Division of Compensation Analysis and Support Technical Basis Document for the DuPont Deepwater Works Deepwater, New Jersey	Document Number: DCAS-TKBS-0006 Effective Date: 03/20/2015 Revision No.: 02 Page 1 of 18
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ISSUE AUTHORIZATION DATE	EFFECTIVE DATE	REV. NO.	DESCRIPTION
02/14/2011	02/15/2011	00	Changes Battelle-TBD-6001 Appendix to a standalone document. Revises external dose model to eliminate dependence on Battelle-TBD-6001. Provides more detailed description of other dose models. Incorporate review comments.
03/08/2011	03/08/2011	00 PC-1	Corrected values in Table 1. Corrected error in table of contents.
12/13/2013	12/13/2013	01	Revised ingestion and external dose estimates to incorporate comments from the Advisory Board Working Group.
03/04/2015	03/20/2015	02	Revised ingestion rates in Table 1 to correct an error.

1.0 Introduction

Technical basis documents and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in the preparation of dose reconstructions at particular Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies). These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used to refer to an area, building, or group of buildings that served a specific purpose at a DOE or AWE facility. It does not mean, nor should it be equated to, an "AWE facility" or a "DOE facility." The terms AWE and DOE facility are defined in sections 7348l(5) and (12) of the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), respectively. A DOE facility is defined as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the [DOE] (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)," and with regard to which the DOE has or had a proprietary interest; or "entered into a contract with an entity to provide management and operation, management and integration, environmental remediation services, construction, or maintenance services." 42 U.S.C. § 7384l(12). On the other hand, an AWE facility means "a facility, owned by an atomic weapons employer, that is or was used to process or produce, for use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining or milling." 42 U.S.C. § 7384l(5). The Department of Labor (DOL) determines whether a facility meets the statutory definition of a DOE or AWE facility. If a facility meets the statutory definition of a DOE or AWE facility, DOL designates the facility as a covered DOE or AWE facility under EEOICPA.

Accordingly, a Part B claim for benefits must be based on an energy employee's eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility's designated time period and location (i.e., covered employee). After DOL determines that a claim meets the eligibility requirements under EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at an AWE facility is categorized as employment either (1) during "a period when the employer was processing producing, for the use by the United States, material that emitted radiation and was used in the production of an atomic weapon, excluding uranium mining and milling," (i.e., the operational period); or (2) during a period that NIOSH has determined that "there is a potential for significant residual contamination outside of the period in which weapons-related production occurred," (i.e., the residual contamination period). 42 U.S.C. § 7384l(3).

Based on the abovementioned definition for eligible employment during an AWE facility's operational period, NIOSH includes radiation exposures incurred in the performance of duty,

such as medical X-rays received as a condition of employment for participating in DOE projects, at an AWE facility in dose reconstructions. This may include radiation exposure related to the Naval Nuclear Propulsion Program and any radiation exposure received from the production of commercial radioactive products that were concurrently manufactured by the AWE facility during the operational period. In contrast, only two categories of radiation exposure as defined in 42 U.S.C. § 7384n(c)(4) should be included in dose reconstructions for claims involving employment during the residual contamination period. First, NIOSH must include exposures to radiological contaminants resulting from activities that had a nuclear-weapon nexus or conducted by or on behalf of the DOE (with an exclusion of activities related to, among other things, the Naval Nuclear Propulsion Program) that took place during the operational period. 42 U.S.C. § 7384n(c)(4)(A). Second, radiation doses from sources not included in the first category but which cannot be distinguished through reliable documentation should also be included in dose reconstructions. 42 U.S.C. § 7384n(c)(4)(B). Furthermore, because all DOE-related activities have ceased during the residual contamination period, NIOSH does not include doses from medical X-rays performed during the residual contamination period (NIOSH 2007) in dose reconstructions.

Likewise, NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment for DOE-related activities at an AWE facility. Therefore these exposures are not included in dose reconstructions for either the operational or residual contamination period (NIOSH 2010):

- Background radiation, including radiation from naturally occurring radon present in conventional structures

- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

The following information from the Department of Energy's Office of Health, Safety and Security EEOICPA Find Facilities webpage defines the EEOICPA covered periods for DuPont Deepwater.

Site:	DuPont Deepwater Works
Location:	Deepwater, New Jersey
Covered Period:	AWE 1942-1949, Residual Radiation 1950-1995; 1997-March 2011; DOE 1996 (remediation)

This document contains a summary of the description of the site as well as the Atomic Energy Commission activities performed there, and provides the technical basis to be used to evaluate the occupational radiation doses for EEOICPA claims.

2.0 Site Description and Operational History

DuPont Deepwater Works was a DuPont facility located in Deepwater NJ. The name of the facility was officially changed from "Dye Works" to "Chambers Works" on 4/7/1944 (Chambers Works 1945). DuPont Deepwater Works conducted work on several projects for the MED. Several involved producing non-radioactive chemicals (Chambers Works 1945). These include

project number 9595 (under Letter Contract W-7412 Eng. 2), project number 9757 (under Letter Contract W-7412 Eng. 6), and project number 9233 (under Letter Contract W-7412 Eng. 8). Project number 9634 was conducted under Letter Contract W-7412 Eng. 3. The letter contract was dated 11/20/1942 and the project was approved by DuPont's Executive Committee on 12/23/1942. Construction was completed in three stages which started production on 2/13/1943, 4/28/1943 and 6/5/1943. The scope of work under this contract included converting U_3O_8 to UO_2, converting UO_2 to UF_4, and converting UF_4 to uranium metal.

Letter Contract W-7412 Eng 3 indicated the U3O8 would be supplied by the Government. However, on 12/30/1942, Letter Contract W-7412 Eng. 22 was issued to direct DuPont to build a facility to produce the U3O8 from various types of uranium scrap. This became Project number 9803 and was approved by DuPont's Executive committee on 3/31/1943. The 100 Section of the plant was operational on 8/16/1943 and the 200 Section of this plant was operational on 10/1/1943 (Chambers Works 1945).

The original research work was conducted at the Jefferson Lab in Building J-16. This building was demolished and several feet of earth removed sometime between 1943 and 1945. Building J-26 was eventually built at that location (DOE 1978).

The other two projects were located in buildings 708 and 845. A portion of building 708 was demolished in 1945. The rest of the building along with several feet of earth was removed in 1953. Radiological surveys of building 845 were conducted in 1977 and 1983 (DOE 1978, Bechtel 1983).

3.0 Process Description

Operations involving uranium at the DuPont Deepwater Works began early in 1942 when DuPont was conducting experiments with uranium hexafluoride (UF_6) under contract to the Office of Scientific Research and Development (OSRD). The method employed utilizing natural uranium oxide and converted it to uranium tetrafluoride (UF_4) and then to UF_6. When the MED was chartered, it took over the OSRD contracts. DuPont operations for MED included 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 ($UO_4 2H_2O$) from scrap uranium for subsequent production of UO_2, production of UF_6 from UF_4, production of uranium metal using the magnesium process and various related research activities. DuPont continued its research activities for AEC until late 1947 (Chambers Works 1945). No documentation was found indicating there were other sources of radiation at Deepwater Works.

4.0 Internal Dose

Air samples were collected at the Deepwater Works plant on various occasions at a variety of locations between 4/3/1944 and 6/7/1945 (DuPont Dust Reports). A total of 252 air samples were collected. These air samples were analyzed by assuming they fit a lognormal distribution. The geometric mean of that distribution was 181 dpm/m3 with a geometric standard deviation of 5.73. These air samples included primarily operational areas but also included some general areas of the facility as well as operational areas while equipment was shutdown. The distribution would therefore not necessarily be representative of operational personnel. Therefore, exposure estimates will rely on three categories of workers. People routinely working with uranium (Operators) will be given the 95th percentile of the air concentration distribution. People working in the vicinity but not normally operating equipment (Supervisors) will be given the 50th percentile of the distribution. People not routinely in the vicinity of the uranium (Clerical) will be given the 5th percentile of the distribution. These values were used to determine an ingestion intake per OCAS-TIB-0009 (OCAS 2004) and are summarized in the table below.

At the end of the weapons related work at DuPont Deepwater Works, the buildings were decontaminated and turned over to DuPont. The last building was turned over in 1949; however the decontamination was performed in 1948. The last building was surveyed after decontamination on 12/30/1948 (DuPont 19449). Therefore, this estimate will cover the time period of 1942 through 1948. Intakes associated with 1949 will be the same as those for the residual contamination period addressed in Section 6.

Table 1: Daily Intakes of Uranium

Category	Years	Description	Inhalation (dpm/day)	Ingestion (dpm/day)
Operators	1942-1948	Routinely working with uranium	25245	478
Supervisors/Laborers	1942-1948	Routinely in the area	1428	27
Clerical	1942-1948	Not routinely in the area	81	1.5

Dose calculated from these intakes is entered into IREP as alpha radiation with a "constant" distribution.

5.0 External Dose

No External dosimetry results were found for the DuPont Deepwater plant. Therefore, the external dose to workers at the plant was modeled. Radiation can be emitted not only from uranium but from its short lived decay products. Since the Deepwater Works plant did not process any uranium ores, all the uranium present at the plant had been processed previously and any decay products removed. While decay products will be produced immediately after the processing, the long-lived decay products can take hundreds or thousands of years to reach an appreciable level. However, short –lived decay products can reach a value near equilibrium in a much shorter period of time. Anderson and Hertel (Anderson and Hertel 2005) showed that the short lived nuclides (Th^{234}, Pa^{234m}, Pa^{234} and Th^{231}) are very close to equilibrium (adjusted for branching ratios) at 100 days following separation. Therefore, for modeling external dose, uranium isotopes (U^{238}, U^{235}, and U^{234}) were assumed to exist in their natural ratios and their short-lived decay products (Th^{234}, Pa^{234m}, Pa^{234} and Th^{231}) were assumed to have reached equilibrium.

External sources of radiation at a uranium facility could include beta and photon radiation from the material being produced, from exposure to contaminated surfaces and from submersion in air contaminated with uranium dust.

When workers are enveloped in a cloud of radioactive dust, they will receive a small amount of external dose. External exposure rates from uranium and its radioactive decay products are shown in Table 2. The doses were calculated using the computer code MicroShield version 6.02 (Grove Engineering 2003). The calculated dose rates are for natural uranium and include the dose contribution from the radioactive decay products of U^{238}, U^{235}, and U^{234}. Radioactive decay product ingrowth of 100 days was assumed for these calculations. Air concentration from DuPont Deepwater Works air samples was used to determine an external dose rate from this route of exposure. This calculation resulted in a dose rate of 4.45×10^{-7} mR/hr. This is negligible when compared to other sources of external radiation.

Table 2: External Dose Conversion Factor for Air Submersion

External Dose Conversion factor	
Time since separation	(mR/h per dpm(α)/m^3)
100 d	2.46E-09

When workers are working on a contaminated surface, they will receive a small amount of external dose. External dose rates from uranium and its radioactive progeny are shown in Table 3. The doses were calculated using the computer code MicroShield version 6.02 (Grove Engineering 2003). The calculated dose rates are for natural uranium and include the dose contribution from the radioactive decay products of U^{238}, U^{235}, and U^{234}.

The quantity of uranium on the floor surface was estimated from measured air concentrations. The level of surface contamination was determined by first calculating a terminal settling velocity for 5-µm activity mean aerodynamic diameter (AMAD) particles. The calculated terminal settling velocity was 0.00075 meters per second. It was assumed that the surface contamination level was due to 30 days of constant deposition from the constant air concentration with no removal. Using this surface concentration and the conversion factors in Table 3, the external dose rates from contaminated surfaces were calculated. This results in a calculated value of 0.000139 mR/hr photon and 0.0134 mrad/hr beta. These values are small when compared to the dose rate directly from uranium. Combined with the large uncertainty applied to the direct values, these values are considered negligible and not included in the estimate.

Table 3: External Dose Conversion Factor for Surface Contamination

Surface contamination dose conversion factor		
Time since separation	Photon Exposure Rate (mR/h per dpm(α)/m^2)	Beta Dose Rate (mrad/h per dpm(α)/m^2)
100 d	3.94E-10	3.82E-8

Next, the external dose rate from direct handling of uranium compounds was considered. Several different chemical compounds of uranium were handled at the Deepwater plant. Also the material was handled in various-sized containers or equipment. However, the external dose rate from uranium is not very sensitive to these variations once a sufficient quantity has accumulated. Table 4 below shows the dose rates calculated for a drum of U_3O_8 using MCNPX (version 2.5.0). The density of the drum was increased allowing for a greater amount of uranium to be contained by the drum. It can be seen that once the density reaches a realistic value, the dose rate does not change appreciably. The same is true of an array of drums or large amounts of uranium contained in equipment.

Table 4: Uranium dose rates from drums of uranium oxide

Density of U_3O_8 (g cm^{-3})	Activity of U in drum (Ci)	Photon emission dose(rad/hr)	Bremsstrahlung dose (rad/hr)	Total dose rate at 30 cm (rad/hr)
0.5*	3.121E-02	3.96E-04	3.20E-4	7.16E-4
1	6.242E-02	5.00E-04	3.60E-04	8.60E-04
2	1.248E-01	5.54E-04	3.76E-04	9.30E-04
4	2.497E-01	5.84E-04	3.84E-04	9.69E-04
6	3.745E-01	5.84E-04	3.64E-04	9.48E-04
7	4.182E-01	5.81E-04	3.74E-4	9.56E-4

*The drum begins to noticeably impact the dose rates at low material concentration.

Also varying the chemical makeup of the uranium compound has little effect on the external dose rates. Table 5 shows the surface beta dose rates from various chemical forms of uranium. Uranium metal exceeds the dose rates from other uranium compounds. However, the dose rates from uranium oxides and UF_4 are sufficiently similar in magnitude to the dose rates from uranium metal so that uranium metal dose rates can be assumed to be representative of the dose rates from all uranium compounds.

Table 5: Beta Surface Exposure Rates from Equilibrium Thickness of Uranium Metal and Compounds (DOE-STD-1136-2004)

Source	**Beta Surface Exposure Rate, mrad h^{-1}**
U-Nat metal slab	233
UO_2	207
UF_4	179
$UO_2(NO_3)_26H_20$	111
UO_3	204
U_3O_8	203
UO_2F_2	176
$Na_2U_2O_7$	167
a. Beta surface exposure rate in air through a polystyrene filter 7mg/cm^2 thick.	

The geometry of the uranium can also have an effect on the external dose rate from the uranium. Table 6 shows the calculated dose rate from several sizes of drums. The dose rates from drums were calculated using MicroShield Version 5.01. The calculations assumed that the time of decay was 100 days, which allows the ingrowth of uranium decay products which will increase the dose rate. The contents of the drums were modeled as soil at a density of 1.6 (Eckerman and Ryman 1993). The calculations did not account for Bremsstrahlung that may have been generated by the interactions of beta particles with the contents of the drum. Calculations performed by others (Anderson and Hertel 2005) indicate that the dose rate due to

Bremsstrahlung may be equal to the photon dose rate. Therefore, the values shown in Table 6 are twice the dose rate that was calculated for photons alone. The one foot (30 cm) values for the 55 gallon drum compare well to the values in Table 4. In Table 6, the photon dose was doubled to account for Bremsstrahlung radiation. In Table 4, the Bremsstrahlung radiation was accounted for separately. In comparing the two tables, it can be seen that the Bremsstrahlung treatment in Table 6 is favorable. It can also be seen that the same treatment would result in total dose values of approximately 1.2 mR/hr from Table 4 which compares well with the 1.3 mR/hr value in Table 6. Values from Table 6 will be used for external photon dose calculations for the Deepwater plant.

Table 6: Dose rates from drums of uranium compounds

Drum Size (gal)	Dose Rates (mR/h)			
	1 cm	10 cm	30 cm	100 cm
100 day decay				
5	3.7	1.4	0.4	0.1
30	4.4	2.5	1.1	0.2
55	4.5	2.8	1.3	0.28

The exact external exposure scenarios at the Deepwater plant vary making it impossible to model each task. However, based on the fact that the external photon dose rates do not vary significantly with most parameters, the external exposure estimate assumes an operator spent 100% of the time one meter from a 55 gallon drum of uranium. This is considered the median of a lognormal distribution and a geometric standard deviation of 5 is assigned to account for the variability of distance.

While the photon dose rates do not vary significantly the beta dose rates do vary a great deal with distance due to air attenuation. The beta dose rates are estimated using the beta dose rates from aged yellowcake (U_3O_8) at various distances from the uranium presented in Figure 1. Using the same distance variation as the gamma dose rate (geometric standard deviation of 5), Figure 1 can be reasonably approximated by a lognormal distribution with a geometric mean of 1 mrem/hr. This distribution is show in Figure 2 superimposed over Figure 1.

The median distance of the gamma dose rate distribution was the dose rate at 1 meter. Since the distribution is assumed to be associated with the operators distance from the source, the same distribution will be used for the beta dose rate. The one meter beta dose rate of the lognormal distribution in Figure 2 is 1 mrem/hr. Therefore, as with the gamma dose estimate, the operator will be based on the beta dose distribution with a GSD of 5 and the GM of 1 mrem/hr.

Figure 1: Beta dose rate from yellowcake separated from ore for more than 100 days as a function of distance from the surface. [Reproduced from US NRC 2002a]

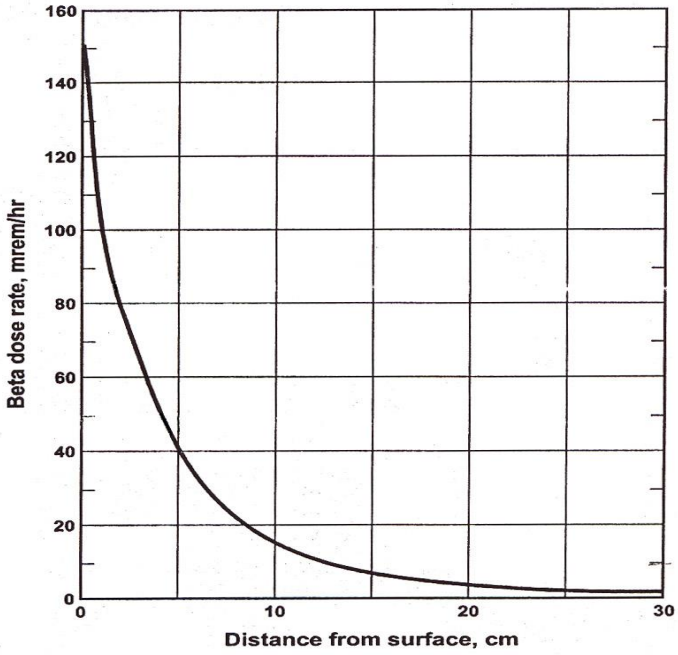
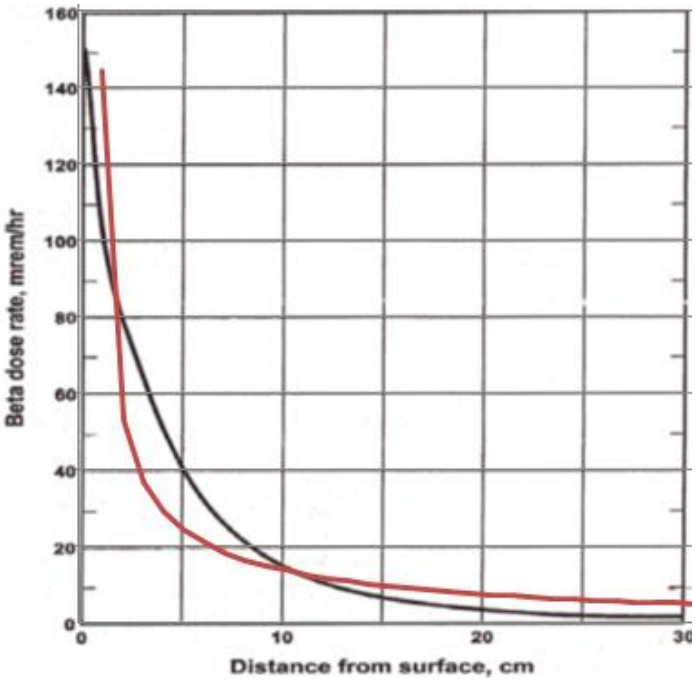


Figure 2: Approximation of beta dose rates in Figure 1



For extremity dose (dose to the hands and forearms), the beta dose distribution would underestimate the dose since operators could be handling the material directly at times. To account for this, it is assumed the operator could be touching the material half the time he is within one foot of the material. The dose rate for used for the estimate will be the uranium metal contact dose rate from Table 5. The amount of time spent within 1 foot is determined from the gamma dose rate distribution. With a geometric mean of 0.28 mr/hr and a geometric standard deviation of 5, the dose rate of 1.3 mr/hr will be exceeded 17% of the time. This is the gamma dose rate at 1 foot (30 cm) shown to Table 6. Therefore, the estimate assumes the operators hands are in contact with the material 8.5% of the time and at 1 foot another 8.5% of the time. The remaining time will be assumed to be at 1 meter. Unlike the other estimates, this estimate is considered bounding and will therefore not be represented by a distribution. Instead, this estimate will be considered a constant.

For exposure estimates, each claim will be evaluated to determine the most appropriate job category to utilize for the external dose estimate. The "operator" job category consists of personnel that were routinely and directly involved in operations with uranium. The "laborer" job category consists of personnel that supported these operations. The "Supervisor" job category consists of personnel that were in the operations area but were not routinely involved in hands on activities with uranium. The "Other" job category consists of personnel that did not routinely enter the testing area.

External exposure scenarios for operators have already been described. The typical work year is assumed to be 2400 hours during the operational period. Laborers will be assumed to receive half the external dose that operators receive. Supervisors are assumed to receive half the dose that laborers receive. Others are assumed to receive one tenth the external radiation that supervisors receive. External doses to the different job categories during operational years are listed in Table 7. Extremity doses should be entered into IREP as a constant distribution. Other doses should be entered into IREP as a lognormal distribution with a GSD of 5.0. Photon doses should be assigned as 50% 30 to 250 keV photons and the remaining 50% as greater than 250 keV photons. Skin and Hands and forearm dose should be assigned as 100% greater than 15 keV electrons.

Table 7: Annual Doses at Deepwater Works

	Years	Photon (mR/yr) [a]	Skin (mrad/yr) [a]	Hands and forearms (mrad/yr) [b]
Operators	1942-1948	672	2400	50000
Laborers	1942-1948	336	1200	25000
Supervisors	1942-1948	168	600	12500
Other	1942-1948	17	60	1250

a GM of a lognormal distribution with a GSD of 5.
b Constant distribution

6.0 Residual Contamination

Even though the last building was released to DuPont in 1949, the last decontamination survey (described below) was completed in late 1948 (DOE 1978). After 1948, there was still the potential for dose from residual contamination remaining in the buildings. The dose estimate from this residual contamination is described below.

The initial research conducted in 1942 at Deepwater Works was conducted in building J-16. This building was demolished and several feet of earth removed sometime between 1943 and 1945 (DOE 1978).

Building 708 was partially demolished in 1945. This building was eventually shutdown, decontaminated and released to DuPont in 1949. The final survey of the building was conducted on 12/30/1948. This survey indicated the northwest tile wall was the most contaminated location in the building. The survey measured beta and gamma dose rates along the wall at several distances from the center of the contaminated area including the center of the contaminated area. The measurements were taken at these locations on contact with the wall as well as one foot away, two feet away, four feet away, six feet away and twenty feet away from the wall. These measurements were conducted on all five floors of the building with the exception of the second and third floors. That section of the wall was not accessible from those floors (DuPont 1949).

The survey also recorded measurements on the floor on all five floors of the building. All of these measurements indicated direct alpha results of less than 500 dpm/100cm^2 and the highest beta gamma dose rate three feet above the floor as 0.05 mrep/hr. It should be noted that mrep is an outdated unit of measure equivalent to the more modern mrad. Building 708 was released to DuPont and in 1953 the building was demolished and several feet of soil were removed.

Building 845 was released to DuPont on 11/15/1948 after decontamination (DuPont 1948c). The decontamination effort consisted of removing all apparatus, contaminated ducts, pipes, tanks, concrete bases, and wood floors as well as sandblasting the concrete floors. The whole interior was washed with water under pressure. A survey conducted on 10/6/1948 indicated all direct alpha measurements were less than 500 dpm/100cm^2. The survey also indicated beta and gamma radiation levels three feet above the floor were less than 0.03 mrep/hr (DuPont 948b).

The building remained standing and was again surveyed in 1977 (DOE 1978) and 1983 (Bechtel 1983). The 1983 survey provided only a range of values with no indication of the average or typical contamination levels. The 1977 survey however, indicated average measurements as well as maximum measurements. This survey also indicated areas of maximum measurements were typically small areas.

The survey indicated beta gamma direct contact dose rates typically around 0.1 mrad/hr on most floors, walls, and ceilings. These readings were not corrected for background radiation so they are slightly high. Every floor of the plant had higher dose rates in small areas. This estimate will assume a dose rate of 0.2 mrad/hr as a favorable average dose rate. Since this is a contact beta plus gamma dose rate, corrections must be made to determine a whole body gamma and whole body beta dose rate.

As part of a test to determine the effectiveness of sandblasting, a survey was conducted in building 845 on 8/30/1948 and 8/31/1948 (DuPont 1948a). Part of this survey measured the open window dose rates (beta plus gamma) from three spots on the floor. Measurements were taken on contact with the floor and at waist height (three feet above the floor) prior to decontamination. The contact readings were 2.6, 2.6, and 15 mrep/hr. The corresponding three foot readings were 0.5, 0.5, and 1.0 mrep/hr. These measurements imply the readings taken three feet above the floor were 5.2, 5.2 and 15 times lower than the contact readings. Based on this, this estimate will use a value of five to estimate the whole body beta plus gamma dose rates from the contact dose rates. Therefore, the average whole body beta plus gamma dose rate is assumed to be 0.04 mrad/hr.

The ratio of beta to gamma from uranium contamination can vary from one to one to as high as 100 to one depending on the geometry, the amount of self shielding, and a number of other factors. For the purposes of this estimate, a ratio of 10 beta to 1 gamma will be used. Therefore, this appendix will assume the 0.04 mrad/hr is composed of a whole body gamma dose rate of 0.0036 mR/hr and a beta whole body dose rate of 0.0364 mrad/hr. Skin of the extremities (hands and forearms) will be assumed to be exposed to the contact dose rate of 0.2 mrad per hour.

While work schedules and locations can vary throughout a large facility such as Deepwater Works, a favorable assumption would be that individuals were exposed to these levels for 2000 hours per year. While it is recognized that some individuals would have worked overtime, it is also very likely they worked in other areas of the site since building 845 was primarily used for storage in later years. This also makes the use of 2000 hours per year a bounding estimate. As such, this portion of the dose estimate will be considered a constant value with no statistical distribution.

With these assumptions in place, this dose estimate will assume for the residual period, an annual whole body dose of 80 mrem. This is divided into 7.3 mrem deep dose and 72.7 mrem shallow dose (beta). Extremities will be estimated with an annual dose of 400 mrem assumed to be beta plus 7.3 mrem deep dose.

Table 8: Annual Whole Body External Dose from Residual Contamination

Operation Phase	Years	Whole Body (mrem/year)[(a)]	Job Category	GSD
Residual	1949-Mar. 2011	7.3	All	Constant

Applied as Photons 30-250 keV. Whole body photon doses are to be converted to organ doses using the Exposure to Organ Dose Conversion Factors (US DHHS 2007).

Table 9: Annual Shallow External Dose from Residual Contamination

Operation Phase	Years	Shallow Dose (mrem/year)[(a)]	Extremity Dose (mrem/year)[(a)]	Job Category	GSD
Residual	1949-Mar. 2011	72.7	400	All	Constant

Applied as Electrons > 15 keV.

Direct alpha contamination measurements of the floor were conducted after decontamination of buildings 708 and 845. These measurements indicated the values were less than 500 dpm/100cm2. The 1977 survey of building 845 confirmed this was still the case even though isolated spots of higher contamination were also found. The isolated spots were primarily less than 500 cm^2 in area but six spots on the first floor ranged up to 5000 cm^2. These readings indicate fixed contamination that cannot be easily resuspended into the air. The fact that the 1948 survey results are near the same values of the 1977 survey results indicates that the contamination is generally not being resuspended or removed in any other fashion. However, in order to account for small amounts of uranium that may have become airborne, a resuspension factor was applied to the 500 dpm/100cm^2 value. This resulted in an estimated airborne concentration of 0.05 dpm/m^3. Again, it will be assumed that an individual was exposed to this level of airborne contamination for 2000 hours per year. This estimate will therefore be considered a bounding estimate and no statistical distribution will be associated with it.

As with the airborne estimate, the fixed contamination will be assumed to be transferable to the point of causing inadvertent ingestion intakes. Again, the 500 dpm/100cm^2 value will be used and combined with a value of 1.1E-4 m^2/hr (NUREG/CR 5512) to estimate an ingestion rate. This results in an estimated ingestion rate of 30.1 dpm/day.

For internal dose estimates, the uranium will be considered to be type M or type S solubility. The dose estimate should be based on the one that produces the highest dose.

Table 10: Daily Intakes from Residual Contamination (Solubility Type S or M)

Operation Phase	Years	Radionuclide	Inhalation (dpm/day)	Ingestion (dpm/day)	Job Category	GSD
Residual	1949-Mar. 2011	U-234	0.329	30.1	All	Constant

Note: intakes rates are normalize to calendar days

7.0 Occupational Medical Dose

No documentation regarding occupational medical dose specific to DuPont Deepwater Works was found. Information to be used in dose reconstructions, for which no specific information is available, is provided in ORAUT-OTIB-0006, Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures (ORAUT 2005c). The assumed frequency in this document is PA chest X-ray for pre-employment, annual, and termination examinations between the years 1942 and 1949 (the covered period). Annual organ doses are entered into the NIOSH-IREP program as the annual dose due to an acute exposure to photons (E=30-250 keV). The distribution is assumed to be normal with a standard deviation of 30%.

8.0 References

Anderson and Hertel 2005, Anderson, J.L., and Hertel, N.E., "Bremsstrahlung Doses from Natural Uranium Ingots," Radiation Protection Dosimetry, 115 (1-4): 298-301, 2005

Bechtel National, Inc., 1983, Radiological Survey Report for the DuPont Chamber Works Plant Deepwater, New Jersey, Oak Ridge, Tennessee [Ref ID 6391].

Chambers Works 1945, Report: History Chambers Works Special Construction, February 9, 1945 [Ref ID 16272].

DOE 1978, Radiological Survey of the E.I DuPont DeNemours and Co., Deepwater, New Jersey, December 1978 [Ref ID 6395].

DOE, Office of Health, Safety and Security, EEOICPA web site. http://www.dol.gov/owcp/energy/regs/compliance/EEOICPA_FacilityList.pdf

DuPont 1948a, Letter from R.E. Hayden to A.R. Piecot regarding Decontamination of Concrete Floor at DuPont, September 9, 1948 [Ref ID 6410 pg 8].

DuPont 1948b, Letter from R.E. Ryan to B. S. Wolf regarding Contamination of DuPont Building, November 15, 1948 [Ref ID 6410 pg 6].

DuPont 1948c, Memo from G. L. Ryan to B. S. Wolf regarding Contamination of DuPont Building, December 17, 1948 [Ref ID 6410 pg. 5].

DuPont 1949, Letter from Merril Eisenbud to E.I. DuPont de Nemours & Co. regarding Radiation Intensities in Building 708, January 18, 1949 [Ref ID 6410 pg 1].

DuPont Dust Reports. Various Air Sample Reports, 1944 through 1945. [Ref IDs 5882, 6420, 6423, 6425, 6432, 6434, 6436, 6438, 6439, 8253, 8256, 17136].

Eckerman, KF and JC Ryman. 1993. *External exposure to radionuclides in air, water, and soil*. Federal Guidance Report No. 12. EPA-402-R-93-081. Environmental Protection Agency. Washington, DC.

Grove Engineering. 2003. *MicroShield Software Program, Version 6.02*. Copyright 1992-2003.

NIOSH (National Institute for Occupational Safety and Health) 2010, Radiation Exposures Covered for Dose Reconstructions Under Part B of the Energy Employees Occupational Illness Compensation Program Act, Rev 1, OCAS-IG-003, National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, Ohio.

NUREG/CR 5512 Vol. 1, *Residual Radioactive Contamination From Decommissioning*, Prepared for the Nuclear Regulatory Commission, October 1992

OCAS (Office of Compensation Analysis and Support) 2004, Estimation of Ingestion Intakes, Rev 0, OCAS-TIB-0009, National Institute for Occupational Safety and Health, Office of Compensation Analysis and Support, Cincinnati, Ohio.

ORAUT (Oak Ridge Associated Universities Team) 2005, ORAUT-OTIB-0006, Technical Information Bulletin: Dose Reconstruction from Occupationally Related Diagnostic X-Ray Procedures, Rev 03 PC-1, December 21, 2005.