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ADVISORY BOARD ON RADIATION AND WORKER HEALTH

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REVIEW OF THE NIOSH SITE PROFILE FOR DUPONT CHAMBERS WORKS, DEEPWATER, NJ

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Prepared by

John J. Mauro, PhD

S. Cohen & Associates
1608 Spring Hill Road, Suite 400
Vienna, VA 22182

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REVIEW OF THE NIOSH SITE PROFILE FOR DUPONT CHAMBERS WORKS, DEEPWATER, NJ	Page 2 of 23
Task Manager/Lead Author: _______________________________ Date:____________ John Mauro, PhD	Supersedes: N/A
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TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

AWE	Atomic Weapons Employer
cm	centimeter
cm^2	square centimeter
DCAS	Division of Compensation Analysis and Support
dpm/m^3	disintegrations per minute per cubic meter
dps/g	disintegrations per second per gram
g/cm^3	gram per cubic meter
GM	geometric mean
GSD	geometric standard deviation
$\mu g/m^3$	microgram per cubic meter
m	meter
m^3/hr	cubic meter per hour
MCNP	Monte Carlo (N-Particle) or (Neutron and Photon)
mg/day	milligrams per day
mR/hr	milli Roentgen per hour
mrad/hr	millirad per hour
mrem	millirem
mrep/hr	millirep per hour
NIOSH	National Institute for Occupational Safety and Health
OCAS	Office of Compensation Analysis and Support
ORAUT	Oak Ridge Associated Universities Team
SC&A	S. Cohen and Associates
TBD	Technical Basis Document
UF_4	uranium tetrafluoride
UF_6	uranium hexafluoride
UO_2	brown oxide
UO_3	orange oxide
U_3O_8	black oxide (yellowcake)
UO_42H_2O	uranium peroxide

1.0 INTRODUCTION

On January 3, 2008, the National Institute for Occupational Safety and Health (NIOSH) issued Appendix B to Battelle-TBD-6001, which provides data and guidance for dose reconstruction of workers at the DuPont facility in Deepwater, New Jersey. The facility has several names, including "Dye Works" and "Chambers Works." Subsequent to authorization to proceed with the review of that document, the NIOSH Division of Compensation Analysis and Support (DCAS) issued a revised site profile on March 3, 2011 (DCAS 2011a). This report presents a review of the revised site profile.

At the beginning of World War II, the DuPont Chemical Company was one of the leading chemical manufacturing companies in the world. Of special interest to the War Department was the company's experience in developing industrial-scale chemical manufacturing and DuPont's practice of designing and constructing their own plants, seen as an advantage for security as well as project management. Uranium production prior to this was only at the laboratory-scale in gram quantities, while the Manhattan Project required thousands of tons.

In the months leading up to the creation of the Army's Manhattan Project, DuPont was hastily contracted to develop industrial-scale facilities for purification of uranium from various ores, recovery of scrap uranium, manufacture of uranium metal and various uranium compounds with oxygen and fluorine, and fluorine-based lubricants. Of interest to this review is the production of uranium from 1942 through 1944, research activities into 1947, and the associated exposure of the workers to ionizing radiation. As described in the site profile, DuPont worked with various forms of uranium and converted it to more useful forms, including conversion of black oxide (U_3O_8) and sodium diuranate to orange oxide (UO_3), and then to brown oxide (UO_2); production of uranium tetrafluoride (UF_4) from uranium oxide (UO_2 and UO_3); production of uranium peroxide (UO_42H_2O) from scrap uranium for subsequent production of UO_2; and production of UF_6 from UF_4; production of uranium metal using the magnesium process and various related research activities (DCAS 2011a). It does not appear that uranium ore was handled at DuPont. Hence, the primary concern at the facility is exposure of workers to external and internal sources of various forms of natural (unenriched) uranium which was separated from its ore.

The Army sent DuPont new tasks in the form of letter contracts in rapid succession during 1942. The focus of these tasks was production of uranium for the war effort, but little was known about the safety of working with uranium and/or the need to control the "dust" (as airborne contamination was referred to in documents from the time period). As a result, little to no control of the "dust" was attempted in the early years of operation. Following shutdown, uranium contamination remained in the buildings that continued in use and on the ground for several decades, and as a result, posed a potential source of internal and external radiation exposure to those working in the area long after the research and production had ceased. The development for safety standards were not to be of much benefit to the Deepwater workers, because the role of Deepwater waned as the safety guidance was being implemented across the weapons complex.

2.0 REVIEW INTERNAL DOSE DURING OPERATIONS

Though the uranium operations at DuPont were performed early during the Manhattan Project, the site profile explains that 252 airborne dust samples were taken between April 3, 1944, and June 7, 1945, and included both general and operational areas. The site profile determined that the geometric mean (GM) of these data is 181 dpm/m^3 and the geometric standard deviation (GSD) is 5.73. Based on these data, and the fact that there were no bioassay data, the site profile assigned the upper 95th percentile of this distribution to uranium operators and other workers who routinely worked with uranium; the 50th percentile to workers who did not routinely work with uranium, such as supervisors; and the 5th percentile value to workers who rarely worked in the vicinity of the uranium operations (e.g., clerical workers). The following table presents the internal exposure matrix, as reported in Table 1 of the DCAS 2011a:

Table 1. Daily Intakes of Uranium

Category	Years	Description	Inhalation (dpm/day)	Ingestion (dpm/day)
Operators	1942–1948	Routinely working with uranium	25,245	438
Supervisors/Laborers	1942–1948	Routinely in the area	1428	25
Clerical	1942–1948	Not routinely in the area	81	1.4

The values in Table 1 are calculated on a calendar-day basis.
Source: Taken from DCAS 2011a, Table 1

2.1 REVIEW OF THE INHALATION EXPOSURE MATRIX

SC&A's approach to reviewing this exposure matrix was to first review the air sampling data; when and how it was collected, where it was collected, the sampling duration, and how it was analyzed. The distribution of the data was then reviewed, in order to assess the degree to which SC&A concurs with the site profile's characterization of that data. This section concludes with an evaluation of the default intake values used in the matrix.

2.1.1 Review of Raw Data

SC&A independently compiled the data from the hardcopy reports of air concentrations measured at the DuPont Deepwater Works from April 1944 through June 1945. The original hardcopy records are in units of μg/m^3 and were converted to dpm/m^3, assuming a specific activity of 25,280 dps/g for natural uranium. Additional details on the air sampling are provided in Appendix A. In the appendix, it is noted that more than 40% of the air samples were collected in the three work areas with the highest dust concentrations. Figure 1 shows a lognormal scatter plot of the 252 sample values reported on the log sheets from DuPont. The dashed line is the best-fitting regression line. The slope and intercept of this regression line are estimates of the lognormal distribution parameters mu and sigma. Despite a deviation from the regression line at the upper tail above the 95th percentile, the regression analysis has an R^2 of 0.986, indicating a relatively high degree of fit to the data.

Table 2 contains a comparison of the lognormal distribution obtained from Figure 1 with the lognormal distribution from DCAS 2011a (p. 6) when all sample values (N=252), including blanks and non-detects, are incorporated into the analysis. The table shows the estimated lognormal parameters mu and sigma, the GM and GSD, and the lognormal mean and 95th percentile of the two lognormal distributions. The NIOSH estimates of the lognormal parameters mu and sigma are only slightly lower than those shown in Figure 1. The parameter mu differs only by a small amount; however, this difference is large enough to make the NIOSH estimates of the mean and 95th percentiles noticeably lower than the SC&A estimates. The difference could easily be explained by transcription differences, as the hardcopy records are very hard to read and interpret in some cases.

Selected statistics from the empirical distribution are shown at the right of Table 2. (The empirical distribution is obtained by ranking the samples and then selecting the mid-point as the median.) The empirical distribution has a median and a mean that are higher than either of the lognormal distributions, while the empirical 95th percentile is lower than both lognormal distribution estimates for this parameter.

Figure 2 shows a lognormal plot of the data when the blanks are removed. All other sample values (N=239) were retained for this analysis. Figure 2 is very similar to Figure 1. The dashed line is the best-fitting regression line. The slope and intercept of this regression line are estimates of the lognormal distribution parameters mu and sigma. Table 3 shows estimates obtained from the lognormal distribution shown in Figure 2, where the 13 samples labeled as blanks have been removed from the dataset. The median, mean, and 95th percentiles of the distribution with the blanks removed are all higher than both the SC&A and NIOSH estimates for these parameters shown in Table 2.

Selected statistics from the empirical distribution are also shown in Table 3. These estimates are also higher than those shown in Table 2. The mean and median of the empirical distribution area are higher than the lognormal-based estimates, while the empirical 95th percentile is lower than the corresponding lognormal estimate.

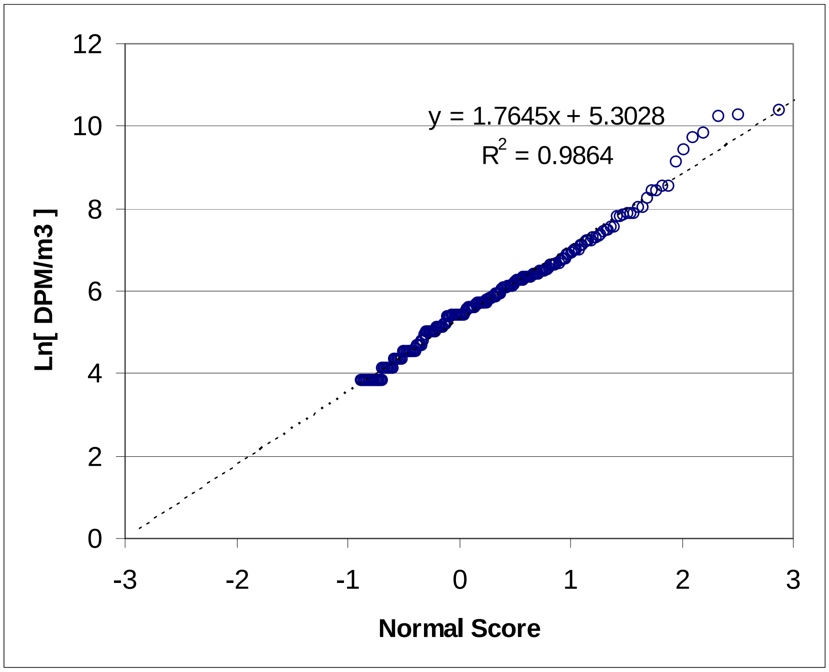

Figure 1. Normal Score Plot of 252 Air Concentrations at Deepwater Works, Including Blanks

Table 2. Comparison of Lognormal Distributions Estimated by SC&A and NIOSH with Empirical Distribution, All Sample Values

Including Blanks (N=252)					
Lognormal Distribution			**Units**	**Empirical Distribution**	
	SC&A	**NIOSH**			
mu	5.30	5.20	–	–	
sigma	1.76	1.75	–	–	
Lognormal GM	201	181	dpm/m^3	228	Empirical Median
Lognormal GSD	5.84	5.73	–	–	
Lognormal Mean	953	831	dpm/m^3	1,074	Arithmetic Average*
Lognormal 95th Pctl.	3,660	3,197	dpm/m^3	3,018	Empirical 95th Pctl.

* All non-detects were set at 25 dpm/m^3 to compute average.

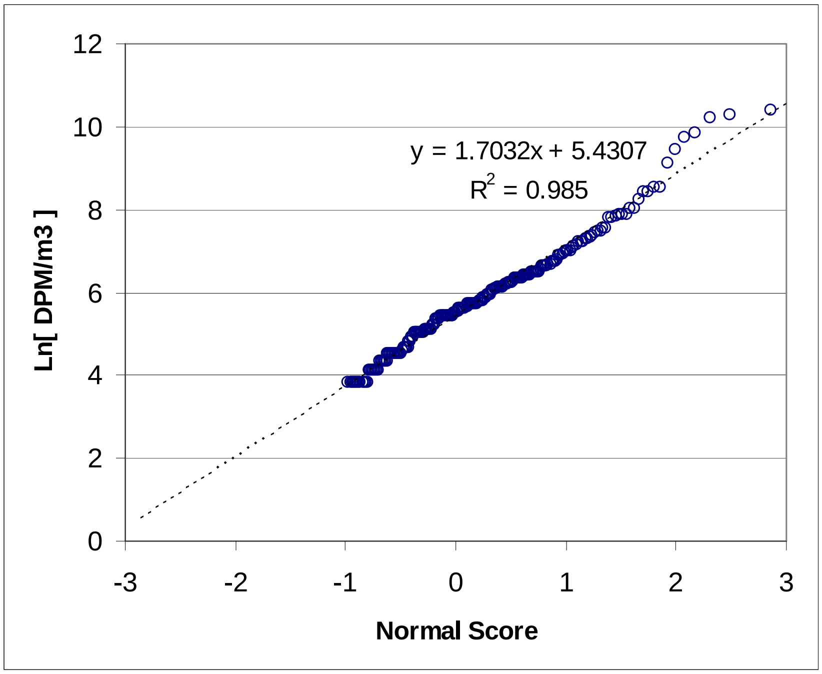

Figure 2. Normal Score Plot of 239 Air Concentrations at Deepwater Works with Blanks Removed

Table 3. Comparison of Lognormal Distribution Estimated by SC&A with Empirical Distribution, 13 Blanks Removed

No Blanks (N=239)				
Lognormal Distribution		**Units**	**Empirical Distribution**	
mu	5.43	–	–	
sigma	1.70	–	–	
Lognormal GM	228	dpm/m^3	243	Empirical Median
Lognormal GSD	5.49	–	–	
Lognormal Mean	974	dpm/m^3	1,131	Arithmetic Average*
Lognormal 95th Pctl.	3,760	dpm/m^3	3,403	Empirical 95th Pctl.

* All non-detects were set at 25 dpm/m^3 to compute average.

As may be noted, our review of the air sampling data reveals similar statistics to the values reported in the site profile, and SC&A concurs with the values for airborne uranium concentrations used in the site profile. However, some discussion is needed regarding the degree to which the time period when the air samples were collected (i.e., 1944 to 1945) is representative or bounding for earlier operational time periods.

Finding 1: The site profile should discuss the degree to which the air sampling data, which were collected in 1944 and 1945, can be used to reasonably bound doses in the earlier years of operation (e.g., 1942–1943).

2.1.2 Review of Default Intake Rates

The default inhalation rate for operators during operations delineated in the site profile is 25,245 dpm/day (Table 1). The following is SC&A's attempt to match this value, given the 95th percentile dust loading reported above:

$$3{,}197 \text{ dpm/m}^3 \times 1.2 \text{ m}^3\text{/hr} \times 2{,}400 \text{ hr/yr} = 9.2\text{E6 dpm/yr} = 25{,}226 \text{ dpm/calendar-day}$$

As can be seen, SC&A matched the default value used by NIOSH and concurs with this default inhalation rate. We concur with the derived median airborne uranium concentration (181 dpm/m^3) and median inhalation rate as adopted in the site profile.

With respect to the ingestion of uranium, the site profile employs OCAS-TIB-009 (OCAS 2004) methodologies, which SC&A accepts under the condition that the facility was not heavily contaminated with uranium during operations. The appropriate application of TIB-009 has been a source of significant discussion between SC&A and NIOSH. SC&A has taken the position that use of the TIB-009 approach (where the amount of activity ingested on a daily basis can be approximated by assuming it to be 0.2 times the activity per cubic meter of air) is appropriate where some surface cleanup has been done. It is not obvious that such cleanup occurred at DuPont Deepwater.

The default ingestion rate for operators during operations delineated in the site profile is 438 dpm/day (Table 1). The following is SC&A's attempt to match this value, given the 95th percentile dust loading reported above:

$$3{,}197 \text{ dpm/m}^3 \times 0.2 = 639 \text{ dpm/day}$$

This value is about 50% higher than that reported in Table 1.

Finding 2: We would request that the site profile discuss the levels of surface contamination at the facility and explain that, at these levels, the default ingestion rate of 0.5 mg/day, which is inherent to TIB-009, applies to this facility. NIOSH should also describe how the ingestion intake in Table 1 was calculated.

3.0 REVIEW EXTERNAL DOSE DURING OPERATIONS

There are no film badge exposure readings for workers, nor are there any external radiation survey data for this facility during operations. As a result, the site profile makes use of external dosimetry models (MCNP) to derive external exposure rates in the vicinity of the uranium as a function of the various chemical and physical forms and geometries of natural uranium handled at the site, and for a broad range of exposure scenarios (i.e., submerged in an airborne cloud of uranium, standing on a surface contaminated with uranium, and standing and working at various distances from different size sources of uranium, including contact dose rates). The following are some of the dose conversion factors that NIOSH derived and used as the basis for developing its external exposure matrix for the site:

Scenario	Dose Conversion Factor
Submersion in a cloud of 100-day old separated natural uranium	2.36E-09 mR/hr per dpm (α)/m^3
Standing on surface contamination of 100-day old separated uranium	5.61E-10 mR/hr per dpm(α)/m^2
30 cm from a 55 gallon drum containing U_3O_8 at a density of 7 g/cm3	1.3 mR/hr
Beta surface exposure rate at contact with a slab of natural uranium	233 mrad/hr

Based on these dose conversion factors, the following are the annual doses adopted for use in the site profile:

Table 4. Annual Doses at Deepwater Works

Category	Years	Photon (mR/yr)	Skin (mrad/yr)	Hands and forearms (mrad/yr)
Operators	1942–1948	519	657	38,614
Laborers	1942–1948	260	329	19,307
Supervisors	1942–1948	130	164	9,653
Clerical	1942–1948	13	16	965

Source: Taken from DCAS 2011a, Table 8

3.1 REVIEW OF EXTERNAL EXPOSURES

3.1.1 Review of the External Dose Conversion Factors

SC&A previously reviewed the external dose conversion factors for uranium as reported in TBD-6000 (see SC&A 2007). As provided in that report, SC&A independently derived the dose conversion factors for the testes from floors contaminated with uranium, which included gamma, electrons, and bremstrahlung for 100-day old natural uranium, and obtained a value of 4.0E-10 mrad/hr per dpm(α)/m^2, which is compatible with the values derived by NIOSH.

We did not derive the external dose conversion factors for submersion, since previous analyses by SC&A reveal that this source of exposure is negligible.

In addition, from the previous analyses provided in SC&A 2007, we also concur with the external exposure dose conversion factors for standing 1 foot (30 cm) from a 55-gallon drum of U_3O_8 or a slab of natural uranium. In addition, we concur with the external contact dose associated with a slab of 100-day old natural uranium.

Hence, SC&A concurs with the external exposure dose conversion factors reported in the site profile. However, NIOSH should provide additional discussion of whether uranium ingots were produced that could have had elevated levels of uranium progeny at the surface of the ingots, which could have resulted in elevated external radiation fields in the vicinity of the ingots.

Finding 3: It appears that uranium metal was produced at the site using the UF_4 to U magnesium bomb reduction process, which, because of the Putzier effect, could have produced uranium ingots that were associated with external beta radiation fields that were 10 to 20 times greater than those adopted in the site profile.

3.1.2 Review of the Exposure Matrix

The site profile explains that the annual photon exposure to operators is based on the operators spending 50% of their time 30 cm (1 foot) from the drums and 50% of their time 1 m (100 cm) from the drums, where the exposure rates are 1.3 and 0.3 mR/hr, respectively. The external exposures for other workers at the facility are expressed in terms of the exposures to the operators. For example, laborers are assumed to have experienced one-half the exposures experienced by the operators, supervisors one-half that of laborers, and others experienced 1/10th that experienced by supervisors. Given these assumptions, the following presents SC&A's evaluation of the external operating exposures experienced by operators, assuming 2,400 working hours per year.

$$1{,}200 \text{ hr/yr} \times 1.3 \text{ mR/hr} + 1{,}200 \text{ hr/yr} \times 0.3 \text{ mR/hr} = 1{,}920 \text{ mR/yr}$$

This value is substantially larger than the value of 519 mR/yr provided in Table 8 of the site profile.

Finding 4: There seems to be a substantial disparity between the explanation of how the annual photon doses to operators were derived and the actual values employed in the site profile.

The site profile also states that the annual contact dose to the skin of operators, as reported in Table 8, is 38,614 mrad/yr, and that this value was derived assuming that the operators' skin (hands) were in contact with the drum 25% of the time. Table 5 of the TBD cites a contact dose rate of 203 mrad/hr for U_3O_8, with which we agree. Given these assumptions, the annual contact dose to skin of operators should be derived as follows:

$$2{,}400 \text{ hr/yr} \times 0.25 \times 203 \text{ mrad/hr} = 121{,}800 \text{ mrad/yr}$$

This value is substantially higher than the value adopted by DCAS in Table 8 of 38,814 mrad/yr. We also note that the default assumption used in Section 6.3 of TBD-6000 (DCAS 2011b) is that the operator spends 50% of his time with hands in contact with a slab of uranium metal, resulting in an annual exposure of 276,000 rad/yr.

Finding 5: There seems to be a substantial disparity between the explanation of how the annual contact doses to operators were derived and the actual values employed in the site profile. In addition, justification should be provided as to why TBD-6000 default values should not be used at DuPont, since no site data are available for external exposure during the operating period.

4.0 REVIEW OF EXPOSURES DURING RESIDUAL PERIOD

The site profile explains that Atomic Weapons Employer (AWE) activities continued until 1947, and that decontamination surveys were performed in Building 708 in 1948, which was released to DuPont in 1949. Building 845 was released on November 15, 1948, after decontamination, and Building J-19 was demolished and several feet of earth were removed between 1943 and 1945.

The site profile further describes beta/gamma and gross alpha surveys of the various buildings after decontamination, and the results of those surveys. These data were used to construct bounding beta and gamma external exposure rates for workers at the facilities following decontamination, along with internal alpha exposures associated with the resuspension and inhalation and ingestion of residual uranium at the facility. The following summarizes the exposure matrix for all workers provided in the site profile for the residual period:

- Whole Body External Dose: 40 mrem/yr from 1949 to October 2009
- Shallow External Dose: 40 mrem/yr from 1949 to October 2009
- Extremity Dose: 400 mrem/yr from 1949 to October 2009
- Uranium Inhalation: 0.329 dpm/day* from 1949 to October 2009
- Uranium Ingestion: 0.00685 dpm/day* from 1949 to October 2009

*Normalized to a calendar day

4.1 REVIEW OF EXTERNAL EXPOSURES

Section 6 of the site profile states that the highest beta/gamma dose rates observed 3 feet above the floor at the locations surveyed in Building 708 and Building 845 after decontamination in 1948 were 0.05 and 0.03 mrep/hr, respectively. A subsequent survey in 1977 indicated that contact doses on the walls and floors were typically about 0.1 mrad per hour. To cover the full range of possible contact dose measurements, NIOSH favorably assumed that the contact dose (beta/gamma) was 0.2 mrad/hr. Using a factor of 5 for the dose reduction between the surface and 3 feet, the site profile assumes that all workers experienced external whole body beta plus gamma dose rates of 0.04 mrad/hr, and that 50% is due to photons and 50% is due to electrons. As stated in the site profile, "Therefore, this appendix will assume the 0.04 mrad/hr is composed of a whole body gamma dose rate of 0.02 mR/hr and a beta **whole body** dose rate of 0.02 mrad/hr" (DCAS 2011a, p. 13, emphasis added).

We further note in Table 3.10 of TBD-6001 that the photon exposure rate (mR/hr) is a factor of 100 lower than the beta dose rate (mrad/hr) at 1 meter (Battelle 2006). Therefore, if the maximum measured dose rate after decontamination was 0.05 mrep/hr, the photon exposure rate would be about 0.0005 mR/hr. This suggests that the photon exposure used by NIOSH (i.e., 0.02 mR/hr) is overstated by a factor of 40.

Finding 6: Assuming 50% of the beta/gamma dose rate measured at 3 feet from a surface is 50% from gamma and 50% from beta does not appear to be appropriate. In addition, beta dose cannot contribute significantly to whole body dose.

Based on the measurements described above, the site profile further assumes that the dose rate to skin of the extremities (hands and forearms) is 0.2 mrad/hr. This appears to be a reasonable assumption, given the data.

The site profile adopts default annual exposures during the residual period of 40 mrem/yr whole body and 40 mrem/yr shallow dose, based on 2,000 hours/yr exposure. The rationale for selecting an exposure rate of 0.02 mrem/hr whole body dose does not appear to be scientifically valid for the reasons described above. Use of the directly measured value of 0.05 mrep/hr would seem more appropriate for beta/gamma exposure at 3 feet above the surface. This dose rate could then be pro-rated based on the TBD-6000 dose conversion factors, assuming 99% beta and 1% photon. This establishes a bounding photon dose rate of 1 mrem per year and a bounding shallow dose rate of 99 mrad/yr, as compared to the NIOISH values of 40 mrem/yr for each type of radiation.

An alternative calculational approach would be to use the conversion factors in Table 3.10 of TBD-6000 and the maximum observed alpha surface contamination level of 500 dpm/100 cm^2 (DCAS 2011a, pp. 12–13). Use of this approach results in a photon exposure rate of 2E-05 mR/hr and a beta dose rate of 2E-03 mrad/hr. Both of these values are significantly lower than those derived in the previous paragraph, indicating that use of the measured beta/gamma value of 0.05 mrep/hr is more claimant favorable.

Finding 7: The development of the photon dose is convoluted and not scientifically sound. A simpler approach would be to assume that the deep dose rate was 0.05 mrad/hr based on measurements at 3 feet from contaminated surfaces, and pro-rate this dose rate between beta and gamma based on Table 3.10 of TBD-6000.

4.2 REVIEW OF INTERNAL EXPOSURES

The site profile explains that, after decontamination, the alpha surveys revealed that surface contamination was generally less than 500 dpm/100 cm^2, and that in 1977, isolated spots were observed with alpha readings ranging up to 5,000 dpm/100 cm^2, but the contamination was relatively fixed. On this basis, the site profile assumes that the average alpha surface contamination throughout the facility was 500 dpm/100 cm^2 and the resulting airborne gross alpha concentration due to resuspension processes was 0.05 dpm/m^3. It was further assumed that all workers were exposed to this airborne uranium concentration for 2,000 hours per year. The site profile does not cite the resuspension factor employed, but we can assume, based on past experience, that 1E-6/m was used. The following is a check on this value:

$$500 \text{ dpm}/100 \text{ cm}^2 \times 1\text{E}4 \text{ cm}^2/\text{m}^2 \times 1\text{E-}6/\text{m} = 0.05 \text{ dpm}/\text{m}^3$$

It appears that the site profile did, in fact, use a resuspension factor of 1E-6/m. Since this resuspension factor is being employed for surfaces that were decontaminated and where the contamination was relatively fixed, SC&A concurs with these assumptions.

5.0 OCCUPATIONAL MEDICAL EXPOSURES

The site profile states there are no records regarding occupational medical exposures at Deepwater. As a result, the site profile adopts the default medical doses recommended in ORAUT-OTIB-0006 (ORAUT 2005). SC&A concurs with this approach.

6.0 REFERENCES

DCAS 2011a. *Technical Basis Document for the DuPont Deepwater Works*, *Deepwater*, *New Jersey*. DCAS-TKBS-0006, Rev. 00. National Institute for Occupational Safety and Health (NIOSH) Division of Compensation Analysis and Support (DCAS), Cincinnati, Ohio. March 8, 2011.

DCAS 2011b. *Site Profiles for Atomic Weapons Employers that Worked Uranium Metals*. Battelle-TBD-6000. Rev. 1. National Institute for Occupational Health and Safety (NIOSH), Division of Compensation Analysis and Support (DCAS), Cincinnati, Ohio. June 17, 2011.

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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. September 14, 2007.

APPENDIX A: AIR SAMPLING CHARACTERISTICS

Each of the 252 air samples collected at DuPont Deepwater Works contains information about what area of the plant the sample was taken, and often indicates what types of activities were undertaken at the time of the sample. Figure A-1 shows an example of the type of air sample records currently available for the site. The first two columns display identifiers such as the sample analysis number and the collection device number. The third column contains the location of the air sample (denoted by a letter such as "L" in this case) and specific information about the conditions/activities in that area at the time of sampling. The fourth column provides the uranium concentration (μg/m^3), while the final column is the fraction of the allowable dust level.

Sample Number	Tube Number	Location	Concentration micro grams of X per cu meter	Times tolerance
		Chamber Works		
163	952	L Preparing to feed	below 25	
164	655	L Feeding	30 ± 10%	0.1
165	578	"	30 ± 10%	0.1

Figure A-1. Example Air Sample Datasheet Extracted from Mears 1945

In many cases, the plant location is followed by a color, such as black or orange, which likely denotes the type of material that was being handled, such as black oxide (U_3O_8) or orange oxide (UO_3). During SC&A's independent compilation of the air sample data, the different locations and conditions/activities were compared, in order to characterize the sampling coverage of the entire dataset.

Table A-1 presents an overview of the air sample data by plant area (referred to as 'rooms' in the air sampling reports), sorted by the total number of samples associated with each area. The table also displays the average and maximum air sample for each area. As the table shows, the three most frequently sampled areas (F, G, and D) also had some of the highest average and maximum air sample results and comprise over 40% of the available data. This would indicate that the air sampling was likely biased towards the dustier areas of the site. One notable exception is Area "J," which only had three air samples associated with it, but had relatively high dust levels (Area J had the highest average value at 6,098 dpm/m^3, and the third highest maximum result at 16,649 dpm/m^3). These three data points are labeled as "black," which likely represents work with black oxide.

Attachment A-1 expands on the analysis displayed in Table 1 by including not only the area of the site, but also the activity description associated with each air sample. Unlike Table A-1, the analysis in Attachment 1 does not show as clear a relationship between the frequency of air sampling and the relative magnitude of results. However, it is worth noting that the four most commonly sampled areas/activities shown in Attachment 1 were associated with "Rooms" F, G, and D, which had some of the highest average and maximum uranium dust loadings.

Table A-1. Summary of Air Sampling Locations by Frequency and Magnitude

Plant Area	# Records	Percentage	Air Sample Result (dpm/m^3)		Flag if Area Results are Greater than Average
			Average	Max	
Room F	49	19.4%	2026.5	32459.5	X
Room G	29	11.5%	1388.7	5157.1	X
Room D	27	10.7%	2505.8	28819.2	X
Room E	27	10.7%	465.7	2654.4	
Room L	23	9.1%	488.7	3837.5	
Room A	17	6.7%	190.9	606.7	
Room C	16	6.3%	431.3	1896.0	
Blank	13	5.2%	44.3	75.8	
Room H	8	3.2%	318.5	1365.1	
Room N	7	2.8%	143.0	455.0	
Room I	6	2.4%	78.4	257.9	
Room M	6	2.4%	134.0	348.9	
Room Q	6	2.4%	303.4	1092.1	
Room B	5	2.0%	389.8	758.4	
Room O	4	1.6%	381.1	1046.6	
Room J	3	1.2%	6097.5	16684.8	X
Room P	3	1.2%	116.3	182.0	
Office	2	0.8%	41.7	45.5	
Room K	1	0.4%	166.8	166.8	

SC&A attempted to categorize the activity/condition descriptions listed in Attachment A-1 by whether they represented operational samples or non-operational samples. Non-operational samples were assumed to be any sample that included the description "idle," "quiet," or being "outside" of a given room. A summary of how many samples fell into each category is shown in Table A-2. The table also includes the number of "Administrative" samples (defined as samples taken in the "office building"), as well as the number of blank control samples taken. As shown in the table, over 78% of the air samples appear to be associated with plant operations.

Table A-2. Summary of the Number of Operational versus Non-Operational Samples

Sample Category	Number of Samples	Percentage of Total
Operational	207	78.41%
Non-Operational	43	16.29%
Administrative	1	0.38%
Control Blanks	13	4.92%

Unfortunately, information could not be found to characterize whether these air samples specifically represent breathing zone, general air, or process samples. The air sampling appears to have occurred on individual days; however, the actual length of time over which each sample was collected is not currently available. The individual days on which sampling occurred are summarized in Table 3. As shown in the table, many air sampling reports had multiple days; therefore, individual samples within a given report may not be able to be tied to an individual day.

Table A-3. Summary of Air Sampling Dates

Dates	# of Records
5/4/44 & 5/6/44	6
6/25/44 & 7/16/44	36
7/3/1944	12
8/6/1944	18
9/24/44 - 9/26/44	12
11/5/1944	17
11/8/1944	78
1/7/1945	16
1/9/1945	12
1/25/1945	6
2/18/1945	18
9/22/44, 4/8/45, 4/9/45, 4/13/45	11
5/27/1945 & 6/7/1945	10

Attachment A-1. Summary of the Areas and Description of Activities Listed Among the 252 Air Samples for DuPont

Room + Process	Type of Record	# Records	Percentage	Average	Max	Flag Greater than Average
Room F - Green	Operational	14	5.6%	453.4	1744.3	
Control Blank	Control Blank	13	5.2%	44.3	75.8	
Room D - Pot Room	Operational	12	4.8%	2759.3	27302.4	X
Room F - Screening	Operational	11	4.4%	6028.6	32459.5	X
Room G - Bomb Loading	Operational	11	4.4%	1582.3	5157.1	X
Room E - Orange	Operational	10	4.0%	604.4	2654.4	
Room C - Outside	Non-Operational	9	3.6%	435.7	1896.0	
Room A - Outside	Non-Operational	7	2.8%	163.6	515.7	
Room A - Black	Operational	6	2.4%	125.1	257.9	
Room D - Digging	Operational	5	2.0%	555.1	1092.1	
Room E - Grinding	Operational	5	2.0%	107.7	379.2	
Room F - Idle	Non-Operational	5	2.0%	236.6	470.2	
Room G - Normal Conditions	Operational	5	2.0%	800.9	1289.3	
Room H - Black	Operational	5	2.0%	429.3	1365.1	
Room I - Grinding	Operational	5	2.0%	42.5	45.5	
Room L - Charging Crusher	Operational	5	2.0%	373.1	758.4	
Room L - Grinding	Operational	5	2.0%	37.9	37.9	
Room N - Operating	Operational	5	2.0%	139.5	455.0	
Room C - Residue Cake	Operational	4	1.6%	392.5	568.8	
Room D - Normal Conditions	Operational	4	1.6%	316.6	606.7	
Room F - Blending	Operational	4	1.6%	261.6	530.9	
Room F - Outside	Non-Operational	4	1.6%	237.0	591.6	
Room L - Black	Operational	4	1.6%	204.8	288.2	
Room Q - Elevating	Operational	4	1.6%	163.1	379.2	
Room D - Operating	Operational	3	1.2%	333.7	515.7	
Room E - Loading	Operational	3	1.2%	1016.3	2426.9	
Room F - Loading	Operational	3	1.2%	1729.2	2654.4	X
Room F - Unloading	Operational	3	1.2%	1284.2	1501.6	X
Room G - Dumping and Mixing	Operational	3	1.2%	485.4	1016.3	
Room G - Operating	Operational	3	1.2%	3392.6	4595.9	X
Room H - Loading	Operational	3	1.2%	134.0	212.4	
Room J - Black	Operational	3	1.2%	6097.5	16684.8	X
Room L - Crushing	Operational	3	1.2%	1997.1	3837.5	X
Room L - Feeding	Operational	3	1.2%	106.2	227.5	
Room M - Operating	Operational	3	1.2%	75.8	106.2	
Office Building	Administrative	2	0.8%	41.7	45.5	
Room A - Normal Conditions	Operational	2	0.8%	326.1	561.2	
Room A - While Dumping	Operational	2	0.8%	348.9	606.7	

Attachment A-1. Summary of the Areas and Description of Activities Listed Among the 252 Air Samples for DuPont

Room + Process	Type of Record	# Records	Percentage	Average	Max	Flag Greater than Average
Room B - Quiet	Non-Operational	2	0.8%	170.6	303.4	
Room C - Idle	Non-Operational	2	0.8%	568.8	568.8	
Room E - Floor Dirty	Operational	2	0.8%	409.5	667.4	
Room E - Idle	Non-Operational	2	0.8%	538.5	985.9	
Room E - Outside	Non-Operational	2	0.8%	364.0	606.7	
Room E - Unloading	Operational	2	0.8%	128.9	151.7	
Room F - Preparing to Screen	Operational	2	0.8%	6275.8	12513.6	X
Room G - Dumping	Operational	2	0.8%	561.2	606.7	
Room G - Idle	Non-Operational	2	0.8%	303.4	303.4	
Room G - Outside	Non-Operational	2	0.8%	170.6	303.4	
Room N - Black	Operational	2	0.8%	151.7	151.7	
Room P - Operating	Operational	2	0.8%	83.4	106.2	
Room Q - In Stack	Operational	2	0.8%	584.0	1092.1	
Room B - Ether Room	Operational	1	0.4%	758.4	758.4	
Room B - Idle	Non-Operational	1	0.4%	348.9	348.9	
Room B - Outside	Non-Operational	1	0.4%	500.5	500.5	
Room C - While Dumping	Operational	1	0.4%	273.0	273.0	
Room D - Idle	Non-Operational	1	0.4%	227.5	227.5	
Room D - Near unit being unloaded	Operational	1	0.4%	28819.2	28819.2	X
Room D - Near unit while running	Operational	1	0.4%	455.0	455.0	
Room E - Getting started	Operational	1	0.4%	60.7	60.7	
Room F - After Screening	Operational	1	0.4%	1198.3	1198.3	X
Room F - Cleaning Box & Loading	Operational	1	0.4%	439.9	439.9	
Room F - No Description	Operational	1	0.4%	227.5	227.5	
Room G - Loading	Operational	1	0.4%	5157.1	5157.1	X
Room I - Black	Operational	1	0.4%	257.9	257.9	
Room K - Black	Operational	1	0.4%	166.8	166.8	
Room L - After Crushing	Operational	1	0.4%	333.7	333.7	
Room L - Near 203A	Operational	1	0.4%	1683.6	1683.6	X
Room L - Preparing to Feed	Operational	1	0.4%	37.9	37.9	
Room M - Black	Operational	1	0.4%	151.7	151.7	
Room M - Center of Room	Operational	1	0.4%	75.8	75.8	
Room M - Idle	Non-Operational	1	0.4%	348.9	348.9	
Room O - Black	Operational	1	0.4%	303.4	303.4	
Room O - Dumping	Operational	1	0.4%	1046.6	1046.6	
Room O - Operating	Operational	1	0.4%	136.5	136.5	

Attachment A-1. Summary of the Areas and Description of Activities Listed Among the 252 Air Samples for DuPont

Room + Process	Type of Record	# Records	Percentage	Average	Max	Flag Greater than Average
Room O - Quiet	Non-Operational	1	0.4%	37.9	37.9	
Room P - Black	Operational	1	0.4%	182.0	182.0	

Appendix A Reference

Mears 1945. Results of Dust Sample Measurements. July 17, 1945. SRBD Ref ID: 642.