mrem/hr × 10 × 8 hr/work-day × 250 work-days/365 calendar-days)
- The estimated non-penetrating doses are assumed to be geometric mean (GM) values with a geometric standard deviation (GSD) of 5

From these data, it can be calculated that the annual exposures to the skin on the hands and arms is 230 rem/yr (230 mrem/hr × 0.5 relative contact time × 2,000 work-hours/yr) and to the skin on other parts of the body is 20.8 rem/yr. The equivalent 95th percentile values are 3,250 rem/yr and 294 rem/yr, respectively. The same doses are assumed to be applicable to all uranium metal-working operations covered in TBD-6000, including extrusion, rolling, forging, slug production, machining, and scrap recovery (e.g., by remelting).

The whole-body dose in Table 6.4 of TBD-6000 is based on the assumption that workers spend half of their time 1 foot from a rectangular uranium ingot. MCNP calculations by Anderson and Hertel (2005) result in a dose of 2.08 mrem/hr, which can be converted to a median annual dose of 2.08 rem/yr or a 95th percentile dose of 29.4 rem/yr.

NIOSH Response

In the Issue I White Paper, NIOSH describes how they used a very large database (HIS-20) consisting of 124,113 annual dose measurements taken at Fernald from 1952 through 2006 (ORAUT 2007b).[3] Work at Fernald covered more operations than were evaluated in TBD-6000 and included other chemical compounds of uranium in addition to uranium metal. Operations at Fernald included uranium melting and casting that can result in increased dose from beta radiation. From this database, NIOSH obtained the maximum annual dose to an individual and compared that maximum dose to the 95th percentile dose based on Table 6.4 of TBD-6000. The comparison is duplicated below as Table 1.

[2] According to the authors of TBD-6000, "For dose to other skin on the worker's body that is not in direct contact with uranium metal, but is nearby (for example, a worker's neck and face when the hands are in contact with metal), a dose relation can be used that estimates this dose to be 10 times the photon dose rate at 1-foot. This relation, based on a review of film badge data, is documented in (ORAUT, 2005)." The citation ORAUT 2005 contains a typographical error that makes traceability of the source of the information difficult. The reference list in TBD-6000 cites five ORAUT 2005 references (ORAUT 2005a, b, c, d, and e). A check of references ORAUTa, b, c and d revealed that ORAUT-2005d (ORAUT-OTIB-0004) makes a similar statement to that quoted above from TBD-6000, but provides no basis for the statement.

[3] While ORAUT 2007b is not specific, we believe that the annual doses in that reference are the summed weekly doses.

Table 1. Annual Dose in Rem - Skin Other than Hands and Arms

	Deep	Shallow
TBD-6000 – 95th	29.375	293.747
Fernald – max	12.300	52.000

From this comparison, it can be seen that the 95th percentile doses calculated from the GM and GSD values in Table 6.4 of TBD-6000 are more limiting than the maximum annual dose actually observed in a large population of film badge measurements at Fernald. Enhanced beta and gamma exposures from melting and casting of uranium are included in the population of Fernald doses from which the maximum value was selected. Since the number of samples collected at Fernald was about 124,000, it is clear that the 95th percentile for that population is subsumed by the recorded maximum. The approach to dose reconstruction developed in TBD-6000 can, in theory, yield more conservative results than those based on actual measurements at Fernald, which SC&A agrees likely included data from operations where Th-234 and Pa-234m were concentrated on uranium surfaces. It should be noted that this comparison applies to the skin other than the hands and arms.

SC&A Comments on NIOSH Response

Another analysis of the Fernald data is provided in ORAUT 2008 (ORAUT-OTIB-0073), which documents 50th percentile and 95th percentile annual coworker doses by year, adjusted for missing doses. The highest reported 95th percentile shallow dose was 9.591 rem for 1963.[4] As expected, this is well below the quoted maximum of 52 rem reported by NIOSH in its white paper. Similarly, the highest reported 95th percentile whole-body dose was 1.769 rem, also for 1963, as compared to a maximum observed deep dose of 12.3 rem. SC&A agrees that the maximum penetrating and non-penetrating doses reported for Fernald workers are substantially higher than the upper 95th percentile of the penetrating and non-penetrating doses observed at Fernald. We also agree that the upper 95th percentile doses provided in TBD-6000 are even higher than the highest penetrating and non-penetrating doses observed at Fernald. Hence, it certainly appears that the upper end of the distribution of the external doses adopted for use in TBD-6000 includes the annual doses to workers that might have experienced the Putzier effect at Fernald.

To broaden the comparison, SC&A examined the external exposure data from the Electro-Met for the period from June 7, 1948, through September 26, 1949 (Dosimetry Results, March 1948 through Jan. 1949, and Dosimetry Results, Jan.–Sep. 1949). Electro-Met cast uranium ingots from remelted uranium derbies and scrap. During this period, about 2,000 weekly film badge measurements were made. The highest annual beta dose was to a [**job category redacted**] who received a dose of 17 rem.[5] This value is below the median value of 20.8 rem, based on Table 6.4 of TBD-6000.

[4] Table 7-1 of ORAUT-OTIB-0073 states that the unit of measure is **rem**. However, David Allen of CDC/NIOSH/OD confirmed in an e-mail dated December 11, 2009, that this was a typographical error and the units should have been reported as **mrem**. The values cited in the text here have been corrected accordingly.

[5] This is based on the sum of 59 weekly measurements made from [**redacted**], 1948, through [**redacted**], 1949, annualized based on a 50-workweek year.

As noted above in the **Background** section, the beta values (on film badges) from Plant 4 at MCW[6] ranged up to 2.7 rep/week. However, it is likely that the weekly exposure of 2.7 rep was not experienced for 50 weeks per year. In support of this assertion, we note in ORAUT 2007a (p. 84) that while two beta exposures at Plant 4 during the period November 1, 1948 through January 24, 1949, were above 1,500 mrep/week, 65% of the weekly measurements were less than 300 mrep/week. From this information, we can make a rough approximation of the maximum annual skin dose – $50 \times (2700 \times 0.04 + 1500 \times 0.31 + 300 \times 0.65) = 38.4$ rep/yr.

The discussion to this point has focused on the dose to the skin other than the hands and arms. The hands and arms dose adopted in TBD-6000 is 630 mrem/calendar-day, or a GM of 230 rem/yr (95^{th} percentile – 3,250 rem/yr). Unlike the shallow dose to the hands and arms, which is based on experimental measurements from a uranium metal source with the radiation attenuated through mylar films, the dose to the skin other than the hands and arms dose is based on MCNP calculations of the photon dose (at 1 foot) from a large uranium metal source and an assumed correlation between photon dose and skin dose derived from film badge studies. We presume that the experimental studies of Coleman et al. (1983) to measure contact doses used uranium samples in which Th-234 and Pa-234m were uniformly distributed throughout the metal mass. Thus, the laboratory measurements would not reflect elevated surface concentrations of the U-238 progeny. While it can be argued that film badge data from Fernald conservatively reflect doses to some areas of the skin, such as the face and neck, care must be taken in extending the argument to doses to the hands and arms, since the dose determined from a film badge suspended from a lapel may not adequately reflect the dose to the hands in direct contact with a radiation source.

NIOSH described modeling results in OCAS 2005 (OCAS-TIB-0013), which developed correlations between film badge exposures and exposures to other body parts. They determined that the hands-to-badge ratio was to 3.65. If one applies this factor to the maximum observed shallow dose at Fernald of 52 rem/yr (see Table 1), the maximum estimated exposure to the hands would be 190 rem/yr. This is below the median value of 230 rem/yr for the hands and arms developed in Table 6.4 of TBD-6000, indicating that values in that table are sufficiently conservative to account for doses to the hands and arms from high surface concentrations of short-lived U-238 progeny.

SC&A concurs with NIOSH that the approach used to develop data for Table 6.4 of TBD-6000 captures exposures from elevated surface concentrations associated with high concentrations of beta-emitting radionuclides. However, SC&A had concerns that the data in TBD-6000 can be used in dose reconstruction in ways that may not be bounding. TBD-6000 does not prescribe how the data are to be used; it only presents the GM and GSD for default external doses to penetrating and non-penetrating radiation. During the Work Group meeting on December 16, 2009, NIOSH explained that since the upper 95^{th} percentile values for external exposures in TBD-6000 include doses that might be associated with the Putzier effect, they plan to simply assign the full distribution to any unmonitored workers, whether or not they experienced the Putzier effect. SC&A expressed concern that if there is a reasonable possibility that a given unmonitored worker at an AWE facility had job responsibilities that included regularly working

[6] Uranium casting was done in Plant 4.

with ingots, this approach could underestimate their annual exposure to both penetrating and non-penetrating radiation.

We recognize that this concern is perhaps broader than the scope of the question considered in the Issue 1 White Paper; however, we believe that it needs to be explicitly addressed in TBD-6000. Table 2 compares several possible metrics based on TBD-6000 for characterizing the shallow dose exposure with various field studies.

Table 2. Comparison of Various Measures of Skin Dose

Metric for Calculating Shallow Dose	Annual Dose to Hands and Arms (rem)	Annual Dose to Skin ex. Hands and Arms (rem)
TBD-6000 95th percentile	3,250	294
TBD-6000 arithmetic mean	840	76.0
TBD-6000 median	230	20.8
Fernald maximum	190[a]	52
Fernald 95th percentile of highest annual doses (1963)	35.0 [a]	9.59
MCW maximum	140[a]	38.4
Electro-Met maximum	62 [a]	17
Theoretical maximum	3000[b]	

a – Annual dose to the skin other than hands and arms multiplied by factor of 3.65.
b – This is the theoretical maximum dose to skin of the hands and arms of a worker if he spends 1,000 hr/yr handling ingots that have experienced the Putzier effect (i.e., 200 mrem/hr × 15 × 1,000 hrs/yr = 3,000,000 mrem/yr or 3,000 rem/yr). This value is provided solely for comparison to the other values in the table. We are not suggesting that such exposures are plausible.

Considering first the skin dose other than the hands and arms, it can be seen from Table 2 that the TBD-6000 median of 20.8 rem/yr is a factor of 2 higher than the highest annual 95th percentile of the Fernald doses (9.59 rem/yr for 1963), but is lower than the maximum observed dose at Fernald of 52 rem. We believe that this may be the result of a conservative assumption regarding the fraction of time spent in close proximity to uranium objects (i.e., 50%). Based on more limited data, the maximum doses at Electro-Met and MCW are lower than those at Fernald by 26% and 67%, respectively.

While use of the TBD-6000 median for the annual dose to the skin other than the hands and arms generally appears to be claimant favorable, it is not clear whether use of the TBD-6000 median of 20.8 rem/yr is always claimant favorable when tested against the various measures summarized in Table 2. Clearly, the median is less than the Fernald maximum. However, all of the measures are less than the TBD-6000 95th percentile. The question of whether a stochastic distribution based on the GM/GSD of 20.8/5 rem is more or less claimant favorable than the use of a deterministic value set at the 95th percentile of distribution (294 rem) is addressed in the next section.

Turning to the hands and arms, as shown in Table 2, the median dose in TBD-6000 is 230 rem/yr, which is higher than the estimated Fernald maximum of 190 rem/yr. The TBD-6000 95th percentile dose of 3,250 rem/yr is about the same as the theoretical maximum dose (3,000 rem/yr), as described in footnote b of Table 2. Hence, we believe using the full

distribution in TBD-6000 for surface exposures to the hands and arms is claimant favorable and takes into account the possibility of the Putzier effect.

A similar analysis was made for total body dose. The maximum observed weekly gamma exposure at Electro-Met was 690 mr. The annual dose for the [**job category redacted**] who received this high weekly dose was 3.3 R, which is about 27% of the Fernald maximum of 12.3 rem reported in Table 1.[7]

Table 3 presents a comparison of various measures of penetrating doses. As indicated, the median value in TBD-6000 is about 1/15th the maximum theoretical value and is comparable to the highest observed annual 95th percentile value at Fernald. However, it lies well below the Fernald maximum of 12.3 rem.

Table 3. Comparison of Various Measures for Estimating Whole-Body Dose

Metric for Calculating Deep Dose	Annual Whole Body Dose (rem)
TBD-6000 95th percentile	29.375
TBD-6000 arithmetic mean	7.60
TBD-6000 median	2.08
Fernald maximum	12.300
Fernald 95th percentile of highest annual doses (1963)	1.769
Electro-Met maximum	3.3
Theoretical maximum	30[a]

a. This is the theoretical maximum penetrating dose a worker might experience if he spends 1,000 hours per year 1 foot from ingots that have experienced the Putzier effect (i.e., 2 mrem/hr × 15 × 1,000 hrs/yr = 30,000 mrem/yr or 30 rem/yr. This value is provided solely for comparison to the other values in the table. We are not suggesting that such exposures are plausible.

Appropriate Metric to be Used in Dose Reconstruction

As described in Table 1, NIOSH compared the maximum annual external doses observed at Fernald with the 95th percentile doses from TBD-6000. The comparison showed that the observed maximum annual doses were lower than the 95th percentile doses in TBD-6000. Consequently, use of the 95th percentile doses appeared to be claimant favorable. However, it is implicit in the TBD-6000 guidance that the dose reconstructor should use the full distribution based on the GM and GSD to estimate doses. At the December 16, 2009, Work Group meeting, NIOSH expressed the opinion that use of the GM/GSD approach could be more conservative than use of the 95th percentile (or some other deterministic metric) in determining probability of causation (POC) of a radiation-related cancer. A worker is entitled to compensation under EEOICPA if there is a 50% or greater probability at the upper 99% confidence interval that his exposure to radiation while working on atomic weapons caused his cancer (42 CFR 81). Because the POC uses the 99% upper confidence interval to assess whether the 50% probability threshold is attained, NIOSH believed that the stochastic approach with a high GSD could be more conservative. SC&A was not convinced. The Work Group requested that SC&A make

[7] For purposes of this report, we assume that exposure to 1 R of gamma radiation results in a dose equivalent of 1 rem.

some hypothetical POC calculations to clarify which approach produced the most claimant-favorable results.

SC&A used IREP to compare POCs for shallow dose and whole-body dose. Assumptions used for the shallow dose calculations included the following:

- Annual dose: stochastic with GM – 20.8 rem/GSD – 5 or deterministic with 95th percentile – 294 rem
- Exposure duration – 1 year (1944)
- White, non-Hispanic male born 1914
- Basal cell cancer diagnosed in 1970

The POC based on the GM/GSD was 82.61%, while the POC based on the 95th percentile was at 89.06%. While the 95th percentile dose resulted in a slightly higher POC than that for GM/GSD, the differences are not relevant, because in either case, the POC is substantially above the 50% probability required for compensation.

A similar comparison was made for whole-body dose based on the following assumptions:

- Annual dose: stochastic with GM – 2.08 rem/GSD – 5 or deterministic with 95th percentile – 29.375 rem
- Exposure duration – 1 year (1944)
- Photon energy: 30–250 keV
- White, non-smoking male born 1914
- Lung cancer diagnosed in 1970

The POC based on the GM/GSD was 48.56%, while the POC based on the 95th percentile dose was at 64.4%. In this hypothetical example, the claimant would not have been compensated based on the full distribution, but would have been compensated if the 95th percentile had been used.

Conclusion

SC&A concurs with the NIOSH position that the Putzier effect can be adequately bounded by the guidance provided in TBD-6000. Although the Putzier effect was not specifically considered in TBD-6000, the assumptions used in that document to develop dose reconstruction parameters for shallow dose (both to the hands and arms, and skin, other) and deep dose are sufficiently conservative to accommodate situations where high surface concentrations are present. This conclusion is specific to sites where uranium ingots were fabricated. Based on actual site measurements, use of the GM and the full distribution should be claimant favorable for those sites.

This conclusion should not be construed as blanket acceptance of the concept that the use of the full distribution is sufficiently claimant favorable under all circumstances. As shown by the hypothetical POC calculations presented here, use of the full distribution may not be bounding when compared with use of the 95th percentile.

Note on TBD-6001

As stated above, this report focuses on TBD-6000. The methodology for determining photon doses relies on MCNP calculations for operators who spend half their time standing near a large uranium slab. Shallow doses to the hands and arms are based on experimental measurements, coupled with the assumption that the operator's hands are in contact with a uranium object for half of the time. Shallow doses to the skin other than the hands and arms are based on the calculated photon dose at 1 foot and the observation from film badge studies that the surface dose is about 10 times the photon dose at 1 foot.

In TBD-6001, on the other hand, dose rates were often obtained from measurements at various work sites (see Table 7.1 of that document). For example, worker exposures from the uranium recasting process were based on measurements made at MCW (ORAUT 2005a). These process-specific dose rates are converted to daily worker dose rates in Table 7.3. Table 4 below compares daily dose rates from TBD-6000 and TBD-6001. The comparison is for operators working 40 hours per week. In each case, the values are the GM with an assumed GSD of 5. The doses are mrem/calendar-day except for the TBD-6001 whole-body dose, which is in units of mR/calendar-day.

Table 4. Comparison of External Dose Rates for Similar Operations Based on TBD-6000 and TBD-6001 (mrem/calendar-day)

Source	Operation	Whole-Body Dose	Hands & Arms Dose (non-penetrating)	Other Skin Dose (non-penetrating)
TBD-6000, Table 6.4	Scrap Recovery	5.70	630	57
TBD-6001, Table 7.3	Recasting	816 (mr/calendar-day)	30.3	842

From this table, it is clear that use of the two guidance documents provides very dissimilar results when addressing operations where the Putzier effect is involved. Detailed reconciliation of the differences is beyond the scope of this analysis. In its review of TBD-6001, SC&A expressed concerns about the lack of transparency in NIOSH's development of Table 7.3 summarizing external occupational doses (SC&A 2008).

References

42 CFR 81, 2002. *Guidelines for Determining the Probability of Causation Under the Energy Employees Occupational Illness Compensation Program Act of 2000;* Final Rule, Federal Register/Vol. 67, No. 85/Thursday, p 22,296; May 2, 2002; SRDB Ref ID: 19391.

AEC (Atomic Energy Commission) 1949b. *Health Hazards in NYOO Facilities Producing and Processing Uranium*. Report by the New York Operations Office Medical Division. April 18, 1949.

AEC (Atomic Energy Commission) 1949g. No subject. Letter to K.J. Caplan of Mallinckrodt Chemical Works from A.R. Piccot of AEC. June 29, 1949.

Anderson, J.L. and N.E. Hertel, 2005. *Bremsstrahlung Doses from Natural Uranium Ingots.* Radiation Protection Dosimetry, Vol. 115, No. 1–4, pp. 298–301.

Battelle-TBD-6000. *Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals*. Rev. F0. Battelle Team. Effective date: December 13, 2006.

Battelle-TBD-6001. *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium Metals*. Rev. F0. Battelle Team. Effective date: December 12, 2006.

Briggs, G.G., T.R. Kato, and E. Schoenegg, 1986. *Process for Reducing Beta Activity in Uranium.* United States Statutory Invention Registration, Reg. Number H137. October 7, 1986.

Christofano E. and W.B. Harris, 1960. *The Industrial Hygiene of Uranium Refining*. Env Health 1(5):74-96.

Coleman, R. L., Hudson, C. G., and Plato, P. A., 1983. "Depth-dose curves for ^{90}Sr and natural and depleted uranium in mylar," Health Physics, 44(4): 395-402. SRDB Ref. ID: 12288.

Dosimetry Results, March 1948–Jan. 1949. *Dosimetry Results for Electro-Metallurgical Employees from March 15, 1948 through January 24, 1949.* SRDB Ref ID: 11547.

Dosimetry Results, Jan.–Sep. 1949. *Dosimetry Results for Electro-Metallurgical Employees from January 3, 1949 through September 26, 1949*; SRDB Ref ID: 11548.

Dust Sample Results, Nov. 1948–Jan. 1949. *Dust Sample Results from November 3, 1948 through January 12, 1949*, includes Job Analysis Sheets; SRDB Ref ID: 8912.

Dust Sample Results, Dec. 1947–May 1948. *Dust Hazard Reports with Dust Sample Results for December 24, 1947, March 30, 1948, and May 14, 1948*; SRDB Ref ID: 8917.

Eisenbud M., 1975. "Early Occupational Exposure Experience with Uranium Processing." In: *Occupational Health Experience with Uranium*, Proceedings of a United States Atomic Energy Commission conference. Arlington, Virginia. ERDA-93; 1975: 9-24.

MCW (Mallinckrodt Chemical Works) 1949a. *Beta Radiation – Metal Plant*. Letter to B.S. Wolf of AEC from H.E. Thayer of Mallinckrodt Chemical Works. February 9, 1949.

ORAUT (Oak Ridge Associated Universities Team) 2004. *Technical Basis Document for the Fernald Environmental Management Project (FEMP) – Site Description*, Rev. 00, ORAUT-TKBS-0017-2. Effective Date May 20, 2004.

OCAS (NIOSH Office of Compensation and Support) 2005. *Special External Dose Reconstruction Considerations for Mallinckrodt Workers,* OCAS-TIB-0013, Rev. 0. National Institute for Occupational Safety and Health. Effective Date: November 26, 2005.

ORAUT (Oak Ridge Associated Universities Team) 2005a. *Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St. Louis Downtown Site and the St Louis Airport Site, St. Louis, Missouri, Period of Operation: 1942–1958*. ORAUT-TKBS-0005, Rev. 01. Effective Date: March 10, 2005.

ORAUT (Oak Ridge Associated Universities Team) 2005d. *Estimating the Maximum Plausible Dose to Workers at Atomic Weapons Employer Facilities,* ORAUT-OTIB-0004. Rev. 03 PC-2. Effective Date: August 12, 2005.

ORAUT (Oak Ridge Associated Universities Team) 2007a. *Basis for Development of an Exposure Matrix for the Mallinckrodt Chemical Company St Louis Downtown Site and St. Louis Airport Site, St Louis, Missouri,* ORAUT-TKBS-0005, Rev. 02. Effective Date: June 14, 2007.

ORAUT (Oak Ridge Associated Universities Team) 2007b. Fernald HIS-20 Health Physics database export; Microsoft Access database format; provided to ORAUT 2007. Available at: Abrwh on 'Sqp-cinc-ocas\Ocas' O:\AB Document Review\Fernald.

ORAUT (Oak Ridge Associated Universities Team) 2008. *External Coworker Dosimetry Data for the Fernald Environmental Management Project,* ORAUT-OTIB-0073, Rev. 00. September 22, 2008.

Putzier, E.A., 1982. *The Past Thirty Years at Rocky Flats Plant*, Rocky Flats Plant, Golden, Colorado. November 1982.

SC&A 2007. *Draft Review of Battelle-TBD-6000, Site Profiles for Atomic Weapons Employers that Worked Uranium and Thorium Metals*. Contract No. 200-2004-03805, Task Order No. 3. SC&A, Inc., Vienna, Virginia, and Saliant, Inc., Jefferson, Maryland.

SC&A 2008. *Draft Review of Battelle-TBD-6001, Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium Metals, Revision FO dated December 13, 2006*. Contract No. 200-2004-03805, Task Order No. 1, SCA-TR-TASK1-0026. SC&A, Inc., Vienna, Virginia, and Saliant, Inc., Jefferson, Maryland. February 2008.

APPENDIX A

BATTELLE-TBD-6000 ISSUE 1 WHITE PAPER
Consideration of Recasting Increasing Progeny Concentration
Prepared by Dave Allen, OCAS
December 10, 2009

Background

Issue 1 of the SC&A review of TBD-6000 indicated that the TBD would benefit from a discussion of the possibility that recasting of uranium metal raises the concentration of Th-234 and Pa-234m close to the surface of the ingots. SC&A referred to Putzier in describing this phenomenon. NIOSH responded in agreement that the TBD would benefit from the discussion. During the October 14, 2009 meeting of the Working Group, it was clarified that SC&A felt the issue was more than simply adding a discussion to the TBD. SC&A felt the phenomenon could cause shallow doses in TBD-6000 to be as much as a factor of ten higher. This white paper explores this issue by comparing the TBD-6000 values with the shallow dose at another facility that recast uranium.

TBD-6000

TBD-6000 provides deep and shallow dose rates for various uranium metal production tasks. The values are provided in Table 6.4 which indicates a deep dose rate of 5.7 mrem per calendar day and a shallow dose rate of 57 mrem per calendar day for a 2000 hour work year. These dose rates are the geometric mean of a lognormal distribution that has a geometric standard deviation of five.

Fernald Data

Dosimeter data from the Fernald plant will be used for the comparison in this white paper. Fernald performed various tasks with several chemical forms of uranium. One of those tasks involved re-melting uranium metal and casting it into molds. The data set consists of annual doses from each employee between 1952 and 2006. A total of 124,113 individual annual doses were reviewed.

Analysis

Since the Fernald data includes operations other than recasting, a distribution of the shallow dose could be reduced by these other operations. Therefore, the maximum doses were compared to the 95th percentile of the TBD-6000 distribution.

The results of these analyses are shown in the Table. The TBD-6000 doses were converted to annual doses. Both the maximum deep and the maximum shallow dose at Fernald are provided in the Table. These represent the maximum from any employee for any year. They are not from the same employee or the same year.

Annual Dose in Rem

	Deep	Shallow
TBD-6000 – 95th	29.375	293.747
Fernald – max	12.300	52.000

Conclusion

The TBD-6000 doses at the 95th percentile exceed the maximum doses recorded at Fernald. While the phenomenon of increased shallow dose rates in recasting areas is well known, it appears other favorable assumptions in TBD-6000 account for this.

Reference

Putzier, E. A. 1982. "The Past 30 Years at Rocky Flats: A Summary of Experiences and Observations at Rocky Flats Plant Over the Past 30 Years with Emphasis on Health and Safety."

ATTACHMENT 8: NIOSH WHITE PAPER ON THE PUTZIER EFFECT

The report attached here, *White Paper: TBD-6000 Working Group – Putzier Effect*, dated September 2010, has been reviewed for Privacy Act-protected information and is cleared for distribution to all interested parties.

White Paper

TBD-6000 Working Group - Putzier Effect

David Allen September 2010

During the May 12th 2010 meeting of the TBD-6000 working group, NIOSH agreed to draft language describing the "Putzier Effect" and provide that language to the working group. The language is intended for incorporation into TBD-6000. The language is presented here. The references included here will be added to the reference section of TBD-6000.

The language indicates in part a review of beta to gamma ratios at several plants. The table below supports this review. It is based on dose values contained in an SC&A document titled "Review of NIOSH Issue 1 White Paper Dated December 10, 2009" (SC&A 2009). The ratios were calculated and added here. The hands to whole body ratio is not used in TBD-6000 but it is instructive to review these as well.

	Whole body dose from Table 3 (rem)	Skin dose from Table 2 (rem)	Dose to the Hands and Arms from Table 2 (rem)	Skin to Whole body ratio	Hands to Whole body ratio
TBD-6000 95th percentile	29.375	294	3250	10.01	110.64
TBD-6000 95th arithmetic mean	7.6	76	840	10.00	110.53
TBD-6000 95th median	2.08	20.8	230	10.00	110.58
Fernald maximum	12.3	52	190	4.23	15.45
Fernald 95th percentile of highest annual doses (1963)	1.769	9.59	35	5.42	19.79
MCW maximum		38.4	140		
Electro-Met maximum	3.3	17	62	5.15	18.79
Theoretical maximum	30		3000		100.00

Proposed Language for TBD-6000

When uranium metal is melted, impurities can separate from the metal matrix. Differences in densities and melting points can then cause impurities to separate from the molten uranium metal and

concentrate on the surfaces. The two processes that routinely involve molten uranium metal are the metal reduction process and the remelting process.

The metal reduction process involves mixing uranium tetrafluoride (UF_4) with magnesium chips and loading the mixture into a lined reduction vessel. The sealed vessel is heated to initiate the exothermic reaction. The reaction results in the formation of magnesium fluoride (MgF_2) and free uranium metal. The temperature inside the vessel exceeds the melting point of uranium and, due to the high specific gravity, the uranium collects in the bottom of the vessel forming a "derby". The MgF_2 is collected above the derby as a slag. After it cooled, the derby is "broken out" of the vessel. The MgF_2 slag had to be broken and chipped away to dislodge it from the derby (Chrisofano 1960).

The derby resulting from the reduction step contained impurities that made it unsuitable for reactor fuel. The metal was both purified and altered in shape in the remelt process. In this process, the derbies are melted in a vacuum furnace and molten uranium metal poured into a graphite mold (Chrisofano 1960). The vacuum casting removes volatile contaminants and allows other impurities to float to the surface concentrating impurities near the top. Impurities can also be concentrated where the molten uranium metal cools rapidly preventing (or minimizing) the time necessary for the impurities to separate. This can cause impurities to also concentrate near other surfaces of the casting. The separation can be improved by controlling the cooling of the cast uranium. If the mold is insulated near the top, a steep temperature gradient is formed causing the ingot to solidify from the bottom to the top. This allows impurities to separate and migrate to the top of the ingot without being trapped in solidifying metal. The "hot-top" that is formed is then cut off (cropped) to eliminate the impurities (Fleishman-Hillard 1967).

A third process worth mentioning is the dingot (direct ingot) process developed at Mallinckrodt. That process produced a finish ingot directly in the metal reduction step. This eliminated the remelting step by increasing the size of the metal reduction vessel and carefully controlling the temperature and ingredients. After separation, the dingot was "scalped" by machining all the surfaces (Fleishman-Hillard 1967).

Some of the impurities in the uranium include Th-234 and Pa-234m, decay products of U-238 (as well as residual magnesium, some slag, hydrogen, and others). These isotopes are beta emitters with relatively short half-lives. The process then causes a high concentration of these beta emitters in the top and other surfaces of the cast ingot. This concentration can produce higher than normal beta dose rates that then decay to a normal dose rate with a half-life of 24.1 days.

The concentrating of decay products during the reduction process does not appear to occur. When the uranium metal is first formed in the reduction process, it exists as molten droplets of uranium intermixed with MgF_2, and unreacted UF_4 and magnesium. These droplets of molten uranium settle to the bottom of the reduction vessel. The droplets are small enough that no appreciable separation can occur within the drop. Separation would be possible once the metal collects in the bottom of the vessel. There is some indication that these decay products are actually collected by the MgF_2 before the derby is formed resulting in a decrease in beta radiation levels on the derby (Briggs 1986). Even if separation were to occur in the derby, the solidified MgF_2 has to be broken or chipped away from the derby (Chrisofano 1960). This likely would remove appreciable amounts of any material concentrated in the surface layer.

The concentrated beta emitters near the surface of castings cause elevated beta radiation levels from the uranium casting with little effect on gamma dose rates. This can cause beta to gamma dose rate ratios to be significantly higher than uranium metal in equilibrium with its decay products. This elevated ratio may not be limited to facilities where recasting of uranium metal is performed. Several months are required to the beta radiation levels decrease to normal levels and castings could be shipped to other sites in that time. Film badge readings at various sites indicate those sites engaged in remelting exhibit the highest ratio. The ratio for those sites can approach 10. Therefore, a ratio of 10 is used in this document to account for this affect.

References

Briggs, G.G., T.R. Kato, and E. Schoeneff, 1986. *Process for Reducing Beta Activity in Uranium*. United States Statutory Invention registration, Reg. Number H137. October 7, 1986.

Christofano E. and W. B. Harris, 1960, *The Industrial Hygiene of Uranium Refining*. Env Health 1(5):75-96.

Fleishman-Hillard, 1967, *Fuel For the Atomic Age, Completion Report on St. Louis-Area uranium Processing Operations, 1942-1967*. September 30, 1967.

SC&A (Sanford Cohen & Associates) 2009, *Review of NIOSH Issue 1 White Paper Dated December 10, 2009*, December 2009