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☐ New ☐ Total Rewrite ☒ Revision ☐ Page Change

FOR DOCUMENTS MARKED AS A TOTAL REWRITE, REVISION, OR PAGE CHANGE, REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
07/27/2006	00	New Technical Basis Document for the Pantex Plant – Occupational Internal Dose. First approved issue. Training required as determined by the Task Manager. Initiated by Jerome B. Martin. Signature on File 05/29/2006 Jack J. Fix, Document Owner Signature on File 04/26/2006 John M. Byrne, Document Owner Signature on File 05/26/2006 Edward F. Maher, Task 5 Manager Signature on File 05/31/2006 Kate Kimpan, Project Director Signature on File 07/27/2006 James W. Neton, Associate Director for Science
02/08/2007	00 PC-1	Page change revision to change the date for the first DU-laden hydroshot from 1952 to 1959 on page 31. Updated the text in Section 5.2.2.6 on page 28 and updated Table 5-11 on page 32 and 5-19 on page 48. Added reference on page 49 for the telephone conversation that confirmed the actual date. Table 5-1 was moved from page 9 to page 10. Results in a decrease in the intake of DU and resultant dose for the years 1952 to 1959. Text was modified or added in Section 5 and References (pages 9-12, 28, 31-32, 48-49, and 53). No sections were deleted. Incorporates internal formal review comments and NIOSH formal review comments. This revision results in a reduction in assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Donald E. Bihl. Approval: Donald E. Bihl Signature on File for 01/24/2007 Jack J. Fix, Document Owner Signature on File 01/25/2007 John M. Byrne, Document Owner Signature on File 01/26/2007 Edward F. Maher, Task 5 Manager Signature on File 01/31/2007 Kate Kimpan, Project Director Brant A. Ulsh Signature on File for 02/08/2007 James W. Neton, Associate Director for Science

06/22/2007	01	Approved revision initiated to include Attributions and Annotations and additional references. No sections were deleted. Minor editorial changes were made in Sections 5.2.1, 5.2.1.1, 5.2.1.1.4, 5.2.2.5, and 5.2.2.6.2. Constitutes a total rewrite of the document. Incorporates formal internal and NIOSH review comments. This revision results in no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Donald E. Bihl.
01/03/2014	02	Revision initiated to add section detailing the Special Exposure Cohort classes and limitations for internal dose assessment from intakes before 1991. Sections 5.2.1 through 5.2.3 were revised to reflect assessment of internal radiation dose only if monitoring data are available for all periods after the end of the SEC periods (1991). Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Dale D. Thomas III.
11/13/2014	03	Revision initiated to correct unmonitored tritium doses in Table 5-3. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Dale D. Thomas III.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
CEDE	committed effective dose equivalent
CEP	Controls for Environmental Pollution
CFR	Code of Federal Regulations
Ci	curie
d	day
DAC	derived air concentration
DHHS	U.S. Department of Health and Human Services
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
DORMS	Dosimetry Records Management System
dpm	disintegrations per minute
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EU	enriched uranium
g	gram
GSD	geometric standard deviation
$H_{E,50}$	committed effective dose equivalent
HE	high explosive
HERS	Historical Exposure Records System
hr	hour
HTO	tritiated water vapor
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
in.	inch
IREP	Interactive RadioEpidemiological Program
L	liter
m	meter
mCi	millicurie
MDA	minimum detectable activity
MeV	megaelectron-volt, 1 million electron-volts
mL	milliliter
mrem	millirem
NDE	nondestructive examination
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH-Office of Compensation Analysis and Support Claims Tracking System
ORAU	Oak Ridge Associated Universities
PAEC	potential alpha energy concentration
PAEE	potential alpha energy exposure
pCi	picocurie

POC	probability of causation
RST	Radiation Safety Technician
SEC	Special Exposure Cohort
SNM	special nuclear material
SRDB Ref ID	Site Research Database Reference Identification (number)
TBD	technical basis document
U.S.C.	United States Code
wk	week
WL	working level
WLM	working level-month
yr	year
µCi	microcurie
µg	microgram
§	section or sections

5.1 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 historical background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

In this document the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility 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 Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)" [42 U.S.C. § 7384l(12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation, 42 C.F.R. Pt. 82) restrict the "performance of duty" referred to in 42 U.S.C. § 7384n(b) to nuclear weapons work (NIOSH 2010).

The statute also includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition excludes Naval Nuclear Propulsion Facilities from being covered under the Act, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally-derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external occupational radiation exposures are considered valid for inclusion in a dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived (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

[1] The U.S. Department of Labor (DOL) is ultimately responsible under the EEOICPA for determining the POC.

5.1.1 Purpose

This technical basis document (TBD) addresses intakes of radionuclides associated with weapons operations as well as radon exposures, which might have been enhanced due to the unique cell design at the Pantex Plant for limiting the consequences of accidents.

5.1.2 Scope

Activities at the Pantex Plant resulted in a limited potential for airborne contamination in bays and cells. The principal function in the bays is the assembly and disassembly of nuclear explosives, particularly the mechanical portion of operations that includes electrical components and tritium reservoirs. Physics package assembly and disassembly, which involved bare high explosives (HE) and sealed pits, occurred in the cells. There are 13 cells for assembly and disassembly at the Pantex Plant. Operations with radioactive components began in these cells in 1956. Cell 1 is no longer in use because of an accidental tritium gas release in 1989 [1].

Internal Dosimetry Technical Basis & Quality Assurance Document (BWXT Pantex 2001) implies that particle size measurements could have been made for specific incidents but had not been performed (at that time) for routine airborne contamination conditions. Data were found for particle size measurements assessed for uranium and thorium during the 1990s. It appears that measurements were used to determine appropriate radiation protection measures but not for dose assessment. The dose reconstructor should use the default 5-µm activity median aerodynamic diameter assumption (with the exception of tritium and radon progeny) unless data on specific particle size are available in the records and are representative of the intakes being considered (ORAUT 2014a).

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 5.4.

5.1.3 Special Exposure Cohort Petition Information for Pantex

5.1.3.1 January 1, 1958, through December 31, 1983

On December 21, 2011, the Secretary of the U.S. Department of Health and Human Services (DHHS) designated the following class of employees as an addition to the Special Exposure Cohort (SEC) (DHHS 2011):

> *All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Pantex Plant in Amarillo, Texas, during the period from January 1, 1958 through December 31, 1983, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the SEC.*

As stated in (DHHS 2011), DHHS finds that it lacks sufficient personnel or area monitoring data, source term data, and operational information to support reconstructing internal dose from intakes of uranium with sufficient accuracy from January 1, 1958 through December 31, 1983 at the Pantex Plant in Amarillo, Texas. Reconstruction of thorium intakes with sufficient accuracy is not feasible for all workers during the same period since the proposed method for estimating those intakes depend on the reconstruction of uranium intakes. However, reconstruction of doses from radon is feasible based on workplace measurements. Plutonium and thorium intakes can be reconstructed for individuals who have specific monitoring results for those radionuclides. Tritium doses can be reconstructed based on tritium bioassay results from monitored workers. Although DHHS found that it is not possible to completely reconstruct internal radiation doses for the proposed class, NIOSH can use

any internal monitoring data that might become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at Pantex Plant, during the period from January 1, 1958 through December 31, 1983, but who do not qualify for inclusion in the SEC, can be performed using these data as appropriate to support a partial dose reconstruction.

5.1.3.2 January 1, 1984, through December 31, 1991

On September 30, 2013, the Secretary of DHHS designated the following class of employees as an addition to the SEC (DHHS 2013):

> *All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Pantex Plant in Amarillo, Texas, during the period from January 1, 1984 through December 31, 1991, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the SEC.*

As stated in (DHHS 2013), DHHS found it lacks sufficient information to reconstruct internal radiation doses adequately for all Pantex Plant employees from intakes of uranium and thorium with sufficient accuracy from January 1, 1984, through December 31, 1991, at the Pantex Plant in Amarillo, Texas. Specifically, DHHS found that the available monitoring data, as well as available process and source term information for the Pantex Plant was inadequate to estimate with sufficient accuracy the internal doses from potential exposures to uranium during the period from 1984 through 1990, and to thorium from January 1, 1984, through December 31, 1991. However, tritium internal doses can be reconstructed for the period based on the available tritium bioassay data. Although DHHS found that it is not possible to completely reconstruct internal radiation doses for the proposed class, NIOSH can use any internal monitoring data that might become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at Pantex Plant, during the period from January 1, 1984 through December 31, 1991 but who do not qualify for inclusion in the SEC, can be performed using these data as appropriate to support a partial dose reconstruction.

5.1.4 History of Internal Dosimetry

Between 1952 and 1954, the primary mission at Pantex was to precision-machine HE castings and send them to Sandia National Laboratory in Albuquerque, New Mexico, for assembly. From 1956 to 1958, with the in-flight insertable design, the only nuclear components handled at Pantex were depleted uranium (DU) cases and tritium reservoirs; during this time there was no processing of nuclear material. Because these DU components were new at the time of assembly, this analysis assumed that removable DU oxide contamination on the components was minimal. In similar fashion, the potential for significant removable tritium contamination was minimal because the tritium reservoirs had to meet rigorous shipping requirements. The only other sources of radiation exposure at Pantex during this period were industrial radiography and medical X-rays (ORAUT 2007).

From 1951 to about 1980, nuclear weapons assembly operations were generally free of contamination. Occasional checks for removable contamination usually demonstrated negative results, so few precautions were taken in relation to personal protective equipment and clothing. There was no evidence of any intakes of radioactive materials by Pantex workers (ORAUT 2007).

There was no routine bioassay program at Pantex before 1972 for uranium, thorium, or plutonium [2]. Bioassay was performed for specific events; for instance, bioassay was obtained from workers involved in a plutonium contamination event in 1961 and from those involved in decontamination of

the facility after the event [3]. A 1967 report that describes an inspection of the radiation protection program states that Pantex used air samples and contamination surveys to indicate the need for bioassay and did not maintain a routine plutonium or uranium bioassay program (Davis 1967). The report further states that Pantex performed about 10 tritium urinalyses a month, and there was no indication of personnel exposure. There might have been a small routine tritium program, but the research for this analysis found no other information.

The 1991 procedure *Analysis of Biological Samples for Uranium, Thorium, and/or Plutonium* (MHSMC 1991a) stated that urinalysis was to be conducted for personnel exposed to 40 derived air concentration (DAC)-hr integrated air concentrations as measured by breathing-zone monitors or was to be estimated if not specifically monitored. The procedure also stated that, "personnel working in potentially contaminated areas shall be entered into the routine bioassay program and shall have a routine bioassay for the suspect heavy metal radionuclide performed every 4 to 6 months." However, the routine bioassay program for radionuclides other than tritium was short-lived, occurring mostly in 1991 and 1992 [4].

The research for this TBD did not reveal the level of air concentrations or other workplace indicators that triggered special bioassays before 1991 [5].

In 1989, Pantex contracted with Delphi Groupe to develop the Historical Exposure Records System (HERS), an electronic database that contains the best-available personnel dose data. Original personnel dose records were reviewed, discrepancies identified and corrected, and data entered in the database. This effort reconstructed and included missing, incomplete, and invalid doses. It included records from 1957 to 1983, with the exceptions of March 1976 and December 1979 because data were not available for those months (BWXT Pantex 2000). HERS reports are available for several contamination events that occurred in 1989, but earlier data were not easy to extract from the files. The dose records in the worker or claimant files contain the HERS data, but those data do not include bioassay data. As of 2007, a review of all worker files in the NIOSH Office of Compensation Analysis and Support Claims Tracking System (NOCTS) revealed that only 10% of the files had any bioassay data and most of the data were for tritium results. Only 3% of the files had uranium bioassay results and all but one of the results were for samples that were collected since 1986. No plutonium or thorium bioassay results were found in the NOCTS files. Table 5-1 provides a historical perspective of bioassay practices at Pantex from 1972 to 2002. The table lists the number of workers monitored for the radionuclides of interest for each year.

In early 1992, several workers' bioassay samples were performed by Controls for Environmental Pollution (CEP), a commercial analytical laboratory. However, there were technical and legal issues associated with any analyses performed by the CEP. For this reason, no worker's samples results which indicated that the analysis was performed by the CEP may be used for the assessment of intake and internal dose reconstruction (CEP 1992).

5.1.5 Current Internal Dosimetry Practices

In the late 1980s and early 1990s, several actions resulted in the current internal dosimetry program. First, there were new regulations from DOE [Order 5480.11 (DOE 1988), the RadCon Manual (DOE 1992), and 10 CFR Part 835]; second, a new contractor came to the site; and third, several workplace incidents occurred that demonstrated the need to improve the internal dosimetry program [6].

The Pantex Plant radiation protection program uses engineering and administrative controls to prevent intakes. However, because of the quantities of tritium, plutonium, uranium, and thorium that have been handled at the Plant, there is the possibility of an accidental intake resulting in 100-mrem committed effective dose equivalent (CEDE or $H_{E,50}$) (BWXT Pantex 2001).

Table 5-1. Number of workers with bioassay monitoring (BWXT Pantex 2005).

Year	Tritium	Uranium	Thorium	Plutonium
1972	4	0	0	0
1973	1	0	0	0
1974	0	0	0	0
1975	0	0	0	0
1976	463	0	0	0
1977	466	0	0	0
1978	519	0	0	0
1979	712	0	0	0
1980	14	0	0	0
1981	41	0	0	0
1982	5	0	0	0
1983	0	0	0	0
1984	0	0	0	0
1985	17	0	0	0
1986	626	0	0	0
1987	481	0	0	0
1988	499	0	0	0
1989	212	0	0	0
1990	2,341	46	0	0
1991	1,115	431	0	0
1992	879	239	17	12
1993	1,078	90	0	0
1994	1,104	138	4	3
1995	971	37	90	33
1996	940	69	56	17
1997	933	89	13	18
1998	610	12	1	2
1999	554	13	16	1
2000	535	33	9	8
2001	512	65	16	1
2002	511	57	11	10
2003	441	87	25	9
2004	421	109	15	0

According to BWXT Pantex (2001), the purpose of the current internal dosimetry program is to detect intakes equal to or greater than 10 mrem $H_{E,50}$ based on International Commission on Radiological Protection (ICRP) Publication 30 dose calculation methodology (ICRP 1982). To meet the requirements of 10 CFR 835.402(c), workers who might be likely to have internal $H_{E,50}$ doses higher than 100 mrem participate in the internal dose evaluation program. Pantex maintains routine bioassay monitoring programs for tritium to demonstrate compliance with 10 CFR 835.402(c). To identify intakes of actinides in a timely manner, the internal dosimetry program is tied closely to the quantification of airborne radionuclide concentrations to which workers are exposed. Pantex does not have a routine bioassay program for actinides but rather uses occurrence-based bioassay sampling to confirm intakes and calculate internal doses (BWXT Pantex 2001). Therefore, with the exception of tritium exposure, there is reliance on personal air sampling to determine the need to conduct bioassay sampling. At present, bioassay sampling occurs within 2 to 3 days of an assessment of airborne exposures exceeding 4 DAC-hr for an individual actinide (BWXT Pantex 2001). For these reasons, personnel without specific individual monitoring data listed after the applicable SEC dates were not likely to have received occupational intakes greater than those from inhalation of the reported maximum environmental airborne concentration(s) at the site.

Knowing the job title and a brief description of duties for that title can be helpful in determining the correct information to use for assessing dose. Production Technicians (also called Assembly Operators) and Radiation Safety Technicians (RSTs) typically had the highest potential for intakes of occupational radionuclides. Other workers could have incurred intakes, but the probability of incurring an intake was smaller and the magnitude of an intake, if it occurred, would have been smaller [7]. Claimant interview files might not state the same job title because the interviewee could have described the type of job rather than the job title and because job titles have changed over the years. Table 5-2 summarizes job titles, descriptions, and possibilities for intakes.

Table 5-2. Job titles and descriptions of work with possibility for occupational intake [8].

Job title	Description of work	Possibility for intake (1 highest)[a]
Production Technician, Assembler, Assembly Operator, Assembly Fabrication	Assembles, disassembles, reassembles, inspects components.	1
Quality Assurance Technician I	Conducts nondestructive evaluations (NDEs) with linear accelerators, X-ray machines, etc.; conducts telemetry testing; performs confirmatory measurements on components, assemblies, containers, etc.	1
Quality Assurance Technician II	Performs NDEs, electronic, destructive, telemetry, and radiation measurement testing.	1
RST (entry)	Performs monitoring and sampling; collects samples; assists RST in monitoring personnel.	1[a]
RST	Performs monitoring and sampling; collects samples; performs radiation and contamination surveys; conducts surveillance work.	1
RST (Senior)	Responds to contamination or radiation alarms; performs surveillance, monitors radiation conditions in workplace.	1
Firing Site Technician	Includes hydroshot operators, drivers, anyone involved with cleanup of hydroshot contamination.	1
Not known, possibly drivers or teamsters	Includes burning of HE and cleanup of ash at burning ground.	1
Material Handler (pits and cans)	Operates material handling/moving equipment; transports material; loads and unloads materials and containers.	2
Operations Manager, Production Supervisor	Supervises personnel engaged in manufacturing, assembly, packaging, material control, etc.	2
Quality Control Inspectors/ Auditors	Conducts special audits; different from quality assurance technicians.	2
Security, protective force, guard	Performs per job title.	2[b]
Engineer, engineering	Performs variety of tasks associated with design, testing, procedure development.	2[c]
Machinist	Machining on DU for one weapon design only.	1[a]
Metrology laboratory staff	Performs nonradiological metrology calibrations.	Environmental only
Fireman	Performs per job title.	Environmental only
Computer Programmer, Electronic Data Processing Analyst	Performs computer programming, maintenance.	Environmental only
Secretary, Administrator, Technical Writer, non-operations management, Planner	Performs per job title.	Environmental only
Tool and die maker	Performs per job title.	Environmental only

Job title	Description of work	Possibility for intake (1 highest)[a]
Food service	Performs tasks associated with operation of cafeteria.	Environmental only
Stores Stockman, Clerk, Supervisor	Performs tasks associated with general stores.	Environmental only

a. Based on actual contact with components or contamination or RSTs assisting potentially contaminated personnel.
b. In general, security personnel had little chance of intakes; however, some small intakes from contamination in cells or igloos are possible. The default assumption is to place security personnel in category 2; however, based on other information in the file, the dose reconstructors can assign environmental intakes only if they believe the worker's tasks did not involve entry into cells, Gravel Gerties, igloos, or locations with resuspendable contamination [9].
c. Engineering tasks cover a wide range, and most have no potential for intakes. However, some tasks might have involved observations during assembly or disassembly work or observations during hydroshots. If the engineer did not have a dosimeter or never had recordable dose, assign environmental dose only unless there is information in the file to indicate otherwise.

5.1.6 Pantex Workers at Other AEC/DOE Facilities

Due to the nature of the work at Pantex, workers were sometimes required to temporarily perform their duties at other U.S. Atomic Energy Commission (AEC)/DOE facilities (e.g., the Nevada Test Site (now Nevada National Security Site), modification centers, national laboratories, etc.) and might have been monitored for occupational radiation exposures by Pantex, the temporary work location, or concurrently by both facilities. In such cases, all available monitoring records should be used to assign claimant doses.

5.2 RADIONUCLIDES WITH POTENTIAL FOR INTERNAL DOSE

Only five groups of radioactive materials are of concern for occupational intake at Pantex: tritium, uranium, thorium, plutonium, and radon progeny (BWXT Pantex 2001). BWXT Pantex (2001) discusses the first four radionuclides; the latest version of ORAUT-TKBS-0013-2, *Pantex Plant – Site Description* (ORAUT 2007) discusses processes and locations where radioactive material could have been present.

5.2.1 Tritium

The principal sources of tritium at Pantex were and are the weapons components known as *reservoirs*, which first arrived at Pantex in late 1956 or early 1957 (Martin 2004). A Cockcroft Walton neutron generator in use before 1956 produced some tritium in the off-gas, and titanium tritide particulate contamination probably existed in the target and the area where the drift tube connected to the target, but the amount would have produced negligible intakes [10]. Tritium sealed under high pressure in the reservoir units has the potential to leak during disassembly. BWXT Pantex (2001) states that tritium could leak through reservoir materials, which presumably refers to concern for migration of molecular tritium through welds. The tritium in the reservoirs is 99% gaseous molecular hydrogen (DT, HT, or T_2) and 1% tritiated water vapor (HTO or T_2O) (BWXT Pantex 2001). Tritium gas interacts over time with moisture in the air, hydrogenated materials (e.g., hydrocarbons, organic compounds, and concrete), and some forms of metals to form tritiated compounds and metal tritides (Peterson and Davis 2002).

Tritium gas is far less hazardous than tritiated water, organically bound tritium, or metal tritides, but it combines with water vapor in the air or body tissues to form compounds (Johnson and Hill 1993). Of particular importance is tritiated water, which the human body absorbs. Elemental tritium is not absorbed through the skin to a significant degree. Tritiated water vapor is readily absorbed through the skin and lungs and retained in the body. Tritiated water that enters the body is chemically

identical to ordinary water and is distributed throughout the entire mass of body water (Johnson and Hill 1993).

5.2.1.1 Internal Assessment for Tritium During Routine Operations

Notes: For tritium, *uptake* refers to total tritium distributed in body fluids regardless of mode of intake. Uptake can be thought of as *total intake* and includes skin absorption. Uptake is equivalent to *whole body* in the Integrated Modules for Bioassay Analysis (IMBA) program, and is the product of the urine concentration in activity per liter multiplied by 42 L of body fluids.

The following discussion makes no distinction between *annual dose* and *committed dose*.

Because the tritium uptakes discussed in this section were determined from Pantex dose calculations, which in turn were determined from urine samples, dose reconstructors should consider uptakes to be considered HTO (inorganic tritium in IMBA) unless otherwise noted in a worker's records.

Pantex analyzed tritium bioassays on the site. For workers assigned to the tritium bioassay program, the frequency of monitoring was monthly. In addition, there were bioassays for new hires and terminations (although it is not clear if this was for all new hires or just those expected to be in the bioassay program). In addition, for each month, one-twelfth of the worker population received an annual urinalysis (Alley 1990).

The following tritium discussion deals with two periods: 1956 to 1971 and 1972 to the present. The discussion explains the selection of those periods.

The extent of a routine tritium bioassay program before 1972 is unclear although there are indications of sampling of about 10 workers per month in the 1960s [11]. Because there is little evidence that workers were monitored for tritium before 1972, dose reconstructors should interpret routine occupational records before 1972 that show "0" for internal dose to mean that no information is available rather than to indicate a dose below detectable levels [12]. Dose records in the 1990s specifically state monitored internal emitters (and give a dose) or state not monitored as "N/M." Only a few NOCTS files had tritium bioassay results for years before 1972. However, the detection sensitivity was poor for the analytical method used, and the results are therefore not a good indicator of true exposure levels. Tritium doses in the files should be treated the same as those for 1972 to 1982 as described below.

From 1972 to the present, although tritium bioassay occurred, there are few routine monitoring data in individual worker dosimetry records. A few urinalysis records for 1972 show consistent use of 0.25 µCi/L as a less-than value (MHSMC 1983). A batch of urinalysis records for 1983 shows background counts per minute, gross counts per minute, and final concentrations in microcuries per liter. It appears that Pantex recorded nonzero concentrations when the gross counts per minute exceeded the square root of twice the background counts per minute, which would be a decision level. The smallest nonzero concentration recorded was 0.023 µCi/L, so 0.05 µCi/L would be a reasonable estimate of the minimum detectable activity (MDA) at that time (MHSMC 1983). *Technical Basis for the Internal Dosimetry Program and the DOE Pantex Facility* (Battelle 1992) lists the tritium urinalysis "detection limit" as 14 dpm/mL (0.0063 µCi/L). Although it does not state so directly, this document implies that this is the MDA. BWXT Pantex (2001) lists the tritium urinalysis minimum detectable activity (MDA) as 15 dpm/mL (0.0068 µCi/L).

Based on the scarcity of individual claimant data, more conservative MDAs were used in the determination of potentially missed and unmonitored tritium doses. For 1956 to 1990, an MDA of 0.500 µCi/L [13] was assumed. For 1991 through the present, an MDA of 0.135 µCi/L [14] was assumed (Table 5-3). However, in cases where individual claimant data are present in the monitoring records, the missed or fitted dose should be calculated based on the claimants' monitoring data.

Table 5-3. Internal dose for missed and unmonitored tritium intakes.

Year	Maximum undetected individual annual tritium dose (mrem)[a]	Maximum annual undetected intake (µCi)	Mode of the annual undetected individual annual tritium dose (mrem)	Mode of the annual undetected intake (µCi)
1956–1990	42	619	21	309
1991–present	12	167	6	83.5

a. Calculated based on 1 month of chronic exposure assuming detection limits of 0.500 µCi/L through 1990 and 0.135 µCi/L for 1991 through the present, and normalized for annual intake using the ICRP Publication 68 dose coefficient of 0.067 mrem/µCi (ICRP 1995). Note that these values exceed any recorded doses or intakes the site reported for any year of operation, including 1989 when a major tritium released occurred.

5.2.1.1.1 Dose to Uptake

The most complete set of tritium information consists of maximum and average doses for 1972 to 2001 (Table 5-3). Because it is likely that the dose reconstructor will find only tritium doses rather than actual bioassay results in the worker files, Attachment C provide methods to convert from recorded dose to uptake (for input into IMBA or the tritium tool).

5.2.1.2 Unmonitored Workers, 1956 to 1971

During weapons assembly, there was little chance that tritium could leak because workers did not manipulate the valves on the tritium reservoir [15]. A very small amount of tritium migration through reservoir welds occasionally occurred, which is why workers surveyed the reservoirs on arrival [16]. However, weapons brought in for inspection, repair, or disassembly provided a possibility for a small release of tritium and subsequent intake for Production Technicians (Assembly Operators), RSTs, and Quality Assurance Technicians. Around 1980, disassembly of weapons became more frequent than assembly, and releases were more likely to occur [17].

5.2.1.3 Unmonitored Workers, 1972 to the Present

It is unlikely that unmonitored workers had higher intakes than monitored workers. However, for the period from 1972 to 1976 and for 1984, there was little or no tritium bioassay monitoring (BWXT Pantex 2005). During the years in which monitoring occurred, there is no guarantee that everyone exposed to tritium was monitored. Nevertheless, for Production Technicians (Assembly Operators), RSTs, and Quality Assurance Technicians, tritium uptakes were possible. This analysis estimated uptakes for unmonitored workers in these job categories using Table 5-3 values; the average uptake was not allowed to become less than that which would result in a dose of 6 mrem/yr [18]. Dose reconstructors should consider tritium uptakes for unmonitored Production Technicians (Assembly Operators), RSTs, or Quality Assurance Technicians to be a triangular distribution with the modes and maximums in Table 5-3 and minimums of zero.

There is no reason to expect workers other than Production Technicians (Assembly Operators), RSTs, and Quality Assurance Technicians incurred uptakes of tritium other than from environmental sources [19].

5.2.1.4 Tritium Release Event in 1989

During a release event in 1989, significant amounts of tritium were released and four workers were exposed. This event is reasonably well documented, and data are available for assessment. Data on this event are from two primary sources: an interoffice memorandum with worker exposure records information (Griffis 1990) and a classified document. An individual had an acute tritium exposure at 2:30 p.m. (1430) on May 17, 1989. No alpha contamination was found on the individual. Urine specimens were taken 2 and 4 hours after the incident. According to unclassified information from the classified report, the first bioassay occurred at 4:30 p.m. using a 0.5-mL aliquot specimen pipetted into 10-mL Biofluor. This sample was analyzed using a Tri-Carb Model 2250 CA liquid scintillation counter. The tritium activity was 291,000 dpm, which was equivalent to 262 µCi/L of tritium.

The individual received medical care for the intake that included many special urine and blood samples and mandatory forced fluids. Urinalysis results are in the worker's records and are summarized in a letter from the Medical Director (Lang 1990).

The latest version of ORAUT-TKBS-0013-4, *Pantex Plant – Occupational Environmental Dose*, addresses the environmental release from this incident (ORAUT 2014b).

5.2.1.5 Assignment of Tritium Doses for Production Technicians (Assembly Operators), RSTs, and Quality Assurance Technicians, 1956 to Present

For workers in which the monitoring records indicate that the individual was monitored for tritium intakes and for production technicians, RSTs, and Quality Assurance Technicians, tritium dose should be assigned using Table 5-3 as a triangular distribution using zero and the mean and maximum from Table 5-3). On occasion, the monitoring records have the individual specific monitoring results. Please refer to Attachment A, Examples of Pantex Plant Bioassay Data Files, for examples of the layout of the data files when individual specific monitoring data are available.

5.2.2 Uranium

5.2.2.1 Background

Uranium at Pantex was enriched (EU), natural, or depleted (DU). Natural uranium was in a form referred to as Tuballoy. EU was in a sealed component with little likelihood of release. No data are available to indicate that EU was ever a contaminant in the workplace. The internal dosimetry technical basis document (Battelle 1992) stated, "All of the unsealed uranium used at the Pantex facility is either depleted uranium or natural uranium." DU manufactured after 1952 could have contained contaminants from movement of recycled uranium and DU throughout the Portsmouth, Paducah, K-25, and Y-12 sites. Exact levels of contaminants in Pantex DU have not been discovered and probably varied from batch to batch. As an upper bound, dose reconstructors should add the following intakes of contaminants to DU intakes: 307 pCi ^{239}Pu/g DU, 3.53 pCi ^{237}Np/g DU, and 509 pCi ^{99}Tc/g DU [20].

According to BWXT Pantex (2001) and interviews with workers, uranium contamination at Pantex is either uranium metal or air-oxidized uranium. Exceptions would be the burning of DU-contaminated HE components at the burn pads and explosion of DU during hydro tests, which would have produced some thermally oxidized DU. BWXT Pantex (2001) states that uranium compounds at Pantex are assumed to exhibit class Y inhalation behavior. However, an earlier internal dosimetry technical basis document (Battelle 1992) used an assumption of 80% class Y and 20% class W. Neither assumption was based on solubility studies of actual Pantex contamination. Because oxides of uranium can exist over a range of solubility, dose reconstructors should assume either absorption type M or S to

maximize the dose to the specific organ of concern. Exposure to significant quantities of type F uranium at Pantex is not credible [21].

Because components are new during assembly operations, there is little likelihood that significant removable DU oxide would have been on them. During disassembly, aged uranium components from certain weapons programs had a coating of oxide in the form of black dust that was potentially present as airborne contamination [22]. Uranium oxide became most noticeable beginning in the early 1980s and was present on eight of the 31 weapons types that were disassembled at Pantex to date, with types 28 and 55 apparently having the highest contamination from black dust according to worker interviews. Following a contamination event in 1989, consideration for preventing contamination by uranium oxide resulted in modifications to disassembly operations, such as the use of downdraft tables.

Some DU was released at the burning grounds from burning of contaminated HE and at the hydro test firing sites when hydro tests involved DU components (Firing Sites 4, 5, and 10 only). In addition, one weapon design required machining of DU-contaminated metal [23].

There is no evidence that workers were routinely monitored for uranium before 1991 and there are numerous references that indicate that bioassay was not performed routinely but rather only when there was a known release [24]. Dose records in the 1990s specifically state whether internal emitters were monitored (and give a dose) or not monitored (N/M). Pantex provided routine urinalysis of uranium in 1991 and 1992 [25]. The technical basis document at the time (Battelle 1992) stated that the uranium urinalysis method was isotopic analysis using alpha spectrometry that "can detect 0.03 pCi/isotope/sample." The document reported an environmental background urinary excretion rate of 0.15 dpm/d of ^{238}U based on studies of potentially exposed and unexposed Pantex workers. This environmental screening level was carried over to the internal dose assessment procedure (MHSMC 1991b), which indicated that dose assessment was to occur for any uranium result with a net activity greater than or equal to 0.15 dpm/d. Battelle (1992) stated that the 0.15-dpm/d screening level would not apply if isotopic ratios implied that the uranium did not derive from DU.

Since 1993, monitoring of uranium exposures has been event driven and is initiated by air-monitoring data. Since the middle 1990s, Pantex has used lapel air samplers to monitor for intakes and trigger bioassay measurements. Because Pantex has performed bioassays on more than 300 workers since 1993 (see Table 5-4), the implication is that there must have been workplace indicators of potential uranium intakes [26]. *Analysis of Biological Samples for Uranium, Thorium, and/or Plutonium* (MHSMC 1991a) provided the following workplace indicators that would trigger bioassay:

- *All personnel … not wearing … respiratory protection whose tracked internal annual exposure is equal to 40 DAC-hours*
- *All personnel whose breathing zone monitor indicates that they have been exposed to 40 DAC-hours* [also lists the DAC for ^{238}U as 6×10^{-11} µCi/mL]
- *All personnel found to have skin contamination equal to or greater than … 1000 dpm/100 cm^2 ^{238}U.*

BWXT Pantex (2001) decreased the trigger value for special bioassay: "Special bioassay samples are collected (usually within 2 to 3 days) when airborne exposures exceed 4 DAC-hours for any single actinide (i.e., >4 DAC-hours for ^{239}Pu, ^{232}Th, or ^{238}U creates an occurrence)." This analysis has not determined exactly when the change occurred between 1991 and 2001.

Table 5-4. Uranium dose to workers.[a]

Year	Workers monitored for uranium	Total worker uranium dose (person-mrem)	Maximum individual uranium CEDE (mrem)	Average worker uranium CEDE (mrem)
1990	46	0	0	0
1991	431	109	109	0.25
1992	239	778	502	3.3
1993	90	76	15	0.84
1994	138	0	0	0
1995	37	0	0	0
1996	69	0	0	0
1997	89	0	0	0
1998	12	0	0	0
1999	13	0	0	0
2000	33	0	0	0
2001	65	0	0	0
2002	57	0	0	0
2003	87	10	7	0.11
2004	109	0	0	0

a. Developed from data in DORMS.

Table 5-4 lists recorded doses (CEDE) from uranium exposures from 1991 to 2004 from the facility's dosimetry records management system (DORMS). Although these doses are not directly relevant to dose reconstruction, the overall trend is indicative of reduced uranium intakes after 1993.

The weight percent and activity fractions of radionuclides of DU and even natural uranium can be variable. Values were listed in the 1992 version of the internal dosimetry technical basis document (Battelle 1992), but their origin was not stated and they were not mentioned in BWXT Pantex (2001). The 1992 values are not significantly different from the default values in the IMBA program, so dose reconstructors should use the IMBA values for consistency.

5.2.2.2 Uranium Reporting Levels or Minimum Detectable Activities

For most of its history, Pantex followed an event-driven approach to uranium bioassay and used many laboratories, so the records for bioassay results are spotty [27]. Table 5-5 summarizes information found in claimant records. For the years prior to 1990, the MDA value in the table was based on the observed less than values listed in the records.

Table 5-5 has temporal gaps likely associated with the absence of bioassay sample submissions for the years in which no data were listed. This is due to the fact that uranium bioassays were generally not obtained routinely but usually driven based on special bioassay samples after events with potential for intake. If necessary, dose reconstructors should use the last previous MDA for years not covered in Table 5-5.

Most documentation of uranium exposure at Pantex focuses on DU, but BWXT Pantex (2001) mentions the possibility of exposure to natural uranium. When interpreting bioassay data, if the type of uranium exposure is not known, it is favorable to claimants to assume the intake was natural uranium (0.685 pCi/µg) (BWXT Pantex 2001).

5.2.2.3 Assessment of Uranium Intake and Internal Dose

Because of the SEC Class, assessment of uranium intakes at Pantex is limited to actual data in the monitoring records. Dose reconstructors should assess occupational intakes in accordance with the guidance in ORAUT-OTIB-0060, *Internal Dose Reconstruction* (ORAUT 2014a). On occasion, the monitoring records have the individual specific monitoring results. Please refer to Attachment A,

Table 5-5. History of uranium urinalysis.[a]

Year	Laboratory	MDA Value
1959	Los Alamos Scientific Laboratory	0.5 µg[b]
1960	Tracer Laboratory	10 µg/L[b]
1963	Controls for Radiation	0.10 µg/L[b]
1965	Controls for Radiation	0.10 µg/L[b]
1967	Controls for Radiation	0.15 µg/L[b]
1968	Isotopes, Inc.	0.10 µg/L[b]
1983	Camp Dresser & McKee	3.30 pCi/L[b] [28]
1983	Los Alamos Scientific Laboratory	5.0 µg/L
1990–2001	Y-12 Bioassay Laboratory	0.15 dpm/d[c][29]

a. ORAUT 2012.
b. From reports from the laboratories (Author unknown 1952; MHSMC 1978; MMES 1990a).
c. The value of 0.15 dpm/d is a conservative estimate of the total uranium MDA for samples processed at the Y-12 National Security Complex after 1989 [30].

Examples of Pantex Plant Bioassay Data Files, for examples of the layout of the data files when individual specific monitoring data are available. However, if the monitoring data indicates that the analyses were performed by CEP, those data should not be used for the assessment of intake and the assignment of internal dose.

5.2.2.4 Thorium

Thorium at the Pantex Plant exists as thorium metal, thorium alloys, or materials impregnated with a thorium compound. Workers handle these forms during assembly and disassembly of certain weapons. Because of the relative hazard of thorium, Pantex uses strict workplace monitoring practices, such as smear checks of components, to verify the integrity of the thorium encapsulation. It is assumed that workers could have encountered oxidized thorium components during disassembly of weapons. Pantex has never conducted machining of components containing thorium [31].

Information on source terms of weapons containing thorium is classified, as is the number or percentage of weapons that contain thorium. However, there is strong indication that controls for contamination have always been in place, as has workplace monitoring for thorium [32].

Natural sources of thorium can exist in rocks and soils (see the latest version of the Pantex TBD on occupational environmental dose (ORAUT 2014b). Thorium can be present in measurable amounts in biological materials in the environment; ingestion of these materials can result in measurable quantities of thorium in bioassay samples collected from workers. Baseline bioassay measurements have shown this to be true. Pantex determined the amount of thorium that is naturally present in baseline bioassay samples for its workers (BWXT Pantex 2001).

Levels of ^{232}Th and ^{228}Th were analyzed in baseline fecal samples. Environmental levels of ^{232}Th and ^{228}Th were determined using a lognormal probability analysis on the bioassay data in accordance with *A Guide for Environmental Radiological Surveillance at U.S. Department of Energy Installations* (Corley et al. 1981). The 95th-percentile results for background levels of thorium in fecal samples were 0.4 dpm/sample (0.18 pCi/sample) of ^{232}Th and 0.39 for the ^{232}Th:^{228}Th ratio. Results that exceed both screening levels are assumed to represent occupational exposure and are adjusted to a net occupational excretion by subtracting the arithmetic mean background excretion rate of 6.7×10^{-2} dpm/sample (3.0×10^{-2} pCi/sample) from ^{232}Th fecal results (BWXT Pantex 2001, p. 80).

BWXT Pantex (2001) states that thorium at the Plant is inhalation class Y, which would be essentially equivalent to absorption type S. This is consistent with the ICRP Publication 68 recommendation that thorium oxides are type S (ICRP 1995). Although processing of thorium at Y-12 and Hanford created

disequilibrium between ^{232}Th and ^{228}Th, material handled at Pantex would have aged long enough that a significant amount of ^{228}Th would have grown back, especially for weapons being disassembled [33]. The dose reconstructor should assume equilibrium without evidence to the contrary [34].

There is no evidence that workers were routinely monitored for thorium before 1991, and there are numerous references that indicate that bioassay was not performed routinely but rather only when there was a known release [35, 36]. Monitoring of thorium exposures has been event-driven since at least 1991 [37]. The procedure *Analysis of Biological Samples for Uranium, Thorium and/or Plutonium* provided criteria for when thorium bioassay monitoring was required (MHSMC 1991a). To summarize, the criteria were exposure to 40 DAC-hr of thorium in the workplace air after accounting for use of respiratory protection, if applicable, or skin contamination equal to or exceeding 200 dpm/100 cm^2. The only reported doses have occurred since 1999 [38]. This analysis found no bioassay data before 1983.

5.2.2.5 Assessment of Thorium Intake and Internal Dose

Because of the SEC Class, assessment of thorium intakes at the Pantex Plant is limited to actual data in the monitoring records. If the monitoring results indicate that the individual was monitored for occupational intakes of thorium, dose reconstructors should assess occupational intakes in accordance with the guidance in ORAUT-OTIB-0060, *Internal Dose Reconstruction* (ORAUT 2014a). If unmonitored, dose reconstructors should assume occupational intakes of thorium were unlikely and assign no thorium internal dose. On occasion, the monitoring records have the individual specific monitoring results. Please refer to Attachment A, Examples of Pantex Plant Bioassay Data Files, for examples of the layout of the data files when individual specific monitoring data are available. However, if the monitoring data indicates that the analyses were performed by CEP, those data should not be used for the assessment of intake and the assignment of internal dose.

5.2.3 Plutonium

5.2.3.1 General Information

Plutonium at Pantex is in the encapsulated pits of nuclear weapons. Workers handle the pits during weapons assembly and disassembly. Strict workplace monitoring practices ensure the integrity of the encapsulation including contamination smear checks during assembly and disassembly (BWXT Pantex 2001). If contamination occurred, exposure to plutonium would be acute rather than chronic. Table 5-6 lists the numbers of workers given plutonium bioassay by year. There were no recorded internal doses associated with these 1991 to 2002 bioassays.

Because the plutonium was encapsulated, it was assumed that the potential for intake was rare (i.e., intakes would have been acute rather than chronic) [39]. BWXT Pantex (2001) states that plutonium at the Plant should be considered an aged weapons-grade mixture. For the following discussion, the intake activities are for the total alpha activity of the mixture. Dose reconstructors should assume the 20-year aged mixture [40]. Table 5-7 lists the composition of weapons-grade plutonium mixtures. Because the source of intake would have been plutonium oxides, dose reconstructors should assume inhalation type S (ICRP 1994).

5.2.3.2 Assessment of Plutonium Intake and Internal Dose After 1983

Because of the SEC Class, assessment of plutonium intakes at the Pantex Plant is limited to actual data in the monitoring records. If the monitoring results indicate that the individual was monitored for occupational intakes of plutonium, dose reconstructors should assess occupational intakes in accordance with the guidance in ORAUT-OTIB-0060, *Internal Dose Reconstruction* (ORAUT 2014a). If unmonitored, dose reconstructors should assume occupational intakes of plutonium were unlikely

Table 5-6. Number of workers on plutonium bioassay, 1991 to 2002 [41].

Year	Number of workers monitored for plutonium
1991	0
1992	12
1993	0
1994	0
1995	28
1996	17
1997	18
1998	2
1999	1
2000	8
2001	1
2002	10
2003	9
2004	0

Table 5-7. Activity composition of weapons-grade plutonium mixtures from Hanford.[a]

Mixture designation:	Fresh	5-yr	10-yr	15-yr	20-yr	25-yr	30-yr
Years of aging:[b]	0	5	10	15	20	25	30
Specific activity in mixture (Ci/g)							
Pu-238	8.56E-03	8.23E-03	7.91E-03	7.60E-03	7.31E-03	7.03E-03	6.75E-03
Pu-239	5.77E-02	5.77E-02	5.77E-02	5.77E-02	5.77E-02	5.77E-02	5.77E-02
Pu-240	1.36E-02	1.36E-02	1.36E-02	1.36E-02	1.36E-02	1.36E-02	1.36E-02
Pu-241	8.24E-01	6.48E-01	5.09E-01	4.00E-01	3.15E-01	2.48E-01	1.95E-01
Pu-242	1.97E-06	1.97E-06	1.97E-06	1.97E-06	1.97E-06	1.97E-06	1.97E-06
Am-241	0	5.83E-03	1.04E-02	1.39E-02	1.66E-02	1.87E-02	2.03E-02
Pu-239+240	7.13E-02	7.13E-02	7.13E-02	7.13E-02	7.12E-02	7.12E-02	7.12E-02
Pu-alpha	7.99E-02	7.95E-02	7.92E-02	7.89E-02	7.85E-02	7.83E-02	7.80E-02
Total alpha	7.99E-02	8.53E-02	8.96E-02	9.28E-02	9.52E-02	9.70E-02	9.83E-02
Activity ratios							
Pu-239+240: total alpha	1.00	0.836	0.796	0.768	0.749	0.735	0.725
Pu-238: total alpha	0.107	0.0965	0.0883	0.0819	0.0768	0.0725	0.0687
Pu-241: total alpha	10.3	7.60	5.68	4.31	3.31	2.56	1.98
Am-241: total	0	0.0684	0.116	0.150	0.174	0.193	0.207

a. BWXT Pantex (2001) did not provide a table of isotopic mixtures. The Hanford mixtures should be close enough for the default assumptions. The total alpha specific activity changes only about 10% from 10 to 30 years of aging.
b. Time since separation of ^{241}Am from the Pu mix.

and assign no internal dose from plutonium intake. On occasion, the monitoring records have the individual specific monitoring results. Please refer to Attachment A, Examples of Pantex Plant Bioassay Data Files, for examples of the layout of the data files when individual specific monitoring data are available. However, if the monitoring data indicates that the analyses were performed by CEP, those data should not be used for the assessment of intake and the assignment of internal dose.

5.3 ASSESSING OCCUPATIONAL INTERNAL DOSE FROM ELEVATED RADON

Uranium occurs naturally in virtually all soils, with average levels of about 1 part per million. Radium-226 is typically in secular equilibrium with ^{234}U and decays to ^{222}Rn with a half-life of 1,600 years. Therefore, the noble gas ^{222}Rn is continuously produced in soil where it can be trapped in the crystalline structure of minerals or released to the interstices between solid materials. In the absence of buildings, ^{222}Rn produced within a meter or so of the soil surface can diffuse into the

atmosphere where diffusion and advection dilute it with outdoor air (NCRP 1984a). During the 1980s, it was discovered that buildings with heating and air conditioning tend to operate at slightly negative pressure [a few tens of pascals, less than 1 in. (water gauge)] in comparison to outdoor air. As a result of this negative pressure, soil gas tends to flow actively into indoor air, where it can build to higher levels than outdoors due to limited air changes and relatively small dilution volumes. This phenomenon is an example of technological enhancement of natural radioactivity (NCRP 1984a, 1984b, 1987).

While the general characteristics of areas with potential for elevated levels of indoor radon as well as construction designs that tend to enhance radon levels are known, it is rarely possible to predict indoor radon levels for a given structure. In general, structures that exhaust air to the environment without adequately engineered replacement air have higher indoor radon levels than structures that do not do this, and structures that have exposed soil (dirt floors, sumps) or exposed minerals (e.g., gravel) tend to have higher radon levels. Underground structures have a higher ratio of soil surface to building volume. All other factors being equal, an underground building would be likely to have a higher radon concentration than an aboveground building.

Thorium has ^{220}Rn progeny that is a radioactive noble gas, commonly called thoron, which has a much shorter half-life (55.6 seconds) than its parent. In general, ^{220}Rn decays before it can build up to significant levels unless there are large quantities of ^{232}Th and its decay products present. There is no reason to expect that Pantex had ^{220}Rn of significance. Work on thorium weapon components was less frequent.

5.3.1 Dose from Radon-222 Progeny

Radon itself produces far less dose to the bronchial epithelium than its progeny. Because radon progeny measurements are more difficult to obtain, measurements of radon are often used as a surrogate for progeny measurements. Radon progeny concentrations are expressed as the quantity potential alpha energy concentration (PAEC), traditionally measured in working levels (WL). Originally, 1 WL was defined as 100 pCi/L (1×10^{-10} Ci/L = 1×10^{-7} Ci/m^3 = 1×10^{-7} µCi/cm^3) of radon in equilibrium with its short-lived decay products. At present, 1 WL is usually defined as any combination of short-lived radon decay products in 1 L of air, without regard to the degree of equilibrium, that will result in the ultimate emission of 130,000 MeV of potential alpha energy per liter of air. This is almost identical to the original definition. Time-integrated exposures to radon progeny are expressed in the quantity potential alpha energy exposure (PAEE), which are traditionally measured in working level-months (WLM) and defined as exposure to 1 WL for 170 hours or any equivalent concentration and time product (ICRP 1981).

5.3.2 Radon Monitoring at DOE Facilities

In 10 CFR 835.2(a), DOE states, "*Background* means radiation from … radon and its progeny in concentrations or levels existing in buildings or the environment which have not been elevated as a result of current or prior activities…." Because background is specifically excepted from monitoring requirements, DOE and its contractors generally do not monitor for radon and its short-lived decay products. However, if radon and its progeny are elevated due to DOE activities, then DOE requires monitoring. This has been the policy of DOE and its predecessor agencies [42] (the U.S. Energy Research and Development Administration, the AEC, and the Manhattan Engineer District).

5.3.3 Underground Buildings

At Pantex, the Gravel Gertie cells are in Buildings 12-44, 12-85, 12-96, and 12-98, which are considered to be underground even though they are not below grade. Bays, which are also considered underground, are in Buildings 12-17, 12-19, 12-21, 12-56, 12-64, 12-84 East, 12-84 West,

12-99, 12-104, and 12-117. Workers in these buildings were likely to have greater exposures to radon and its decay products than workers in other buildings [43].

5.3.4 Radon Concentrations

A DOE-wide survey of radon levels (UNC Geotech 1990) sampled 137 locations at Pantex and made duplicate measurements at 13 locations. Attachment B lists complete survey data.

Eight buildings at Pantex measured above 4 pCi/L (4×10^{-9} µCi/cm^3), which is the U.S. Environmental Protection Agency reference point for considering remedial action for indoor radon (UNC Geotech 1990). As listed in Table 5-8, the average for all buildings was 1.62 ±1.24 pCi/L with a geometric mean (median) of 1.37 pCi/L and a geometric standard deviation (GSD) of 1.68. Values ranged from 0.8 to 8.1 pCi/L. Underground buildings had a higher average, and aboveground buildings had a lower average.

Table 5-8. Summary statistics of 1990 radon measurements [44].

Parameter	All buildings	Underground buildings	Aboveground buildings
Mean (pCi/L)	1.62	1.81	1.56
Standard deviation (pCi/L)	1.24	1.35	1.21
Coefficient of variation	0.77	0.75	0.77
Geometric mean (pCi/L)	1.37	1.51	1.33
GSD	1.68	1.75	1.66
Minimum (pCi/L)	0.8	0.8	0.8
Maximum (pCi/L)	8.1	7.1	8.1
Maximum/Minimum	10.1	8.9	10.1
Count	137	31	106

Considering the uncertainty in these measurements, the average absolute difference between duplicate measurements was 0.27 pCi/L with no obvious dependence on the average value of the measurement (Figure 5-1). The average ratio was 1.03, which indicates no significant bias.

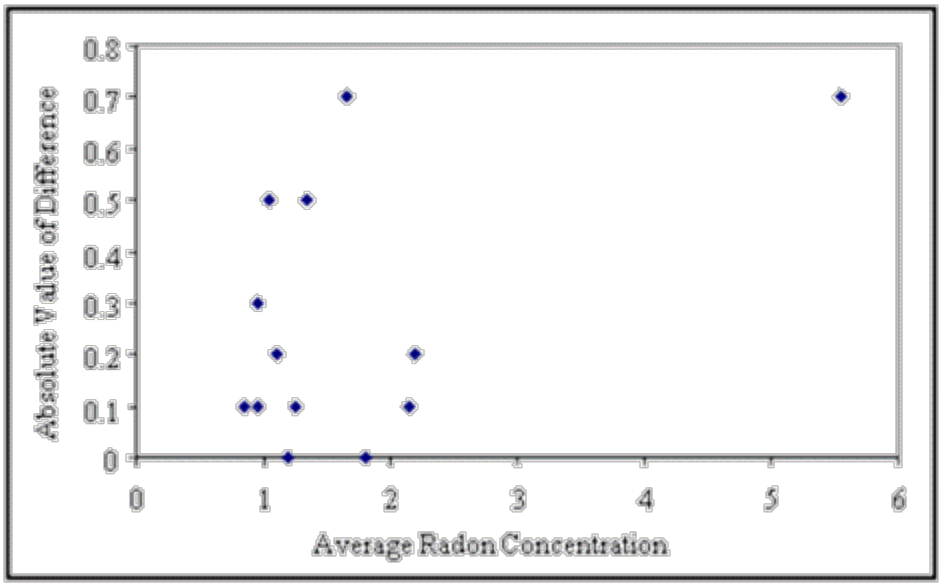

Figure 5-1. Absolute differences between duplicate radon measurements [45].

Far more important than measurement uncertainty is the issue of representativeness (i.e., an uncertainty that cannot be quantified from available measurements). Most of these Pantex

measurements were made over a 2-month period during the winter, which is normally expected to be the time with the highest radon concentrations because buildings are closed and heated most of the time [46].

There is an earlier set of radon measurements. For 6 months at the beginning of 1969, Pantex monitored radon levels in Cells 1 to 6 on a twice-monthly basis using Eberline-supplied radon film badges. The raw results were reported as number of tracks in exposed and covered areas, and the integrated radon concentration (in picocurie-hours per cubic meter) was inferred from the net number of tracks (McFall 1969). The integrated radon concentration was converted to an average radon concentration in picocuries per liter by dividing by the number of hours of exposure and multiplying by 1,000 cm^3/L. Of the 66 radon film badges issued, this TBD analysis found no record of analysis for 6, and 60 had reported analyses. Of the 60 reported analyses, 6 were damaged. Of the 54 undamaged results, 33 were reported as zero. When the zeros are included, the overall mean concentration in the cells was 4.2 ± 8.6 pCi/L with a range from 0 to 47.2 pCi/L. Fitting a lognormal distribution to all 54 points yielded a median of 1.2 pCi/L with a GSD of 6.7. This median is slightly lower than the median from the 1990 data, and the GSD is considerably larger. These results probably reflect (1) the time of year of the sampling and the longer period over which the sampling took place and (2) the difference in the sampling methods [47]. Table 5-9 summarizes the statistics from the 1969 radon datasets.

Table 5-9. Summary of 1969 radon measurements in Cells 1 to 6 [48].

Parameter	pCi/L	WL
Mean	4.24	0.0170
Standard deviation	8.58	0.0343
Coefficient of Var.	202%	
Minimum	0	0
Maximum	47.22	0.1889
Count	54	
Using 54 measurements (including 33 zeroes):		
Lognormal median	1.20	0.0048
GSD	6.70	6.70
Lognormal mean	7.33	0.0293
Lognormal std. dev.	44.2	0.1767
Using 21 nonzero measurements:		
Lognormal median	7.34	0.0293
GSD	2.47	2.47
Lognormal mean	10.91	0.0437
Lognormal standard deviation	10.89	0.0436

5.3.5 Working Level-Months

The Pantex-measured radon concentrations were converted to equilibrium equivalent concentrations by multiplying the radon concentration *C* by the equilibrium factor *F* using an assumed value of 0.4 as recommended by the ICRP (1981) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1993). The equilibrium equivalent concentration was divided by 100 pCi/L/WL to arrive at the PAEC. These operations were combined to create:

$$PAEC = C \times F / 100 \text{ pCi/L/WL} \quad (5\text{-}1)$$

where *C* is the radon concentration in picocuries per liter and *PAEC* is in WL. Dose reconstructors should multiply the PAEC by the months per year of exposure to determine the WLM for input to the Interactive RadioEpidemiological Program (IREP).

For workers who spent most of their time in a facility with an earthen cover (Level 1 from Table 5-2), dose reconstructors should use the 1990 median value for underground buildings of 1.5 pCi/L for *C* and 12 months for the period (unless the person only worked for part of a year). This results in an annual average exposure of:

$$(1.5 \text{ pCi/L})(0.4)(12 \text{ months})/100 \text{ pCi/L/WL} = 0.027 \text{ WLM/yr} \quad (5\text{-}2)$$

For workers with possible occasional entries into underground buildings (e.g., those with a risk ranking of 2 in Table 5-2), dose reconstructors should assume that the WLM are one-tenth of those from Equation 5-2 [49].

Radon exposure applies from 1958 when the Gravel Gerties were completed to the present [50]. The exposure distribution is lognormal [51]. Parameter 1 is the median value in WLM from Equation 5-2. Parameter 2 is the GSD. Dose reconstructors should use a GSD of 3 to allow for uncertainties in the application of the 1990 radon measurements to a full year (rather than only winter months) and to account for possible yearly differences in radon due to frozen ground or snow cover [52].

5.4 ATTRIBUTIONS AND ANNOTATIONS

Where appropriate in this document, bracketed callouts have been inserted to indicate information, conclusions, and recommendations provided to assist in the process of worker dose reconstruction. These callouts are listed here in the Attributions and Annotations section, with information to identify the source and justification for each associated item. Conventional References, which are provided in the next section of this document, link data, quotations, and other information to documents available for review on the Project's Site Research Database (SRDB).

[1] Hickey, Eva Eckert. Oak Ridge Associated Universities (ORAU) Team. Principal Health Physicist. April 2004.
Information on the use of the cell was verified during an interview trip.

[2] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
Review of records from data capture and interview trips revealed no routine bioassay before 1972 (see Table 5-1). Review of the HERS database confirmed this.

[3] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
Review of materials showed letters and memoranda in the 1960s that discussed bioassays. Because the statement is of a general nature and does not provide specific data, a reference was not given.

[4] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
Comment made based on data reviewed from the records in DORMS as well as discussion in the Pantex Internal Dosimetry Technical Basis Document (Battelle 1992).

[5] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
The author and others on the Pantex team repeatedly requested air-monitoring and -sampling data. They were told that the data were not retrievable and the data would not be useful for analyzing intakes from radionuclides.

[6] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
Based on discussions with Plant employees familiar with the work during data capture and interview trips to the Plant and confirmed by a former manager.

[7] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
The Cell 1 tritium incident and the W28 disassembly/uranium issues are the basis for this comment.

[8] Hickey, Eva Eckert. BPNNL. Principal Health Physicist. November 2003.
The list in this table was developed from discussions with Pantex employees, including a former manager. The list was then confirmed using information on Job Titles/Classifications from 1954 to 2003 (MHSMC 1983).

[9] Hickey, Eva Eckert, and Bihl, Donald E. BPNNL. Principal Health Physicists. April 2006.
This statement is based on discussions with Plant employees familiar with the work and with a former manager. The risk of intakes was highest in the cells during disassembly operations, but some contamination, and therefore risk of intake, might have been present in cells after disassembly operations ceased when security personnel were performing security checks. Security personnel also had potential for intake while performing duties in weapons storage igloos. Security personnel were in areas with potential for contamination only a small percentage of their work hours, as opposed to workers who were involved in disassembly operations, who spent more daily hours in potential contamination areas.

[10] Bihl, Donald E. ORAU Team. Principal Health Physicist. September 2006.
Assuming a resuspension factor of 10^{-4}/m, an acute 2-hr exposure during target changeouts, no respiratory protection, and changeouts once a year, the titanium tritide contamination level needed to produce an intake that would result in a 1-mrem dose to the lung would have been 1.6×10^{8} dpm/100 cm^2. Doses to all other organs would have been less. Although actual contamination levels have not been found, the author judged that they would have not reached this level.

[11] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. November 2005.
These data are from DORMS and were accessed November 17, 2005, by M. Prather (BWXT Pantex 2005). In addition, there was an occasional reference to bioassay in memoranda from the 1960s or 1970s. No data were available from these memoranda.

[12] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. February 2004.
Review of dosimetry records from the 1960s and 1970s often showed a zero in the column for "internal emitters"; however, there are numerous references that indicate that bioassay was not performed routinely but rather only when there was a known release. Therefore, the dose reconstructors need to be careful and not assume that a zero means that someone was monitored. The dose records in more recent years (1990s forward) clearly indicate when an individual was monitored for internal dose.

[13] Thomas, Dale D., ORAU Team, Senior Health Physicist, October 2014.
Review of the records shows that the detection limit for tritium analysis was somewhat less than 0.5 uCi/L. However, some individual records listed the detection limit as high as 0.5 uCi/L; therefore, the unmonitored tritium dose was calculated based on the higher detection limit to ensure favorability to claimants through 1990.

[14] Thomas, Dale D., ORAU Team, Senior Health Physicist, October 2014.
Similar to [13] except that the value was selected based on the highest detection limits for years after 1990.

[15] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. May 2004.
Based on discussions with Plant employees familiar with the work during data capture and interview trips to the Plant, and was confirmed by a former manager.

[16] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. May 2004.
Based on discussions with Plant employees familiar with the work during data capture and interview trips to the Plant. Confirmed by a former manager.

[17] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. May 2004.
This information was verified during an interview trip and was originally interpreted from a slide presentation from a data capture trip (BWXT Pantex ca. 2000).

[18] Bihl, Donald E. ORAU Team. Principal Health Physicist. May 2004.
The mode of the triangular distribution for tritium missed-dose calculations is 6 mrem. It was used for unmonitored workers based on the premise that unmonitored workers were at less risk than monitored workers, especially for tritium because the source of tritium exposure came from handling tritium reservoirs during disassembly. The possibility of casual exposure to tritium during the disassembly operations by unmonitored workers was considered remote because of the security and other safety requirements of the work.

[19] Bihl, Donald E. ORAU Team. Principal Health Physicist. May 2004.
Calendar year 1981 had the highest maximum uptake of any year monitored except 1989, so this value was considered favorable to claimants as a surrogate for 1989.

[20] Hickey, Eva Eckert, and Bihl, Donald E. ORAU Team. Principal Health Physicists. May 2004.
Tritium exposure occurred during disassembly. Tritium that leaked into the cell was removed by ventilation, so residual contamination was not an issue (at normal release levels). Therefore, those workers in the cell during disassembly incurred the tritium intakes. There is always the possibility that other workers were occasionally in the cell or close by during a tritium leak, but these would have been infrequent and the doses would have been less than 1 mrem/yr.

[21] Chew, Melton H. ORAU Team. Principal Health Physicist. April 2006.
The values for the impurities were provided by Mel Chew based on research at Y-12 (ORAUT 2007).

[22] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
The *Internal Dosimetry Technical Basis and Quality Assurance Document* (BWXT Pantex 2001) states, “The compounds for uranium at Pantex are pure metal or air-oxides; it is assumed that all forms encountered will exhibit class Y aerosol behavior.” This is the basis for the statement that there would not be significant quantities of type F uranium at Pantex.

[23] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
The presence of black dust DU contamination was mentioned by many Pantex employees during site visits. It is also discussed in a presentation on DU contamination during investigation of the 1989 incident (BWXT Pantex ca. 2000).

[24] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
As an example of improvements in contamination control, a presentation from 1989 discussed the lessons learned and improvements for contamination control in a presentation on DU contamination during investigation of the 1989 incident (BWXT Pantex ca. 2000).

[25] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. July 2004.
Review of dosimetry records from the 1960s and 1970s often showed a zero in the column for “internal emitters”; however, there are numerous references that indicate that bioassay was not performed routinely but rather only when there was a known release. Therefore, the dose reconstructors need to be careful and not assume that a zero means that someone was

monitored. The dose records in more recent years (1990s forward) clearly indicate when an individual was monitored for internal dose.

[26] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
Table 5-4 provides the data for uranium dose to workers from 1990 to 2004. This table was created using data from DORMS.

[27] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
This statement was made based on inference from the statement that uranium exposures were monitored only based on air-monitoring data (i.e., that the presence of uranium was detected). If bioassays were made on 300 workers, there must therefore have been the potential for uranium intakes.

[28] Bihl, Donald E. ORAU Team. Principal Health Physicist. May 2005.
If 1.4 is the 2-sigma value, then the 1-sigma value is 0.7. One frequently used formula for MDA is 4.65σ. 0.7 x 4.65 = 3.3. The sigma value in the MDA equation is arguably not just the counting error, but there are not enough data to do a more rigorous calculation.

[29] Thomas, Dale D. ORAU Team. Senior Health Physicist, October 2013.
The total uranium MDA of 0.15 dpm per day was derived based on reasonable assumptions regarding possible uranium enrichments and an isotopic specific MDA of nominally 0.03 pCi/sample for each predominant uranium isotope. The value of 0.15 dpm per day accounts for all potential uranium enrichments and normalized twenty-four hour excretion rates.

[30] Bihl, Donald E. ORAU Team. Principal Health Physicist. May 2005.
The MDAs for the Y-12 analyses were printed on the report but they varied for each sample. The values shown in Table 5-5 were generally the higher of the various MDAs listed on the report (Reichert 1994, pp. 14–17).

[31] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. July 2004.
The determination that there have been strict workplace restrictions in relation to thorium comes from discussions with the staff at Pantex during interview trips and from the Internal Dosimetry Technical Basis Manual (BWXT Pantex 2001).

[32] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. July 2004.
The determination that there have been strict workplace restrictions in relation to thorium comes from discussions with the staff at Pantex during interview trips and the Internal Dosimetry Technical Basis Manual (BWXT Pantex 2001).

[33] Bihl, Donald E. ORAU Team. Principal Health Physicist. September 2005.
The age of thorium during disassembly is not known and probably varied from weapon to weapon. Thorium-228 activity decreases relative to ^{232}Th activity upon purification of the thorium (i.e., removal of the ^{228}Ra) and reaches a minimum of about 44% in 5 to 6 years, then increases slowly to reach 90% in about 23 years (see, for instance, West 1965).

[34] Bihl, Donald E. ORAU Team. Principal Health Physicist. September 2005.
Because the degree of disequilibrium of the ^{232}Th progeny is not known, it was judged favorable to claimants to assume equilibrium. That assumption increases the activity of progeny during intake and consequently increases annual organ doses.

[35] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. July 2004.
Review of dosimetry records from the 1960s and 1970s often showed a zero in the column for "internal emitters"; however, there are numerous references that indicate that bioassay was not performed routinely but rather only when there was a known release. Therefore, the dose reconstructors need to be careful and not assume that a zero means that someone was monitored. The dose records in more recent years (1990s forward) clearly indicate when an individual was monitored for internal dose.

[36] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. September 2005.
This information was obtained by review of dose records from this period.

[37] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
This statement was made based of review of dosimetry data in DORMS.

[38] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. April 2004.
This statement was made based of review of dosimetry data in DORMS.

[39] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. July 2004.
The assumption that the potential for intake was rare is inferred from discussions in BWXT Pantex (2001).

[40] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. July 2004.
BWXT Pantex (2001) states that the plutonium at Pantex is likely to be an aged weapons-grade mixture. Therefore, the assumption in this section was made to be a 20-year-aged mixture.

[41] Hickey, Eva Eckert. ORAU Team. Principal Health Physicist. July 2004.
The data are from the DORMS database.

[42] Strom, Daniel J. ORAU Team. Principal Health Physicist. February 2004.
This is certainly the policy that has been stated verbally by various DOE policymakers over time and by inference from the lack of requirements to monitor for radon in most DOE buildings. Finding unequivocal documentation of this policy is difficult, but DOE Order 5480.11 states in article 9.b, "Note: Natural background and therapeutic and diagnostic medical exposures are not to be included in dose records or in assessment of dose against limiting values" (DOE 1988). The exact history of the policy is not particularly germane to dose reconstruction except to explain the lack of radon and progeny measurements at DOE and predecessor organization facilities over the years.

[43] Strom, Daniel E. ORAU Team. Principal Health Physicist. February 2004.
This statement follows from the first paragraph in Section 5.3 and the fact that a building that is surrounded by soil on more sides than just the floor generally has more radon emanating into the building than a building with just soil under the floor, unless barriers to radon emanation are employed.

[44] Strom, Daniel J. ORAU Team. Principal Health Physicist. February 2004.
These values are the result of calculations by the author from the data in Table B-1.

[45] Strom, Daniel J. ORAU Team. Principal Health Physicist. February 2004.
These values are the result of calculations by the author from the Eberline data (McFall 1969).

[46] Strom, Daniel E. ORAU Team. Principal Health Physicist. February 2004.
Soil gas is the principal source of indoor radon. In winter, buildings are closed and heated, which leads to decreased air pressure in the building because hot air rises and heat leaks draw air out of the building. This effect depressurizes the building in relation to soil gas, which draws radon in at an increased rate. This effect is especially strong when there is a combustion source (with a flue) in a building (e.g., a gas hot water heater or a gas or oil furnace). In addition, exhaust ventilation systems and clothes dryers generally depressurize buildings and, with closed windows limiting air makeup, there is more soil gas infiltration than in seasons when windows are open.

[47] Strom, Daniel J. ORAU Team. Principal Health Physicist. February 2004.
These values are the result of calculations by the author.

[48] Strom, Daniel J. ORAU Team. Principal Health Physicist. February 2004.
These values are the result of calculations by the author from the data in Table B-1.

[49] Bihl, Donald E. ORAU Team. Principal Health Physicist. June 2004.
The use of one-tenth intakes for workers in the second risk category is consistent throughout the TBD. It is based on two exposure modes: either occasional exposure to the same air concentrations as the high risk workers (modeled as 4 instead of 40 hr/wk), or continuous exposure to one-tenth of the contamination levels incurred by the high risk workers, such as reduced airborne concentrations in hallways or rooms in the same buildings but distant from the cells and bays.

[50] Bihl, Donald E. ORAU Team. Principal Health Physicist. June 2004.
Radon intakes apply to unusual structures that enhance radon beyond normal concentrations; Gravel Gerties were constructed with gravel roofs and soil high on the sides, so they fit the criterion.

[51] Bihl, Donald E. ORAU Team. Principal Health Physicist. June 2004.
Lognormal distribution for air concentrations of contaminants is the usual default unless there are data that clearly show otherwise. Radon air concentrations have been shown to have lognormal distributions (see, for instance, NCRP 1984a, p. 49).

[52] Bihl, Donald E. ORAU Team. Principal Health Physicist. June 2004.
Table B-1 shows the radon concentrations for the underground buildings to have a GSD of 1.75 for that set of measurements, which is less than the Project default of 3. Therefore, the Project default of 3 takes precedence. For matters that influence internal dose, the smallest allowable GSD is 3.

[53] Bihl, Donald E. ORAU Team. Principal Health Physicist. July 2004.
Extrapolation prior to 1972 is based on the issue date of ICRP Publications 10 (1968) and 2 (1959), so it was assumed that the equations were used throughout these years.

[54] Bihl, Donald E. ORAU Team. Principal Health Physicist. May 2004.
This statement is based on personal review of records from Pantex in several claims files.

[55] Hickey, Eva Eckert, and Bihl, Donald E. ORAU Team. Principal Health Physicists. May 2004.
The factor of 2 was a professional judgment made to be favorable to claimants. As explained in the text, the risk of tritium intake was less during assembly than disassembly and fewer disassemblies took place from 1956 to 1972 than afterward.

[56] Bihl, Donald E. ORAU Team. Principal Health Physicist. July 2004.
This general statement was made by a former manager and by other Pantex employees during site visits. The documentation that would verify the statement is classified. However, Table 5-9 provides information that supports the statement in a general way.

[57] Bihl, Donald E. ORAU Team. Principal Health Physicist. April 2004.
This statement is made because missed dose calculations assume chronic rather than acute intake as would be applicable to incident follow-up samples.

[58] Bihl, Donald E. ORAU Team. Principal Health Physicist. May 2004.
The mode of the triangular distribution for tritium missed-dose calculations is 6 mrem. It was used for unmonitored workers based on the premise that unmonitored workers were at less risk than monitored workers, especially for tritium because the source of tritium exposure came from handling tritium reservoirs during disassembly. The possibility of casual exposure to tritium during the disassembly operations by unmonitored workers was considered remote because of the security and other safety requirements of the work.

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GLOSSARY

age or aging
In relation to reactor fuel and mixtures of plutonium isotopes, time since the step in the refinement process that separates americium from the mixture.

depleted uranium (DU)
Uranium with a percentage of ^{235}U lower than the 0.7% found in natural uranium.

dose of record
(1) Dose records that the U.S. Department of Energy provided to the National Institute for Occupational Safety and Health as part of each worker's file. (2) Individual recorded dose such as that on a dosimetry card or in a dosimetry database.

equilibrium factor (F)
In relation to the potential alpha energy of radon and its progeny in air, the ratio of the equilibrium equivalent concentration to the actual activity concentration of radon. See *potential alpha energy concentration*.

Gravel Gertie
Facility with the distinguishing characteristic of having blow-out roof panels overlain with gravel to dissipate the pressure surge and energy of a conventional high-explosive detonation. This design was developed to allow the energy of the blast to be dissipated while minimizing the spread of contamination of any radioactive material present. Also called Gertie.

hydroshot
Detonation of a mixture of explosives and depleted uranium used as a quality control technique for measuring the performance of plastic-bonded explosives.

Parameters 1, 2, and 3
Columns in the Interactive RadioEpidemiological Program template where the dose reconstructor enters the calculated doses and expected variance based on the distribution applied. Multiple entries based on year of employment, type of radiation, appropriate energy ranges, and internal and external exposures are possible.

potential alpha energy concentration (PAEC)
Kinetic energy in units of working levels potentially released in a unit volume of air by alpha particles emitted by the short-lived radioactive progeny of ^{222}Rn (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) and ^{220}Rn (^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po). See *potential alpha energy exposure* and *working level*.

potential alpha energy exposure (PAEE)
Average potential alpha energy concentration to which a worker is exposed multiplied by the time of exposure in working months of 170 hours (units of working level months). PAEE is the potential alpha energy concentration multiplied by time. See *potential alpha energy concentration* and *working level month*.

progeny
Nuclides that result from decay of other nuclides. Also called decay products and formerly called daughter products.

radon (Rn)
Radioactive gaseous element with atomic number 86. Radon is a decay product (progeny) of other radioactive elements such as thorium and radium.

thoron

Informal name for ^{220}Rn.

U.S. Atomic Energy Commission (AEC)

Federal agency created in 1946 to assume the responsibilities of the Manhattan Engineer District (nuclear weapons) and to manage the development, use, and control of nuclear energy for military and civilian applications. The U.S. Energy Research and Development Administration and the U.S. Nuclear Regulatory Commission assumed separate duties from the AEC in 1974. The U.S. Department of Energy succeeded the U.S. Energy Research and Development Administration in 1979.

working level (WL)

Unit of concentration in air of the short-lived decay products of ^{222}Rn (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) and ^{220}Rn (^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po) defined as any combination of the short-lived radioactive progeny of radon or thoron in 1 liter of air, without regard to the degree of equilibrium, that results in the ultimate emission of 130,000 megaelectron-volts of alpha energy; 1 WL equals 2.083×10^{-5} joules per cubic meter. See *potential alpha energy concentration*.

working level month (WLM)

Unit of exposure to radon progeny defined as exposure for 1 working month (170 working hours) to a potential alpha energy concentration of 1 WL; 1 WLM equals 1 WL times 170 hours, which is 0.00354 joule-hours per cubic meter. See *potential alpha energy exposure* and *working level*.

ATTACHMENT A
EXAMPLES OF PANTEX SITE BIOASSAY DATA FILES

Tritium Bioassay Data File

Badge No	Void Date	Reason or Loaction	µCi/L	dpm/mL	MDA (µCi/L)
[redacted]	9/21/1994 16:45 3	[redacted]	0.001	17	0.00765
	10/25/1994 10:41 7		0.001	17	0.00765
	11/16/1994 16:36 3	OTHER	0	17	0.00765
	12/14/1994 16:36 3	OTHER	0	17	0.00765
	1/25/1995 16:53 3	OTHER	0.002	15	0.00675
	2/22/1995 16:48 3	OTHER	0	16	0.0072
	3/22/1995 16:47 3	OTHER	0.001	16	0.0072
	4/19/1995 13:03 3	OTHER	0.001	17	0.00765
	5/17/1995 15:59 3	OTHER	0	16	0.0072
	7/17/1995 12:20 7	OTHER	0.001	15	0.00675

Uranium/Plutonium/Thorium Bioassay Data Files

Badge No	SSN	Reason Code	Radionuclide	Void Date/Time	Sample Type	Sample Size	Units	Concentration	Units	MDA
[redacted]	[redacted]	3	U-236	2/10/1992 0:00	URINE	1468.119995	G	0.029999999	DPM/ML	0
		3	U-238	2/10/1992 0:00	URINE	1468.119995	G	-0.02	DPM/ML	0
		3	U-234	5/8/1992 0:00	URINE	1733.5	G	0.100000001	DPM/ML	0
		3	U-235	5/8/1992 0:00	URINE	1733.5	G	0	DPM/ML	0
		3	U-238	5/8/1992 0:00	URINE	1733.5	G	0.01	DPM/ML	0
		3	U-238	5/8/1992 0:00	URINE	1733.5	G	0.109999999	DPM/ML	0
		3	U-234	2/17/1992 0:00	URINE	1652.680054	G	-0.01	DPM/ML	0
		3	U-235	2/17/1992 0:00	URINE	1652.680054	G	0	DPM/ML	0
		3	U-238	2/17/1992 0:00	URINE	1652.680054	G	0	DPM/ML	0
		3	U-238	2/17/1992 0:00	URINE	1652.680054	G	0.07	DPM/ML	0

ATTACHMENT B
RESULTS OF 1990 RADON MEASUREMENTS

Table B-1. Results of 137 radon measurements in 1990 (UNC Geotech 1990).

RPIS Bu-Ins-Bldg Code	Building number	General description	Gross area (ft^2)	Number of floors	Radon (pCi/L)	Dupl. radon (pCi/L)	Install date	Retrieve date	Room
01001DOE BLDG	DOE Building	DOE Building (12-36) is of brick construction (with bricks from the Panhandle area).			8.1		01/10/90	02/16/90	Main Office
0100111-48	11-48	11-48	3,200	1	7.8		01/10/90	02/16/90	Maintenance Shop
0100112-104	12-104 East	12-104 is bay building	99,680	2	7.1		01/10/90	02/16/90	Bay 5
0100112-66	12-66	12-66 is special nuclear material (SNM) warehouse	25,900	1	5.4		01/10/90	02/16/90	Center Of building
01001FS-01	FS-1	FS-01 is an earth covered storage facility for HE	5,364	1	5.2	5.9	01/10/90	02/16/90	Break room
0100112-23	12-23	12-23	3,200	1	4.5		01/10/90	02/16/90	North wall middle
0100112-15	12-15	12-15	16,800	1	4.2		01/10/90	02/16/90	Training Room 103
0100112-60	12-60	12-60 is Mass Properties Facility	8,600	1	4.1		01/10/90	02/16/90	Office - Vault
0100112-79	12-79	12-79 is warehouse/ loading dock	28,700	1	3.2		01/10/90	02/16/90	South Warehouse Area
0100112-104	12-104	12-104 is bay building	99,680	2	3		01/10/90	02/16/90	106f R Collins Office
0100112-15	12-15	12-15	16,800	1	2.8		01/10/90	02/16/90	Training Graphic Arts
0100112-58	12-58	12-58 is bay building	2,600	1	2.8		01/10/90	02/16/90	East Wall Between Bay 4&5
0100112-15	12-15	12-15	16,800	1	2.6		01/10/90	02/16/90	Training Office
0100112-44	12-44-4	12-44 is Gravel Gertie cell building	27,100	1	2.6		01/10/90	02/16/90	Round Room
0100112-6	12-6	12-6	23,700	1	2.6		01/10/90	02/16/90	Room 131 Quality Records
0100112-14	12-14	12-14	900	1	2.4		01/10/90	02/16/90	Office
0100112-26	12-26 Tooling Warehouse	12-26 is bay building	87,500	1	2.4		01/10/90	02/16/90	Tooling Warehouse Office
0100112-26	12-26	12-26 also has pit	87,500	1	2.3		01/10/90	02/16/90	Bay 28

ATTACHMENT B
RESULTS OF 1990 RADON MEASUREMENTS (continued)

RPIS Bu-Ins-Bldg Code	Building number	General description	Gross area (ft^2)	Number of floors	Radon (pCi/L)	Dupl. radon (pCi/L)	Install date	Retrieve date	Room
		vault							
0100112-35	12-35	12-35	13,400	1	2.3	2.1	01/10/90	02/16/90	Area Mechanics Office
0100111-17	11-17	12-17is bay building	6,700	1	2.2		01/10/90	02/16/90	Bay 7 Lab
0100112-1	12-1	12-1 is cafeteria/ change room	27,600	2	2.2		01/10/90	02/16/90	Lepor Colony
0100112-5	12-5	12-5	74,400	1	2.2		01/10/90	02/16/90	Electric Shop Office
0100112-86	12-86	12-86 is an Inert Assembly and Test Facility			2.2		01/10/90	02/16/90	Electrical Testing Area
0100111-7	11-7	12-7	34,100	1	2.1	2.2	01/10/90	02/16/90	Break room
0100112-61	12-61	12-61	24,000	1	2.1		01/10/90	02/16/90	Warehouse Area
0100112-44	12-44	12-44 is Gravel Gertie cell building	27,100	1	2		01/10/90	02/16/90	Cell 8
0100112-64	12-64	12-64 is bay building	32,000	1	2		01/10/90	02/16/90	Bay 9
01001STATION 30	Zone 4 Station 30	4-30 is underground igloo SNM storage building			2		01/10/90	02/16/90	Control Room
0100112-28	12-28		3,500	1	1.9		01/10/90	02/16/90	Quality Hallway
0100112-37	12-37		22,700	1	1.9		01/10/90	02/16/90	Room 120 Control Room
0100112-42	12-42 Radiation Safety		47,400	2	1.9		01/10/90	02/16/90	12-42 Cr
0100112-84	12-84	Bay	1	1	1.9		01/10/90	02/16/90	Bay 13
0100111-29	11-29		4,200	1	1.8		01/10/90	02/16/90	Office
0100112-37	12-37		22,700	1	1.8		01/10/90	02/16/90	Room 121 Tech Doc
0100112-37	12-37		22,700	1	1.8		01/10/90	02/16/90	Room 112 Mail Room
0100112-5	12-5		74,400	1	1.8		01/10/90	02/16/90	Plant Eng Annette Covington
0100112-5	12-5		74,400	1	1.8	1.8	01/10/90	02/16/90	Plant Design Eng
0100116-2	16-2 Courier		20,072	1	1.8		01/10/90	02/16/90	114 Break room
0100110-9	10-9		15,500	1	1.7		01/10/90	02/16/90	Office
0100111-27	11-27		5,100	2	1.7		01/10/90	02/16/90	Room 119
0100112-50	12-50		1,400	1	1.7		01/10/90	02/16/90	West Of 12-50 Door
0100112-75	12-75		21,862	1	1.7		01/10/90	02/16/90	Desk Lieutenants Office
0100112-99	12-99		60,716	1	1.7		01/10/90	02/16/90	Break Room

ATTACHMENT B
RESULTS OF 1990 RADON MEASUREMENTS (continued)

RPIS Bu-Ins-Bldg Code	Building number	General description	Gross area (ft^2)	Number of floors	Radon (pCi/L)	Dupl. radon (pCi/L)	Install date	Retrieve date	Room
0100111-20	11-20		16,600	1	1.6		01/10/90	02/16/90	Office South Wall
0100112-16	12-16		5,000	1	1.6	1.1	01/10/90	02/16/90	Plastic Shop Office
0100112-2	12-2 Safety		13,456	1	1.6		01/10/90	02/16/90	Dosimetry Lab Room 157
0100112-2B	12-2B		3,220	1	1.6		01/10/90	02/16/90	North Wall By Clock
0100112-42	12-42		47,400	2	1.6		01/10/90	02/16/90	South Vault
0100112-6	12-6		23,700	1	1.6		01/10/90	02/16/90	Room 103 Cafeteria
0100112-84	12-84			1	1.6		01/10/90	02/16/90	125d
0100112-36	12-36		29,400	1	1.5		01/10/90	02/16/90	Emergency Preparedness
0100112-52B	12-52B1				1.5		01/10/90	02/16/90	Meteorology
0100112-9	12-9		18,500	3	1.5		01/10/90	02/16/90	HE Side
0100112-96	12-96	Gravel Gertie	7,865	1	1.5		01/10/90	02/16/90	Round Room
0100112-99	12-99	Bay	60,716	1	1.5		01/10/90	02/16/90	Bay 7
0100112-26	12-26	Bay	87,500	1	1.4		01/10/90	02/16/90	Bay 30
0100112-107	12-107 South		10,000	1	1.4		01/10/90	02/16/90	By C.L. Saban's Office
0100112-44E	12-44-E	12-44 is Gravel Gertie cell building	1,900	1	1.4		01/10/90	02/16/90	Marion Everett's Office
0100112-6	12-6		23,700	1	1.4		01/10/90	02/16/90	Room 112 Tom Folks
0100112-68	12-68		35,900	1	1.4		01/10/90	02/16/90	Machine Shop Office
0100112-69	12-69		9,800	1	1.4		01/10/90	02/16/90	Emmett Hallway
0100111-5	11-5	Bay	9,000	2	1.3		01/10/90	02/16/90	Control Bay
0100112-2	12-2		13,456	1	1.3	2	01/10/90	02/16/90	Medical Office
0100112-24	12-24 South	Bay			1.3		01/10/90	02/16/90	Bay 27
0100112-49	12-49		3,900	1	1.3		01/10/90	02/16/90	Electronics Room
0100112-6	12-6		23,700	1	1.3		01/10/90	02/16/90	104 Room Standards
0100116-12	16-12		28,500	2	1.3		01/10/90	02/16/90	Employment
0100112-61	12-61		24,000	1	1.2		01/10/90	02/15/90	Break Room
0100112-107	12-107 North		10,000	1	1.2		01/10/90	02/16/90	Preventive Maint Section
0100112-11	12-11		2,900	1	1.2		01/10/90	02/16/90	Data Management
0100112-42	12-42		47,400	2	1.2	1	01/10/90	02/16/90	Upstairs Assembly Ops
0100112-6	12-6		23,700	1	1.2		01/10/90	02/16/90	Room 121 Elaine Miller
0100112-64	12-64	Bay	32,000	1	1.2	1.3	01/10/90	02/16/90	Bay 15
0100112-69	12-69		9,800	1	1.2		01/10/90	02/16/90	DOE Office
0100112-9	12-9		18,500	3	1.2		01/10/90	02/16/90	Office
0100112-97	12-97B		10,000	1	1.2		01/10/90	02/16/90	By Refrigerator in Break

ATTACHMENT B
RESULTS OF 1990 RADON MEASUREMENTS (continued)

RPIS Bu-Ins-Bldg Code	Building number	General description	Gross area (ft^2)	Number of floors	Radon (pCi/L)	Dupl. radon (pCi/L)	Install date	Retrieve date	Room
									Room
0100112-98	12-98	Gravel Gertie	34,358	1	1.2	1.2	01/10/90	02/16/90	Cell 2
0100112-21	12-21 Gas Lab		29,300	2	1.1		01/10/90	02/16/90	Break Area
0100111-18	11-18 Control Room		1,500	1	1.1		01/10/90	02/16/90	Control Room
0100111-2	11-2		9,600	2	1.1		01/10/90	02/16/90	110
0100111-51	11-51		11,600	1	1.1		01/10/90	02/16/90	Office
0100112-32	12-32 South Side		7,600	1	1.1		01/10/90	02/16/90	Above Phone on Ramp
0100112-98	12-98-3	Gravel Gertie	34,358	1	1.1	0.8	01/10/90	02/16/90	Round Room
0100111-36	11-36		5,000	2	1		01/10/90	02/16/90	Office
0100111-50	11-50		22,151	1	1		01/10/90	02/16/90	Room 110 Office
0100112-100	12-100		4,360	1	1		01/10/90	02/16/90	Environmental Protection
0100112-11A	12-11A		5,200	1	1		01/10/90	02/16/90	Quality Hallway
0100112-5	12-5		74,400	1	1		01/10/90	02/16/90	General Stores Office
0100112-52B	12-52B				1		01/10/90	02/16/90	Meteorology
0100112-52C	12-52C		3,600	1	1	0.9	01/10/90	02/16/90	Meteorology
0100112-6	12-6		23,700	1	1		01/10/90	02/16/90	Assy Eng Office
0100112-6	12-6		23,700	1	1		01/10/90	02/16/90	Room 700 Stoddard
0100112-61	12-61		24,000	1	1		01/10/90	02/16/90	Office Area
0100112-82	12-82	Bay	6,800	1	1		01/10/90	02/16/90	E-Bay Office
01001STATION C	Station C				1		01/10/90	02/16/90	West Wall By Exit
0100112-21	12-21		29,300	2	1		01/10/90	02/16/90	X-Ray Office
0100112-2B	12-2B		3,220	1	0.9		01/10/90	02/16/90	South Wall - Nancy's Office
0100112-104	12-104	Bay	99,680	2	0.9		01/10/90	02/16/90	Bay 13
0100112-104-EAS	12-104 East	Bay			0.9		01/10/90	02/16/90	Bay 2
0100112-106	12-106		5,400	1	0.9		01/10/90	02/16/90	Across From Room 105 Janitor
0100112-24	12-24 North	Bay			0.9		01/10/90	02/16/90	Bay 10
0100112-31	12-31	Bay	7,600	1	0.9	0.8	01/10/90	02/16/90	Bay 3 Outside

ATTACHMENT B
RESULTS OF 1990 RADON MEASUREMENTS (continued)

RPIS Bu-Ins-Bldg Code	Building number	General description	Gross area (ft^2)	Number of floors	Radon (pCi/L)	Dupl. radon (pCi/L)	Install date	Retrieve date	Room
0100112-64	12-64		32,000	1	0.9		01/10/90	02/16/90	D&I Office
0100112-99	12-99		60,716	1	0.9		01/10/90	02/16/90	105-F Manufacturing Office
0100112-84	12-84-East			1	0.8		01/10/90	02/16/90	Break Room
0100112-84	12-84	Bay	1	1	0.8		01/10/90	02/16/90	Bay 4
0100112-84	12-84		1	1	0.8		01/10/90	02/16/90	Break Room
0100112-84	12-84	Bay	1	1	0.8	1.3	01/10/90	02/16/90	Bay 7
0100112-101	12-101 Portable Maint		5,334	1	0.8		01/10/90	02/16/90	By Sign-Out Board
0100112-102	12-102		5,778	1	0.8		01/10/90	02/16/90	Tech Applications
0100112-103	12-103		23,608	1	0.8		01/10/90	02/16/90	Smoking Area
0100112-104	12-104 West		99,680	2	0.8		01/10/90	02/16/90	128f Manufacturing Office
0100112-111	12-111		7,416	1	0.8		01/10/90	02/16/90	Carpenter Shop
0100112-112	12-112		6,525	1	0.8		01/10/90	02/16/90	Camera Room
0100112-17	12-17		32,500	2	0.8		01/10/90	02/16/90	Break Area
0100112-19	12-19 EAST		32,500	2	0.8		01/10/90	02/16/90	Break Area East Side
0100112-20	12-70				0.8		01/10/90	02/16/90	Cafeteria
0100112-3	12-3		2,000	1	0.8		01/10/90	02/16/90	Transportation
0100112-35	12-35		13,400	1	0.8		01/10/90	02/16/90	Utilities Console Room
0100112-39	12-39 Fire Department		8,200	1	0.8		01/10/90	02/16/90	Sleeping Room
0100112-41A	12-41A		3,000	1	0.8		01/10/90	02/16/90	North Wall
0100112-42A	12-42A		19,900	1	0.8		01/10/90	02/16/90	Outer Wall by Sandia Sign
0100112-5	12-5		74,400	1	0.8		01/10/90	02/16/90	Master Mechanics
0100112-59	12-59		8,300	1	0.8		01/10/90	02/16/90	Chem Lab Office
0100112-5C	12-5C		21,700	2	0.8		01/10/90	02/16/90	Sheet Metal Shop
0100112-84	12-84	Bay		1	0.8		01/10/90	02/16/90	Bay 12
0100112-86	12-86				0.8		01/10/90	02/16/90	86-2e-5
0100112-86	12-86				0.8		01/10/90	02/16/90	206s Upstairs Assembly Ops Office
0100112-86	12-86	Bay			0.8		01/10/90	02/16/90	Bay 10

ATTACHMENT B
RESULTS OF 1990 RADON MEASUREMENTS (continued)

RPIS Bu-Ins-Bldg Code	Building number	General description	Gross area (ft^2)	Number of floors	Radon (pCi/L)	Dupl. radon (pCi/L)	Install date	Retrieve date	Room
0100112-97	12-97A		10,000	1	0.8		01/10/90	02/16/90	By Clock in Hallway
0100112-97	12-97C		10,000	1	0.8		01/10/90	02/16/90	Above Fire Ext by Copier
0100112-99	12-99	Bay	60,716	1	0.8		01/10/90	02/16/90	Bay 6
0100116-1	16-1 VMF		54,200	1	0.8		01/10/90	02/16/90	Office
0100116-12	16-12		28,500	2	0.8		01/10/90	02/16/90	Purchasing
01001STATION B	Station B				0.8		01/10/90	02/16/90	East Wall Center
01001Trailer	Parking Lot				0.8		01/10/90	02/16/90	West Trailer from 12-2
01001Trailer	Parking Lot				0.8		01/10/90	02/16/90	East Trailer from 12-2

ATTACHMENT C
ASSESSING TRITIUM INTAKES

Tritium Intakes, before 1983

To convert from tritium dose back to uptake for 1972 to 1982, dose reconstructors should use a dose conversion factor of 3.5 µCi/mrem. This conversion results from the approach in ICRP Publication 10 (ICRP 1968) explained in NUREG-0938 (Brodsky 1983; 1.5 mCi = 425 mrem). It assumes an acute intake and a quality factor of 1.7 for tritium beta particles. Dose reconstructors should use a lognormal distribution with a geometric standard deviation (GSD) of 3 (ORAUT 2014a) and should apply this same conversion to recorded tritium doses for years before 1972 if they encounter any such doses [53]. Because this conversion produces a dose lower than the recorded dose by nearly 44% when input into IMBA, it is permissible to use the doses as recorded for likely noncompensable, maximum internal dose cases.

Tritium Intakes, 1983 to 1988

Ikenberry (1983) described the uptake to dose calculation method used at that time, which was based on ICRP Publication 2 (ICRP 1959) but used a quality factor of 1:

$$doserate\ in\ rem / d = 8.12 \times 10^{-6} q \quad \text{(C-1)}$$

where q is the uptake in microcuries. Total dose was determined by integrating over the dose rate curve. For an acute exposure:

$$dose\ in\ rem = 1.4 \times 10^{-4} q \quad \text{(C-2)}$$

and for chronic exposure:

$$dose\ in\ rem = 8.12 \times 10^{-6} qt \quad \text{(C-3)}$$

where t is the period of chronic exposure in days.

Equation C-2 produces a conversion factor of 7.1 µCi/mrem and, assuming a 365-day exposure, Equation C-3 produces a conversion factor of 0.33 µCi/mrem. Ikenberry (1983) does not specify a particular intake scenario, so it is not known which of the two equations produced the reported doses. Both were probably used to fit whichever intake scenario was appropriate for each worker but, for the purpose of establishing a default intake, Equation C-2 is favorable to claimants along with the assumption of a lognormal distribution with a GSD of 3 (ORAUT 2014a).

Tritium Intakes, 1989 to Present

In 1989, DOE Order 5480.11 (DOE 1988) required sites to convert to ICRP 30 internal dose methodology (ICRP 1982). Spot-checking of case files showed that Pantex used both acute and chronic assumptions for different cases [54]. For instance, a May 1991 letter to a worker's file (case xxxx) states that a 0.5-mL aliquot was analyzed by liquid scintillation and that "Doses were calculated by the use of computer algorithms incorporating an assumption of a single intake 30 day before the measurement." Two other cases (xxxx and xxxx), dated 1991 and 1993, respectively, showed outputs from the REMedy© internal dosimetry computer code, and both assumed a chronic intake mode to calculate the dose.

For the acute intake scenario, BWXT Pantex (1992) provided Equation C-4 to convert from calculated dose to uptake assuming a single exponential retention curve with a 10-day retention half-time:

$$dose\ in\ mrem = 1.3 \times 10^{-3} C_0 \quad \text{(C-4)}$$

ATTACHMENT C
ASSESSING TRITIUM INTAKES (continued)

where C_0 is the initial body water concentration in disintegrations per minute per milliliter and the dose is in millirem. The concentration is distributed in 42,000 mL of body water, so the uptake in disintegrations per minute is 42,000C_0. Therefore:

$$\text{uptake in dpm} = (42{,}000)(\text{dose})/(1.3 \times 10^{-3}) = (3.23 \times 10^{7})(\text{dose in mrem}) \quad \text{(C-5a)}$$

and

$$uptake\ in\ pCi = (1.46 \times 10^{7})(dose\ in\ mrem) \quad \text{(C-5b)}$$

For the chronic intake scenario, the same document provides Equation C-6 for calculating dose from a urine sample:

$$dose\ in\ mrem = \left[\left(8.7 \times 10^{-5} t\right) + 1.3 \times 10^{-3}\right] C_e \quad \text{(C-6)}$$

where C_e is the urine concentration in disintegrations per minute per milliliter. Monthly sampling was the normal frequency for workers potentially exposed to tritium [55] so, with a *t* of 30 days:

$$dose\ in\ mrem = 3.9 \times 10^{-3} C_e \quad \text{(C-7)}$$

Distributing the tritium in 42,000 mL of body water gives:

$$uptake\ in\ dpm = (1.07 \times 10^{7})(dose\ in\ mrem) \quad \text{(C-8a)}$$

$$uptake\ in\ pCi = (4.82 \times 10^{6})(dose\ in\ mrem) \quad \text{(C-8b)}$$

The same equation for an intake period other than 30 days is:

$$uptake\ in\ pCi = \frac{(1.89 \times 10^{4})(dose\ in\ mrem)}{\left(8.7 \times 10^{-5} t\right) + 1.3 \times 10^{-3}} \quad \text{(C-9)}$$

Equation C-5 differs from Equation C-8 by a factor of 3, so if the doses are large it could be important to know if the original calculation of the recorded tritium dose assumed the chronic or acute scenario. It is implied, although not explicitly stated, in the Pantex procedure *Internal Dose Assessment* (MHSMC 1991b) that chronic intakes were applied to workers receiving routine monthly bioassay and an acute intake scenario was applied to workers receiving termination or infrequent bioassay. Disassemblies were occurring more often than assemblies during this period, so chronic intakes were more likely [56].

Equation C-8 and IMBA produce a slightly smaller dose than originally recorded. For instance, a recorded dose of 10 mrem for a monthly sample results in a recalculated dose of 7.4 mrem. Therefore, if the only information available is the recorded tritium dose, and it is evident from the records that the worker was on a monthly sampling frequency, dose reconstructors can use the recorded dose directly for the likely noncompensable, maximum internal dose approach. Therefore, for tritium doses in the records for 1989 to the present, the dose reconstructor should apply the following steps:

ATTACHMENT C
ASSESSING TRITIUM INTAKES (continued)

If the worker's file provides (in order of priority):

- Actual bioassay results and an acute intake date or chronic exposure period, use that information to determine dose; or
- Dose and a chronic intake period, use the recorded dose unless better accuracy is required, in which case use Equation C-8 for monthly sampling frequency or Equation C-9 for another exposure period; or
- Dose calculated from a termination sample or single sample when the worker was not on a monthly routine, use Equation C-5.

Regardless of the step used to determine the dose, dose reconstructors should assume a lognormal distribution with a GSD of 3 (ORAUT 2014a).

Tritium Missed Dose, 1972 to 1988
See Sections 5.2.1.1.5 and 5.2.1.1.6 for unmonitored worker discussions.

Tritium Missed Dose, 1989 to Present
The 1991 internal dose assessment procedure (MHSMC 1991b) lists urinalysis results above for which a dose assessment is necessary (Table C-1). By inference, results below the values in the table did not need dose assessment because, as the procedure states, "The activities cited below have been calculated to result in 1 mrem of exposure based on methods described in ANSI N13.14" (HPS 1983). This TBD analysis has not established how far back in time these screening values were in place, but it is plausible that Pantex started using them in 1989 with the implementation of DOE Order 5480.11 (DOE 1988). Assuming a chronic intake for the monthly sample period and a urinalysis result of 0.135 µCi/L at the end of the period, the IMBA Version 3.1.99 calculates a daily uptake of 4.28×10^5 pCi/d (or 0.87 mrem to all organs). The daily uptake rate and the total potentially missed dose are dependent on the number of monitoring periods, as listed in Table C-2. However, the potentially missed dose is reasonably close to 1 mrem/30 d, so it is favorable to claimants and efficient to use 1 mrem for each monitoring period. Therefore, if a worker's record shows, for example, 2 mrem for three monitoring periods in a year and zero dose for the remaining nine periods, the unrecorded dose would be 9 mrem and the recorded dose would be 6 mrem (or could be adjusted using Equation C-8). This dose would apply equally to all organs [see, for instance, ICRP 1995, Table 5.1.2(d)]. [Using the formula from ANSI Standard N13.14-1983 (HPS 1983), the acute intake in Table C-2 results in a 1-mrem dose if the time after intake is 7 days, so Pantex must have used the 0.357-µCi/L value for incident follow-up samples. It would not be appropriate for potentially missed dose estimation] [57].

If the annual tritium dose is recorded as zero but it appears that bioassay occurred, the dose should be assigned as a triangular distribution with a minimum of 0 mrem, a mode of 6 mrem, and a maximum of 12 mrem [58].

Table C-1. Tritium urinalysis screening levels, 1991.[a]

Analysis period	Urine tritium concentration (µCi/L)
Termination	1.35 E-2
Monthly	1.35 E-1
Acute	3.57 E-1

a. From MHSMC (1991b); assumed to apply to 1989 to present.

ATTACHMENT C
ASSESSING TRITIUM INTAKES (continued)

Table C-2. Potentially missed intake and dose from monthly sampling for chronic intake of tritium, 1989 to Present.[a]

Monthly periods missed	Daily intake (× 10^5 pCi)	Total missed dose (mrem) (all organs)
1	4.28	0.869
2	3.73	1.51
3	3.62	2.23
4	3.58	2.93
5	3.56	3.64
6	3.55	4.37
7	3.54	5.08
8	3.54	5.82
9	3.54	6.55
10	3.54	7.27
11	3.54	7.98
12	3.54	8.73

a. Based on 0.135 µCi/L excretion at end of total period from Table 5-4.