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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
08/24/2004	00	New technical basis document for the Pantex Plant – Occupational Environmental Dose. Incorporates internal review and NIOSH comments. Incorporates additional internal review and NIOSH comments. First approved issue. Initiated by Dillard B. Shipler.
06/22/2007	01	Revised to include Attributions and Annotations. Constitutes a total rewrite of the document. Incorporates formal internal review comments. No changes were needed as a result of formal NIOSH review. This revision results in no change to the assigned dose and no PER is required. Initiated by John J. Fix.
01/03/2014	02	Revision initiated to clarify dose assignments. Updated Section 4.1. Added paragraphs to Attachment A for clarification of dose assignments. Updated format; includes editorial changes. Added Tables A-3 and A-4 to simplify on-site ambient dose assignment. Figure 4-4 was deleted. 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.

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ACRONYMS AND ABBREVIATIONS

AMAD	activity median aerodynamic diameter
ASER	annual site environmental report
Bq	becquerel
Ci	curie
CED	committed equivalent dose
CEDE	committed effective dose equivalent
CFR	Code of Federal Regulations
CY	calendar year
DHHS	U.S. Department of Health and Human Services
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
EMR	environmental monitoring report
F	fast absorption type
g	gram
HE	high explosive
hr	hour
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Analysis
in.	inch
m	meter
M	moderate absorption type
mm	millimeter
mrem	millirem
mph	miles per hour
mSv	millisievert
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
ORAU	Oak Ridge Associated Universities
POC	probability of causation
s	second
S	slow absorption type
SRDB Ref ID	Site Research Database Reference Identification (number)
Sv	sievert
TBD	technical basis document
TBq	terabecquerel
TLD	thermoluminescent dosimeter

U.S.C.	United States Code
yr	year
µBq	microbecquerel
µCi	microcurie
µm	micrometer
µSv	microsievert
§	section or sections

4.1 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.

4.1.1 Purpose

The purpose of this technical basis document (TBD) is to describe the Pantex Plant occupational environmental doses. The Oak Ridge Associated Universities (ORAU) Team will use this information as needed to evaluate environmental doses for EEOICPA claims.

4.1.2 Scope

Pantex operations have played an important role in the U.S. nuclear weapons program. Historically, Pantex provided several roles associated with the assembly, disassembly, retrofit, and modification of nuclear weapon systems (Mitchell 2003). Today, Pantex continues to fabricate high explosives and to assemble nuclear weapons. The principal operations at this site, however, are the dismantling of retired nuclear weapons and the maintenance of the nation's nuclear weapons stockpile. Pantex, which is operated by DOE's Office of Defense Programs, is the only facility in the United States that performs these operations.

The occupational environmental dose is the dose received by workers on the site but outside facilities. This dose can be internal and external depending on the characteristics of the individual radionuclides. Radionuclides at the Pantex Plant have included tritium, uranium, plutonium, and thorium. Pantex neither uses or releases noble gases (BWXT Pantex 2001). While most inhaled radionuclides would give a dose to particular organs in the body, tritium gas would give a dose to the whole body. Sections 4.2 and 4.3 discuss internal and external dose, respectively, from these radionuclides at Pantex. Section 4.4 discusses uncertainty. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 4.5.

4.1.3 Special Exposure Cohort Information

4.1.3.1 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 (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.

4.1.3.2 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 (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.

4.2 INTERNAL DOSE FROM ONSITE ATMOSPHERIC RADIONUCLIDE CONCENTRATIONS

The internal dose to workers outside facilities is determined from air concentrations that resulted from individual facility releases, ground-level releases (e.g., burning activities), and the resuspension of radioactive materials in soil. Unmonitored workers could have received internal or external occupational doses (or both) from any or all of these sources. Figure 4-1 shows the major areas of the Pantex Plant site.

To determine the offsite effective dose equivalent from airborne releases, Pantex used the U.S. Environmental Protection Agency-approved CAP88-PC computer program to evaluate the radiological dose that a member of the public could receive during the year (BWXT Pantex 2001, pp. 72–73). Figure 4-2 shows the percent contributions to dose that resulted (BWXT Pantex 2001). The results indicate the importance to dose of the various radionuclides involved in Pantex operations.

The analysis encompassed all potential environmental pathways for radioactive material released to the air. The source terms for releases to air result from process knowledge, the number of operations during the year, and other modifying factors. The source terms represent the maximum possible releases from a point (stack or vent), an area, or both. Actual releases to the air were much less than the maximum estimates, which are essentially the minimum limits of monitoring or detection equipment. The total estimated releases and monitoring data from the site were available, but not specific source terms [1].

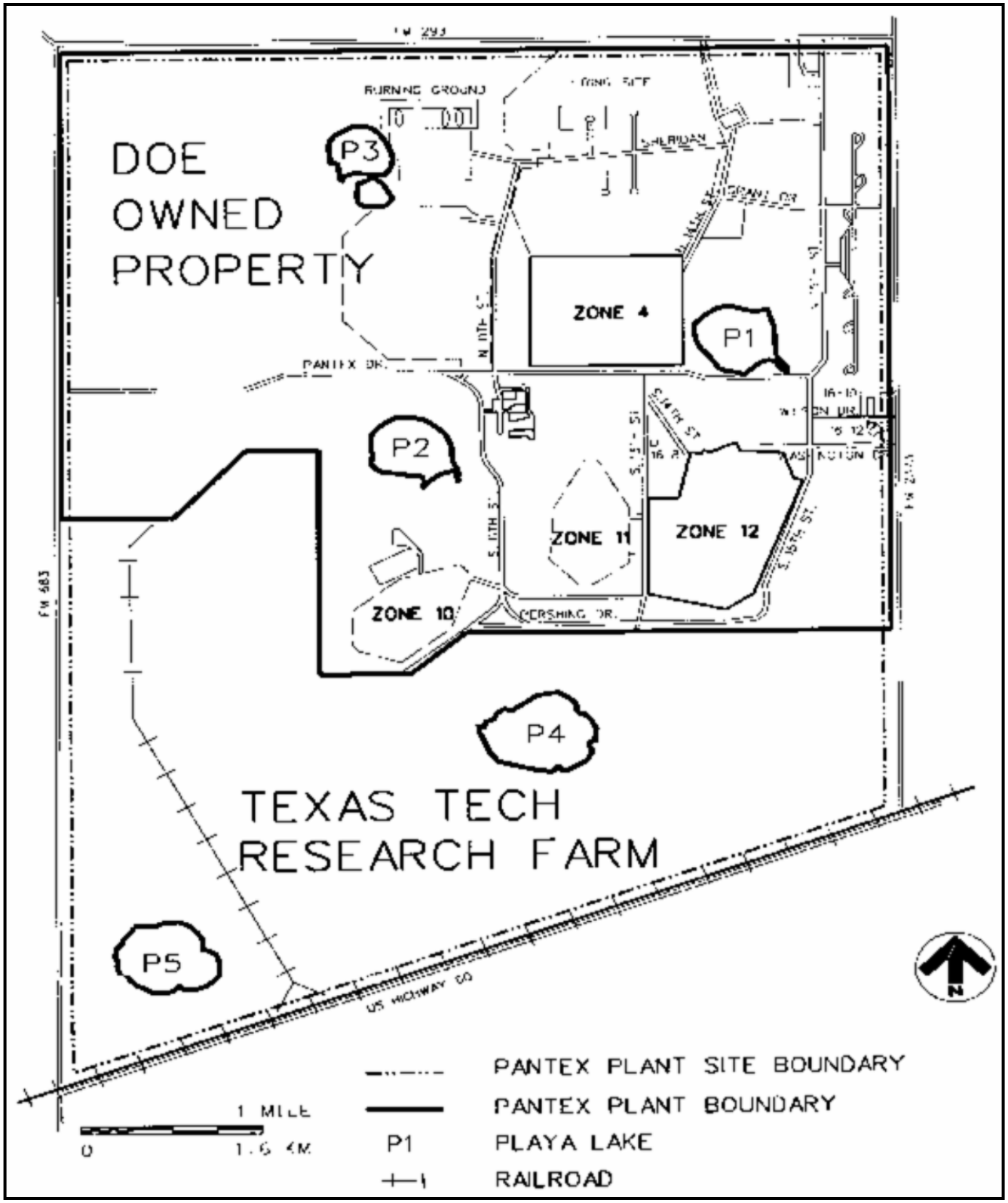

Figure 4-1. Pantex Plant site (BWXT Pantex 2001).

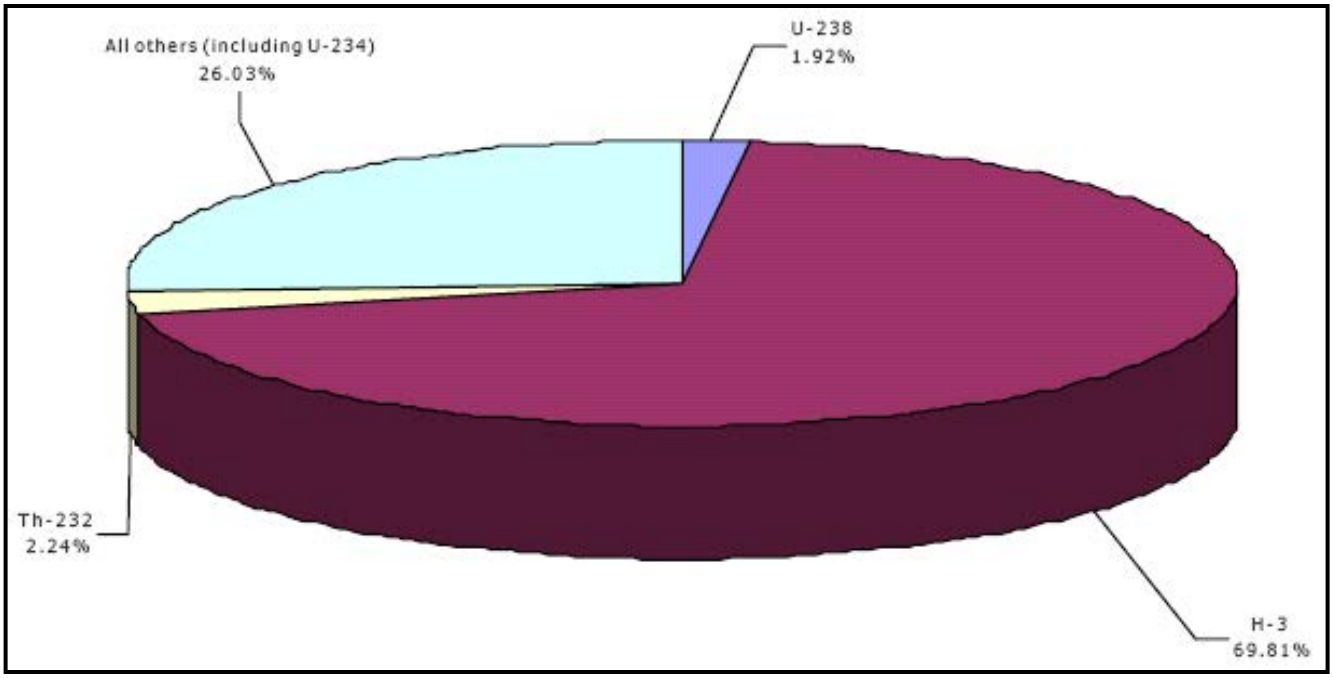

Figure 4-2. Isotopic contributions to offsite dose from Pantex operations in 2000 (BWXT Pantex 2001).

4.2.1 Onsite Releases to Air

Information on releases of radionuclides from Pantex facilities during the Plant's operating period from 1952 through 2000 was obtained from environmental monitoring reports (EMRs) and annual site environmental reports (ASERs) (Alexander 1974, 1975, 1976, 1977; Alexander, Cornelius, and Horton 1978; Alexander and Cornelius 1979, 1980; Alexander and Laseter 1981; Laseter 1982, 1983, 1984, 1985, 1986, 1987; Laseter and Langston 1988, 1989; MHSMC 1990, 1991; Battelle and MHMSC 1992, 1993, 1994, 1995; DOE 1996, 1997; Battelle and MHC 1998; DOE 1999, 2000; BWXT Pantex 2001, 2002a, 2003), annual summaries of radiological doses and releases reported to DOE (DOE 1982, 1984, 1992, 1994; BMI 1985, 1988, 1990a, 1990b; PNL 1993; PNNL 1997a, 1997b), radiation safety department incident records (MHSMC 1986), and radiation safety department technical basis manuals (BWXT Pantex 2002b). EMRs and ASERs contain air release and soil monitoring data, and thermoluminescent dosimeter (TLD) monitoring data from on and off the site. Table 4-1 summarizes releases to the atmosphere from plant vents. Figure 4-3 shows air sampler locations.

A review of the references determined that the monitoring data are representative for assessing dose. The analysis considered the release and monitoring data, coupled with understanding of historical meteorology (Snyder 1993), to be adequate estimates of radionuclide-specific airborne concentrations for ^{3}H, ^{238}Pu, $^{239/240}Pu$, $^{233/234}U$, and ^{238}U. The uranium used in weapons at Pantex is depleted uranium (DU) that consists primarily of ^{238}U and small amounts of ^{234}U, ^{235}U, and ^{236}U, all of which are alpha particle emitters with long half-lives (Battelle 1992, Chapter 5). The ^{235}U is about 1% of the total activity in DU [2]. Because ^{233}U and ^{234}U cannot readily be chemically separated, they are measured and reported together. In reality, there is no ^{233}U on the Pantex Plant [3]. Though small quantities of ^{232}Th were released from Pantex facilities, "monitoring of ^{232}Th was not consistent because the releases were small and contributed little to dose, as well as that ^{232}Th is a naturally occurring form of the element" (BWXT Pantex 2001).

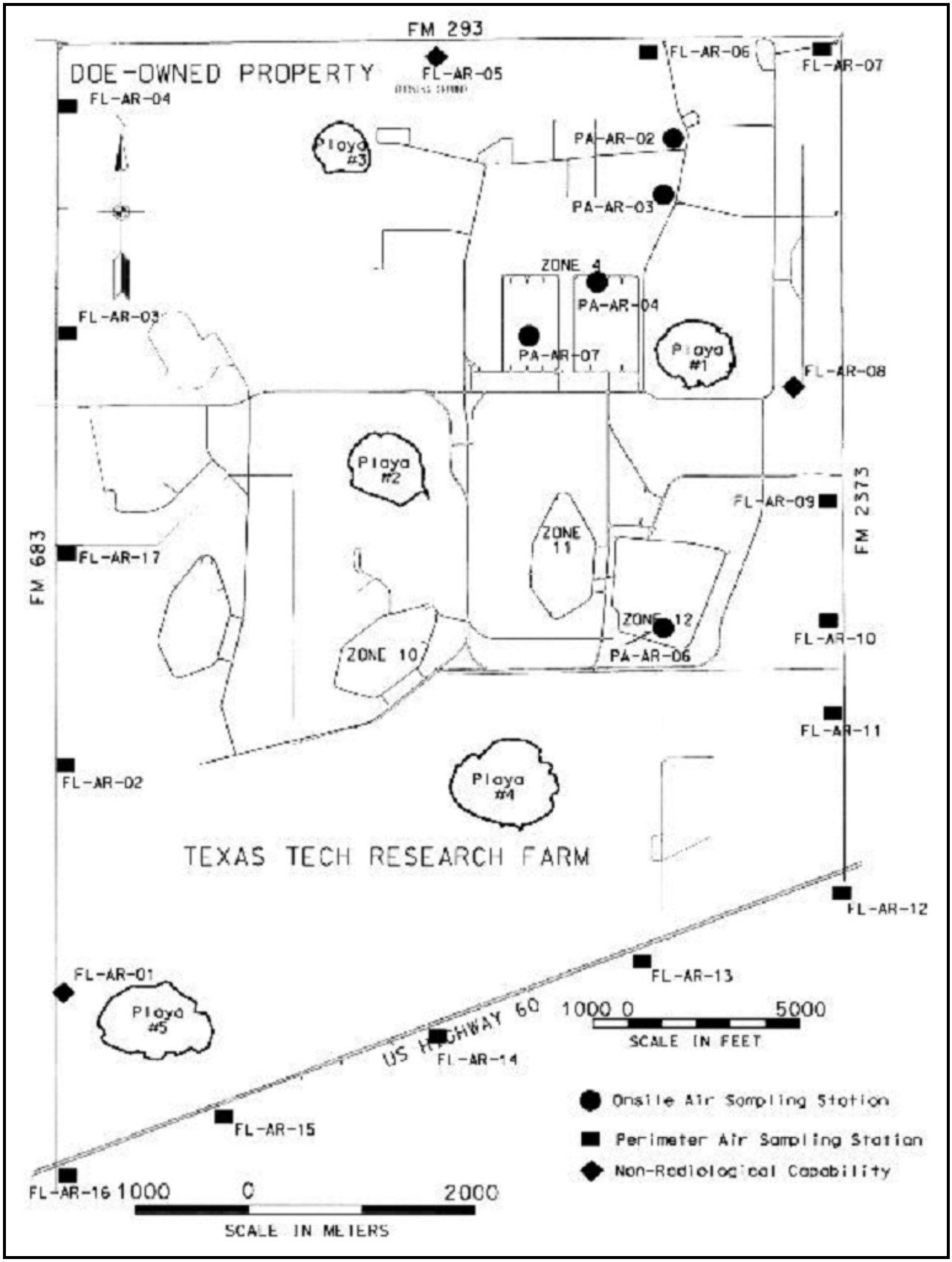

Figure 4-3. Air monitoring stations in 2000 (BWXT Pantex 2001).

Table 4-1. Annual releases (curies) to atmosphere.

Year	Tritium	Total uranium	Total plutonium[a]	All others	Reference
1981	9.5E-02	1.0E-05	--	--	DOE 1982
1983	5.0E-02	1.0E-05	--	--	DOE 1984
1984	1.2E-04	--	--	--	BMI 1989
1985	--		--	--	
1986	1.3E-01	1.0E-05	--	--	BMI 1988
1987	9.6E-02	--	--	--	BMI 1990b
1988	1.2E-01	--	--	--	BMI 1990a
1989	4.0E+04	2.1E-05	--	--	PNL 1993
1990	2.55E+03			--	MHSMC 1991
1991	1.7E-01	--	--	--	DOE 1992
1992	1.3E-01	--	--	3.5E-07	DOE 1994
1993	3.0E-01	--	--	--	Battelle and MHSMC 1994
1994	4.46E-01	--	--	--	Battelle and MHSMC 1995
1995	1.0E-01	--	--	--	DOE 1996
1996	1.3E-01	1.46E-04	--	1.67E-17 ^{232}Th	DOE 1997
1997	1.17E-01	1.32E-04		1.27E-09 ^{232}Th	Battelle and MHC 1998
1998	5.34E-02	1.78E-04	--	1.59E-08 ^{232}Th	DOE 1999
1999	1.58E+00	6.97E-05	--	7.14E-07 ^{232}Th	DOE 2000
2000	2.71E+00	6.73E-07	--	2.76E-07 ^{232}Th, 3.28E-06 All other radionuclides	BWXT 2001

a. = no releases.

It was assumed that monitoring data, and particularly air monitoring data, is appropriate for dose reconstruction and account for resuspension of radionuclides in soil. Particularly, monitoring data account for the accumulation of long-lived radionuclides in soil during the life of the Plant. In addition, the occurrence of radioactive materials on site changed over time, as follows:

- In 1956, tritium began arriving in sealed containers (ORAUT 2004).
- In 1958, plutonium began arriving in sealed metal forms (ORAUT 2004).
- Thorium began arriving at the plant as new, bare metal forms in the 1960s (ORAUT 2004).

In addition, operations changed over the years:

- From 1952 to 1958, the only operation at Pantex was weapons assembly (ORAUT 2004).
  - No tritium containers were manipulated, so no tritium was released [4].
  - No metal oxides formed or burned, so no metal oxides were released [5].
  - No testing involving radioactive material was performed [6].
  - Small amounts of tritium were released when weapons were disassembled [7].
  - There are no specific data to substantiate specific releases of tritium prior to 1972 [8].
  - Some DU was released at the burning grounds with the burning of high-explosive (HE) components (ORAUT 2007a).
  - Some DU was released at the firing sites when HE firings involved DU components (ORAUT 2007a).

  - Starting in 1958, all assembly and disassembly operations were on complete sealed-pit weapons (Mitchell 2003).

- From 1958 to 1979, the primary operation at Pantex was weapons assembly (Mitchell 2003). Some component testing was performed. A small number of weapons were disassembled for testing and quality control.

- From 1980 to 1990, disassembly of weapons was performed more often than assembly (DOE 2001a).

- From 1990 to the present, the primary operation at the plant has been large-scale disassembly of weapons (DOE 2001a).

Although ^{238}Pu has been part of the monitoring program in recent years, the monitoring was to establish background concentrations in anticipation of a program that would have involved ^{238}Pu. However, that program never started and unencapsulated ^{238}Pu was never on the Pantex Plant (Griffis 2004).

With the exception of hydrodynamic testing, it is evident from this information that operations that could lead to releases of radioactive materials were limited until about 1980 [9]. Table 4-1 lists site release data from 1981. Although operations have increased with time and employment, releases from operations have been relatively stable and remain small. As a result, atmospheric dispersion modeling was deemed unnecessary [10]. This selection was based on the maturity of the monitoring program, the technical level of analytical techniques, and the application of quality programs [11]. In other words, these are the best available data.

Considering time-related operations, time-related presence of radioactive materials on the site, and the small concentrations of radioactive materials in the air and soil when releases of radioactive materials could have occurred after 1980, initial analyses of potential intakes and resulting doses indicated that potential doses from intakes would be negligible [12]. Additional guidance for evaluation of potential intake based on the type of worker and location is provided in the latest revision of ORAUT-TKBS-0013-5, *Pantex Plant – Occupational Internal Dose* (ORAUT 2007a).

4.2.1.1 Tritium

Tritium is one of the principal nuclear materials used at the Pantex Plant. It is the heaviest and only radioactive isotope of hydrogen, with a physical half-life of 12.35 years. Nuclear operations involving tritium have occurred at Pantex since 1956.

Tritium comes to Pantex in sealed containers that are placed into nuclear assemblies without being opened. Therefore, no tritium releases occur during normal assembly operations. Small amounts of tritium (a few microcuries per unit) are routinely released during disassembly operations [13].

A major unplanned accident that resulted in a tritium release occurred at Pantex on May 17, 1989, when a conservatively estimated 40,000 Ci were released in a Gravel Gertie cell (ORAUT 2007b). It was assumed that all the tritium leaked from the cell and the building within 12 days; doses were estimated for that period. The estimated potential individual whole body-dose was 1.43 mrem at the closest downwind fenceline (MHSMC 1990). The estimated maximum individual onsite dose in the downwind direction (north-northeast) was about 10 times the fenceline dose (MHSMC 1990). Therefore, dose reconstructors should assign a 15-mrem dose to the whole body for a worker in the area during that period [14].

At the beginning of 1990, an estimated 2,550 Ci of residual tritium remained trapped in the walls and gravel overburden of the cell in which the 1989 release occurred (MHSMC 1991). The analysis conservatively assumed that this entire amount was released to the atmosphere during 1990. The estimated maximum individual onsite dose in the downwind direction (north-northeast) was 1.0 mrem. Therefore, dose reconstructors should also assign a 1-mrem dose to the whole body for a worker in the area during that period [15].

4.2.1.2 Uranium

Uranium arrives at Pantex as a metal (DU, primarily ^{238}U), uncoated and unsealed (ORAUT 2004). Uranium oxidizes fairly readily in air. When aged weapons are dismantled for inspection, refurbishment, or disassembly, significant amounts of uranium oxide powder can be associated with the parts with which it has come in contact [16]. One type of these parts is the HE, which is generally destroyed by burning. During the burning, associated powdered uranium is released to the atmosphere (ORAUT 2007a).

The alpha-emitting radionuclides of this uranium represent a potential radiological risk if inhaled. Isotopes known to be present through measurement include $^{233/234}U$ and ^{238}U. Dose reconstructors should assume that ^{234}U, the isotope that results in the maximum organ dose, is present at 100%. This assumption results in a small overestimation of the actual dose that is favorable to the claimant (BWXT Pantex 2001).

The only unplanned release of uranium occurred on January 10, 1986, when exhaust fans were inadvertently turned on and off several times after a test detonation at Firing Site 23. This action resulted in the release of particulate material containing DU (BWXT Pantex 2004). All personnel in the area were upwind (northeast at that time) of the release point. The release lasted a short time (1 to 2 minutes) (BWXT Pantex 2004). The curie activity of this release was not monitored, and soil samples could not determine event deposition because previous uncontained test shots had contaminated the area around the Firing Site (MHSMC 1986).

4.2.1.3 Plutonium

Plutonium concentrations are very low (e.g., around 0.01 to 0.02 $\mu Bq/m^3$); they can probably be accounted for by fallout from atmospheric testing because plutonium arrives at Pantex as sealed pits, which preclude oxidation or other means of dispersal (BWXT Pantex 2001). Even when aged weapons are dismantled for inspection or refurbishment, plutonium is not available in a form for release [17].

4.2.1.4 Thorium

Thorium releases to the atmosphere have not been routinely monitored as have uranium, plutonium, and tritium (BWXT Pantex 2001), although monitoring for thorium has been a component of the environmental monitoring program (at least in air and soil since about 1998). Although thorium arrives at the Plant as an uncoated and unsealed metal, it does not oxidize readily. Even when aged weapons are dismantled for inspection or refurbishment, little or no thorium is available in a form for release. Any thorium released would likely be ThO_2 and International Commission on Radiological Protection (ICRP) absorption type S (ICRP 1996) [18].

4.2.2 Rationale for Showing that Organ Doses Due to Intakes of Environmental Levels of Radionuclides at Pantex Are Negligible

4.2.2.1 Negligible Individual Dose Level

The National Council on Radiation Protection and Measurements (NCRP) has defined a negligible individual effective dose as 10 µSv (1 mrem) per year (NCRP 1993). It follows that an annual dose to an organ or tissue that is 10 µSv (1 mrem) or less is also negligible. Furthermore, a committed dose of 10 µSv (1 mrem) or less to an organ or tissue from intakes during a year is also negligible. If it can be shown that measured airborne concentrations of radionuclides in the Pantex environment are negligible in the sense that they produce negligible doses using these criteria, then no effort need be expended to assess them [19].

4.2.2.2 Evidence that Onsite Airborne Uranium and Thorium Levels Are Mostly of Natural Origin

Of the four principal measured radionuclides in the air at Pantex, ^{232}Th and uranium occur naturally, while ^{3}H and plutonium do not occur in significant quantities in nature (BWXT Pantex 2001). A concentration from which a background or control value has been subtracted is called a "net concentration." Because nonzero concentrations of ^{232}Th and uranium are observed off the site due to natural sources that are not related to Pantex operations, it is logical to subtract such "control" values from observations at the Plant. Thorium and uranium emissions from Pantex operations are unlikely to have temporal correlation with each other because they arise from different campaigns. The observation that uranium air concentrations at a given sampler location correlate strongly with thorium air concentrations at that location supports the hypothesis that much of the uranium and thorium is due to uranium and thorium in local dust, not to uranium and thorium releases from Pantex operations. These correlation coefficients (r^2) are 0.854 for the 2000 means and 0.895 for the historic means, with seven data pairs contributing to each, as shown in Figures 4-4 and 4-5, respectively.

A further argument that all or virtually all of the uranium in Pantex air samples is of natural origin is the isotope ratio of $^{233/234}$U to ^{238}U. For 2000, this ratio is 1.007 ±0.037 (1 standard deviation), and for the historical data it is 0.981 ±0.086 (1 standard deviation). If the uranium were DU from the vast majority of Pantex uranium operations, the ratio would be 0.127 (DOE 2001b). The expected value of this ratio is 1.000 for natural uranium, in which ^{234}U is in secular equilibrium with ^{238}U and their activities are equal.

The credible upper bound concentrations to which workers could have been exposed in a year are equal to the upper 95% confidence of the mean net concentration [20]:

$$C_{mzx.cred.} = \overline{C}_{net,95} \quad [21] \tag{4-1}$$

A worker performing light work breathes 1.2 m^3 of air per hour. Assuming a 2,000-hour work year, the worker takes in the radioactive material in 2,400 m^3 during a year. The credible upper bound intake is therefore:

$$I_{mzx.cred.} = 2{,}400 m^3 \times \overline{C}_{net,95} \tag{4-2}$$

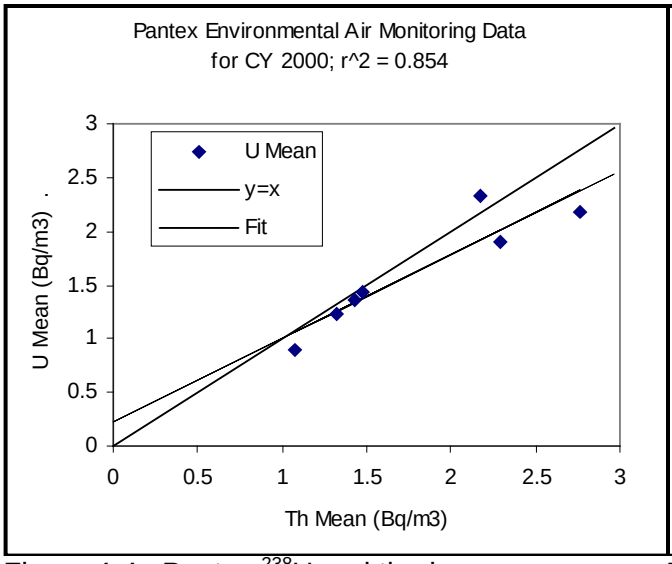

Figure 4-4. Pantex ^{238}U and thorium mean environmental air monitoring data for 2000 at seven locations (BWXT Pantex 2001).

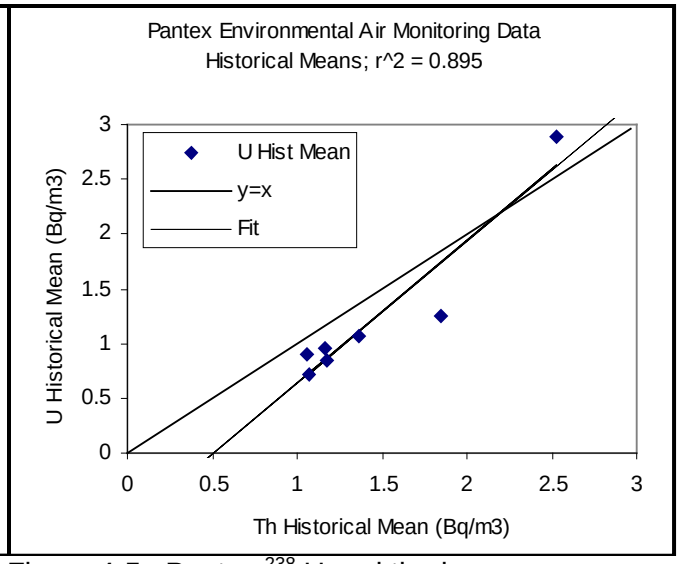

Figure 4-5. Pantex ^{238} U and thorium mean environmental air monitoring data (historic) at seven locations (BWXT Pantex 2001).

4.2.2.3 Upper 95% Confidence of the Mean Net Concentration

Environmental data for Pantex (Attachment A, Table A-1) was used to calculate the values in Equation 4-1. The standard error *S.E.* of a value $\overline{C}$ is related to the standard deviation *S.D.* by the reciprocal of the square root of the number n of measurements:

$$S.E.(\overline{C}) = \frac{S.D.(\overline{C})}{\sqrt{n}} \tag{4-3}$$

The upper 95% confidence level of the mean $\overline{C}_{95}$ is the mean increased by adding the standard normal deviate for 0.95; that is, 1.645 times the standard error of the mean, so that:

$$\overline{C}_{95} = \overline{C} + 1.645 \times S.E.(\overline{C}) \tag{4-4}$$

The upper 95% confidence level of the mean net concentration $\overline{C}_{95,net}$ (assuming the same number of measurements was made of each) is:

$$\begin{aligned} \overline{C}_{95,net} &= (\overline{C} - \overline{C}_{background}) + 1.645 \times S.E.(\overline{C} - \overline{C}_{background}) \\ &= (\overline{C} - \overline{C}_{background}) + 1.645 \times \sqrt{\{S.E.(\overline{C})\}^2 + \{S.E.(\overline{C}_{background})\}^2} \end{aligned} \tag{4-5}$$

The maximum values for thorium and uranium, the two elements for which net concentrations are needed, are listed in Table A-1, as are the references for the maximum value for plutonium and ^{3}H.

The observed 95% upper confidence intervals of the net means were calculated for Pantex for calendar year (CY) 2000 and for historical means. For the latter, it was necessary to estimate the standard error of the means because the standard deviations for the historic data are not given. The standard deviation of the population of means was assumed to be a reasonable estimate of the standard error of the mean of an individual measurement. Table 4-2 lists the greatest onsite (that is, "onsite" or "fenceline" but not "offsite") values [22].

Table 4-2. Maximum values of 95% upper confidence intervals of means or net means (BWXT Pantex 2001).

Nuclide	Location	Historical mean or CY 2000	Maximum value of upper 95% confidence interval (μBq/m^3)	Type
H-3	Onsite PA-AR-06	Historical mean	819,663	Mean
Th-232	Fenceline FL-AR-10	CY 2000	2.21	Net mean
U-233/234 + U-238	Fenceline FL-AR-10	Historical mean	4.97	Net mean
Pu-239/240	Fenceline FL-AR-10	Historical mean	0.137	Mean

4.2.2.4 Dose Coefficients

The ICRP has published, and the Integrated Modules for Bioassay Analysis (IMBA) computer program calculates, dose coefficients in units of sievert per becquerel. These coefficients are the committed equivalent dose (CED)[2] $H_T(\tau)$ in organ or tissue T per unit intake $h_T(\tau)$, where τ is the integration time in years after the intake. The integration time τ is 50 years for the reference worker. Dose coefficients depend on radionuclide, intake route (e.g., inhalation or ingestion), particle size (e.g., 1 or 5 μm), absorption type (e.g., S, M, F), and the selection of biokinetic models. The assumptions most favorable to claimants about dose coefficients are those that result in the highest dose per unit intake.

The intake that leads to a dose D or H_T for various dose coefficients is:

$$I(D) = \frac{D}{dose\,coefficient} = \frac{H_T(\tau)}{h_T(\tau)} \tag{4-6}$$

The concentration that leads to a dose D or H_T for various dose coefficients is:

$$C(D) = \frac{I(D)}{2{,}400\ \mathrm{m}^3} = \frac{D}{(2{,}400\ \mathrm{m}^3)(dose\,coefficient)} = \frac{H_T(\tau)}{(2{,}400\ \mathrm{m}^3)(h_T(\tau))} \tag{4-7}$$

Substituting 10 μSv for H_T in the above equation gives:

$$C(10\ \mu\mathrm{Sv}) = \frac{10\ \mu\mathrm{Sv}}{(2{,}400\ \mathrm{m}^3)(h_T(\tau))} \tag{4-8}$$

Selecting the greatest value of $h_T(\tau)$ for the intake from each element (for example, thorium, uranium, or plutonium) results in specifying values of particle size, absorption type, and radionuclide for each element that give worst-case (i.e., favorable to claimant) results. That is, the lowest concentration of a radionuclide that results in 10 μSv CED to an organ or tissue after a year breathing that concentration in air.

If the observed $\overline{C}_{95,net}$ is less than the concentration calculated from the previous equation, environmental doses from that radionuclide are negligible and need not be calculated.

If the observed $\overline{C}_{95,net}$ is greater than the concentration calculated in the previous equation, annual equivalent doses should be examined to determine if these, when combined over the individual's exposure history, result in more than 10 μSv to the tissue in any one year.

[2]NIOSH does not use CED in its dose reconstructions for POC calculations. This quantity is introduced here as a simple bounding value to establish that airborne concentrations are too small to result in significant annual dose to a tissue or organ. If a committed dose value is not exceeded, an annual dose value will never be exceeded.

4.2.2.5 Criteria for Determining that Maximum Credible Intakes Lead to Doses Less than 10 Microsievert to Most Highly Dosed Tissue or Organ

Table 4-3 lists dose conversion coefficients and air concentrations leading to 10 µSv CED for ^{3}H, ^{232}Th, ^{234}U, and ^{239}Pu, as calculated with IMBA. The table lists the tissues or organs receiving the highest $H_T(\tau)$. These values are from ICRP Publication 71 for ^{232}Th (ICRP 1996). If the 95th percentile concentrations are below these values, the resultant doses would be below 10 µSv (1 mrem), and there is no need to reconstruct doses due to inhalation of environmental radionuclides. The resultant doses from the 95th percentile concentrations are below 1 mrem for all but type M ^{232}Th. A discussion on why Pantex ^{232}Th is not type M follows [23].

Table 4-3. Dose conversion coefficients and air concentrations leading to 10 µSv for ^{3}H, ^{232}Th, ^{234}U, and ^{239}Pu (ICRP 1996).

Nuclide	Details	Organ with highest $H_T(\tau)$	Air concentration breathed for 2,000 hours leading to 10-µSv CED (µBq/m^3)	Dose from breathing 95th-percentile concentration (mrem)
Tritium	Water vapor	Small intestine	185,000,000	0.0044
Th-232	Type M, 1 µm, f_1 = 5E-4	Bone surface	1.89	1.17
Th-232	Type S, 1 µm, f_1 = 5E-4	Bone surface	14.4	0.15
U-234	Type S, 1 µm, f_1 = .002	Lung	59.0	0.084
Pu-239/240	Type M, 1 µm, f_1 = 5E-4	Bone surface	2.85	0.048

For type M thorium the largest upper 95% confidence level of net mean air concentration is 2.21 µBq/m^3, which indicates that a CED of 117 µSv (1.17 mrem) to bone surfaces would accumulate for each year of exposure. However, for thorium type S, the only plausible environmental form of ^{232}Th at Pantex, the largest upper 95% confidence level of net mean air concentration is 14.4 µBq/m^3, which indicates that a CED of 1.5 µSv (0.15 mrem) to bone surfaces would accumulate for each year of exposure. For thorium intakes, CED to the red bone marrow is always far below 10 µSv [24].

Because simultaneous exposure to the observed 95% upper confidence intervals of the means or net means of all environmental radionuclides at Pantex never leads to a CED to the most highly dosed tissue or organ that equals or exceeds 10 µSv, there is no need to reconstruct doses due to environmental exposures to airborne radioactive materials at Pantex.

The quantity of interest is the dose to the tissue or organ during each year, which would have contributions from intakes in each previous year. Figure 4-6 shows IMBA equivalent dose to four tissues or organs unit intake (Sv/Bq) during each year for 1-µm AMAD type W ^{232}Th inhalation. Figure 4-7 shows the annual contribution to equivalent dose to bone surfaces per unit intake for inhalation of a 1-µm activity median aerodynamic diameter (AMAD) type M ^{232}Th aerosol. The greatest value occurs in year 22 after the intake, and the peak value is 2.41% of the average. Figure 4-8 shows the equivalent dose rate to bone surfaces for 10, 20, 30, 40, and 50 years of intakes of 1 Bq/yr of the same aerosol. Figure 4-7 is derived from the results in Figure 4-6 by summing contributions to annual equivalent dose in a given year over the various years of intake. Figure 4-7 shows that the annual equivalent dose rate peaks at differing intervals (28, 35, 43, 49, and 50 years, respectively) after intake begins for different intake durations and for differing intervals (18, 15, 13, 9, and 0 years, respectively) after intake ends for the different intake durations.

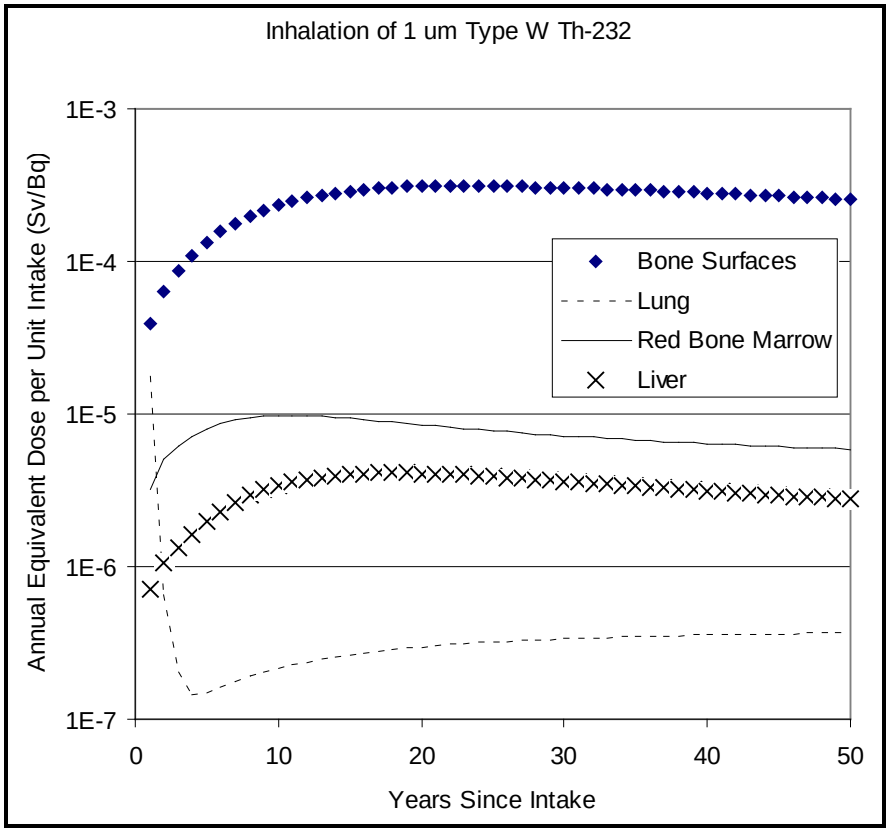

Figure 4-6. IMBA equivalent dose to four tissues or organs per unit intake (Sv/Bq) during each year for 1-µm AMAD type W ^{232}Th inhalation.

The concentration that, if breathed for the duration of a worker's employment at Pantex, would yield a peak annual equivalent dose of 10 µSv to bone surfaces can be deduced from the data in Figure 4-7. They are 6.62, 3.36, 2.30, 1.78, and 1.58 µBq/m^3, respectively, for intakes lasting 10, 20, 30, 40, or 50 years. Therefore, a worker would have to breathe the 95% upper confidence level concentration at location FL-AR-10 for 33 years to reach a peak annual dose rate of 10 µSv in a year, and for 34 or more years to exceed 10 µSv in a year to bone surfaces. It is noted that lung clearance classification W is from the ICRP 30 dosimetric models. Dose coefficients for the ICRP 66 internal dosimetry model lung absorption type M ^{232}Th material yield comparable results.

As a further measure of how this calculation tends to overestimate the dose, it is implausible that released thorium from Pantex operations could be type M, because thorium was not machined or cut, only assembled or disassembled. Therefore, the only plausible means for thorium to become airborne would be for oxidation products to become airborne [25]. The dose factor for type S thorium is $2.5 \times 10^{-5}/4.5 \times 10^{-5}$ or 55% of the dose factor for type M thorium. If the thorium is type S, then even a 50-year continuous exposure to the maximum credible concentration does not lead to an annual equivalent dose to bone surfaces in excess of 10 µSv, as shown above.

For all other organs and tissues, combining maximum credible intakes to all combined radionuclides never exceeds 10 µSv in any calendar year, even for 50 years continuous exposure.

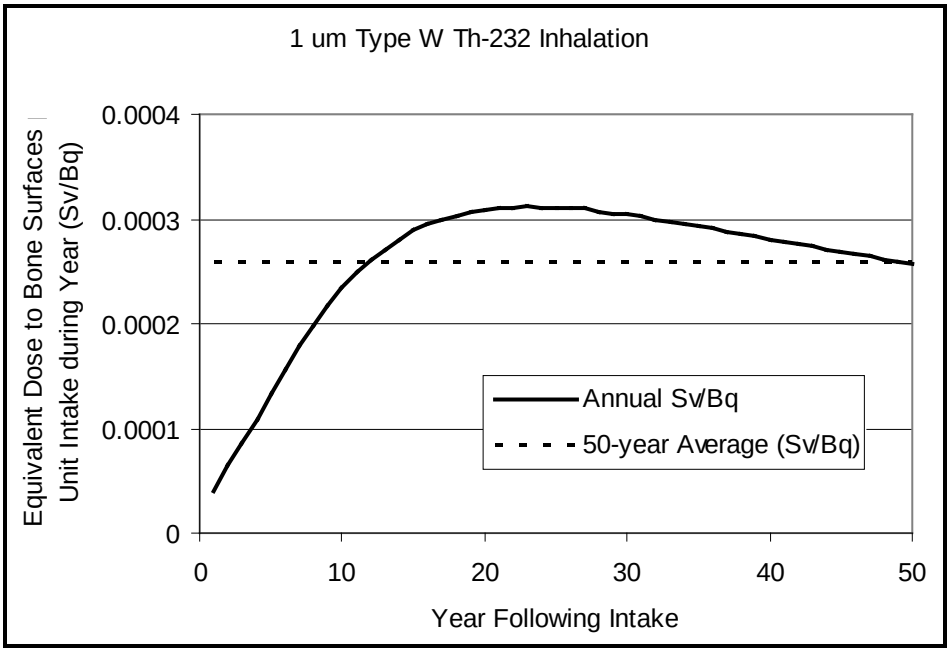

Figure 4-7. IMBA equivalent dose and average equivalent dose to bone surfaces per unit intake (Sv/Bq) during each year for 1-µm AMAD type W ^{232}Th inhalation.

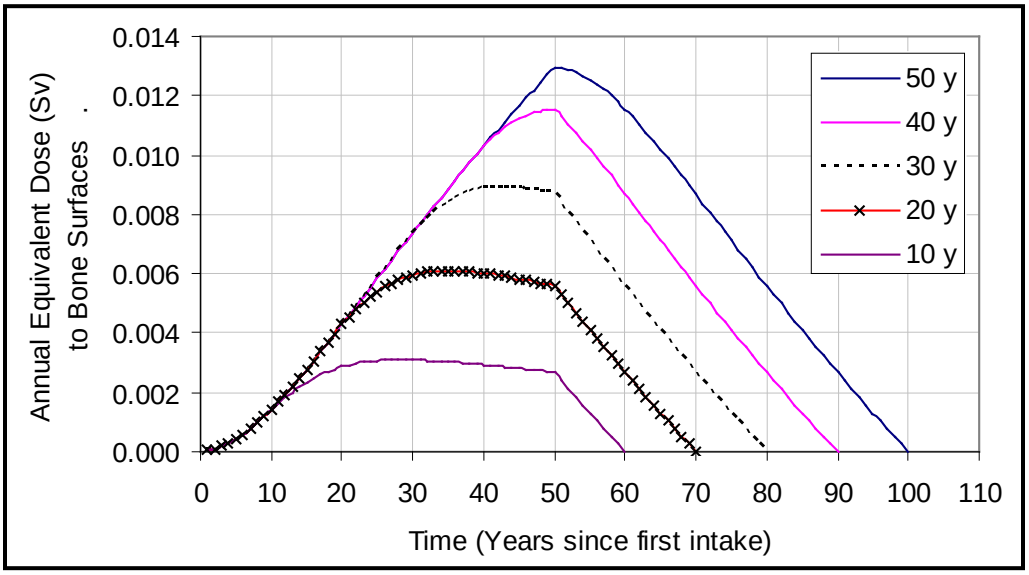

Figure 4-8. IMBA annual equivalent dose (Sv) to bone surfaces for 10-, 20-, 30-, 40-, and 50-year inhalation intakes of 1 Bq/yr of 1-µm AMAD type W ^{232}Th.

4.2.3 Annual Intakes from Resuspension

Soil sampling and analysis were routinely performed at the Pantex Plant (BWXT Pantex 2001). In addition, several special surveys were performed, but methods for soil sampling and analysis were not standardized throughout the DOE weapons complex until the early 1970s. In 1973, DOE dedicated a laboratory to soils analysis and purchased or fabricated the necessary field and laboratory equipment.

As stated in Section 4.2.1, concentrations of radionuclides in soil were not used to determine resuspension as part of the concentration of radionuclides available for inhalation. This analysis assumed that monitored air concentrations included a real-time resuspension fraction. This assumption is reasonable because:

- The topography of the site and the region is very flat and dry (BWXT Pantex 2001).
- The meteorology of the site and the region is very consistent and relatively invariable (Snyder 1993).
- Wind speed and direction are relatively consistent and constant, respectively (see Figure 4-9 and Table 4-4) (BWXT Pantex 2001).

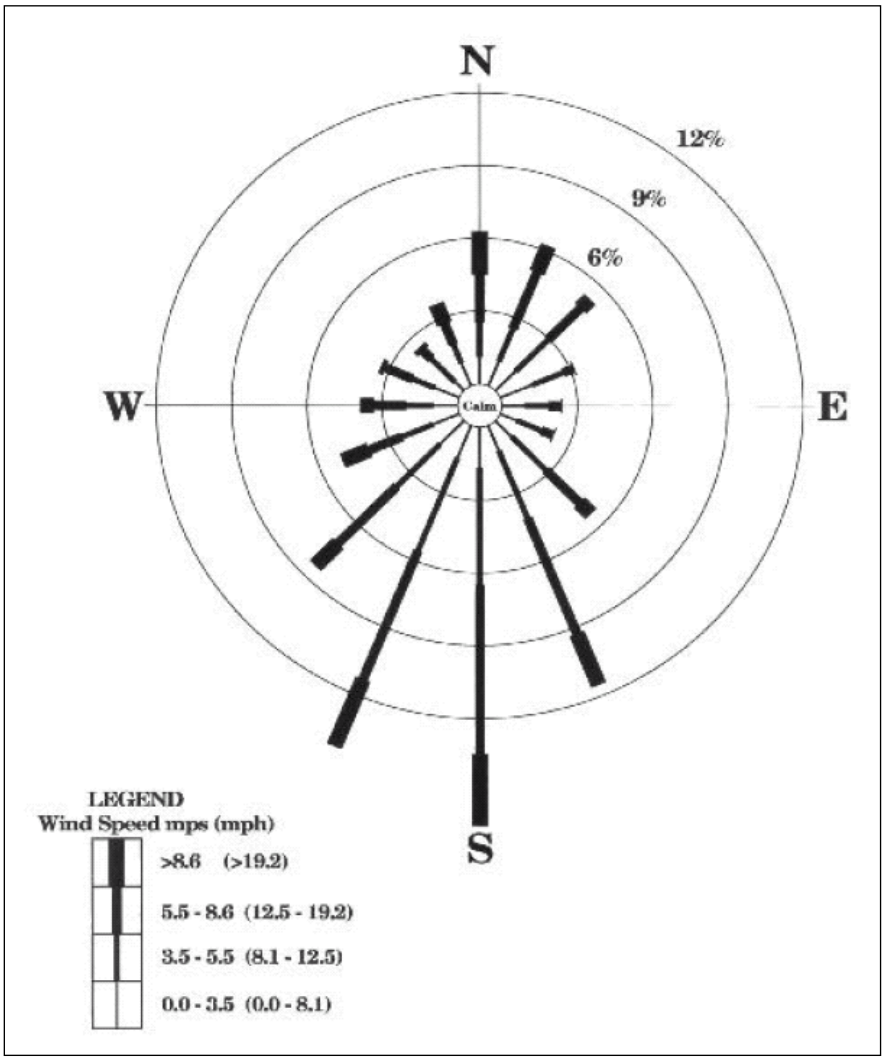

Figure 4-9. Wind rose for 2000 (BWXT Pantex 2001).

Table 4-4. Climatological data for 2000 by month (BWXT Pantex 2001).

Month	Temperature, °Celsius (°Fahrenheit)			Mean relative humidity (%)	Precipitation[a], mm (in.)	Wind speed, m/s (mph)	
	Maximum	Minimum	Mean monthly			Mean	Maximum
January	22.4	-11.3	3.8	46	3.05	4.8	15.3
	(72.3)	(11.7)	(38.8)		(0.12)	(10.7)	(34.0)
February	25.0	-8.5	7.7	41	0.00	5.6	15.7
	(77.0)	(16.7)	(45.9)		(0.00)	(12.5)	(34.9)
March	26.2	-4.7	8.4	63	105.66	5.8	16.8
	(79.2)	(23.5)	(47.2)		(4.16)	(12.8)	(37.4)
April	32.8	-1.7	13.9	52	7.37	6.2	15.1
	(91.0)	(28.9)	(57.0)		(0.29)	(13.8)	(33.6)
May	38.7	3.8	20.7	46	21.59	6.4	17.0
	(101.7)	(38.8)	(69.3)		(0.85)	(14.1)	(37.8)
June	34.6	11.7	25.3	75	176.02	5.9	17.5
	(94.3)	(53.1)	(70.1)		(6.39)	(13.2)	(38.9)
July	38.3	16.1	26.1	55	0.00	5.3	15.5
	(100.9)	(61.0)	(79.0)		(0.00)	(11.8)	(34.4)
August	36.6	15.9	27.5	38	0.00	5.1	12.3
	(97.9)	(60.6)	(81.5)		(0.00)	(11.3)	(27.3)
September	37.8	-0.1	22.7	38	0.00	5.5	14.1
	(100.0)	(31.8)	(72.9)		(0.00)	(12.2)	(31.3)
October	35.7	-0.1	14.7	71	134.62	5.1	14.2
	(96.3)	(31.8)	(58.5)		(5.30)	(11.3)	(32.7)
November	20.8	-8.5	3.5	71	0.00	4.9	13.4
	(69.4)	(16.7)	(38.3)		(0.00)	(10.8)	(29.7)
December	17.9	-13.6	-0.8	70	0.00	4.6	15.8
	(64.2)	(7.5)	(30.6)		(0.00)	(10.3)	(35.1)
Annual[b]			14.5	56	443.31	5.4	
			(57.4)		(17.65)	(12.1)	

a. Includes water equivalent of snowfall.
b. Annual mean of parameter (when indicated) except for precipitation. Total precipitation is indicated. Annual maximum and/or minimum temperatures and/or annual maximum wind speed may be obtained by reviewing the data in the appropriate column.

For reconstructing potential unmonitored dose, annual concentrations at all site locations are less than the maximums in the calculations in Section 4.2.2 [26]. These concentrations result in negligible doses. Therefore, no dose should be assigned resuspension of radionuclides.

4.3 EXTERNAL DOSE

Before 1989, only radiation workers were monitored for radiation exposure. These personnel worked primarily in facilities in Zones 4 and 12 [27]. Radiation workers accounted for about half of the workers on the site [28]. Therefore, employees working in other areas or zones were not monitored. Estimated occupational environmental dose would have to be added for those employees who were not monitored.

Pantex workers have received external doses from ambient radiation levels on the site. Ambient radiation levels were not reported until 1986 [29].

4.3.1 Ambient Radiation

The environmental radiological profile for the Pantex Plant is for dose reconstruction when personal dosimetry or bioassay program participation was not required or was not available. ASERs were reviewed for data that would be useful in reconstructing ambient radiation levels. Data in these historical documents (see the References section) included ambient TLD radiation measurements. An ambient radiation level program was initiated and reported beginning in 1986. Figure 4-10 shows the locations of the monitors and TLD dosimeters in 2000 (Laseter 1987).

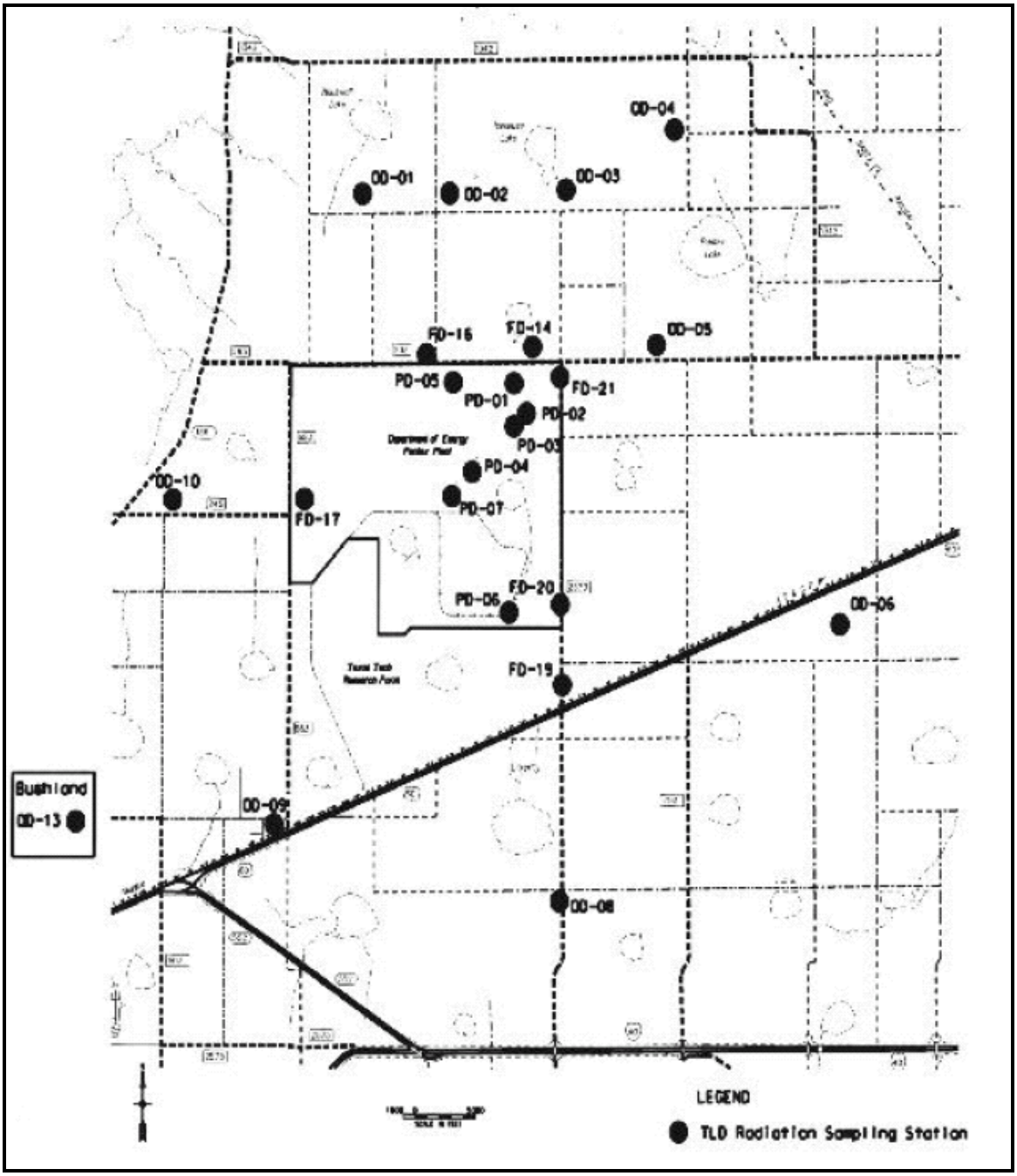

Figure 4-10. Locations of thermoluminescent dosimeters in 2000 (BWXT Pantex 2001). FD = fenceline dosimeter; OD = onsite dosimeter; OS = offsite dosimeter; PD = onsite dosimeter.

The dosimetry results from the ambient environmental monitoring program for the Pantex facility were analyzed to determine whether there was a difference in the dose rates on and off the site.

No environmental dose rates were recorded before 1986 [30]. Before this time, the environmental data consisted of radionuclide concentrations in air, water, soil, vegetation, and jackrabbits [31]. Therefore, the analysis is most appropriate for 1986 to 2002, but extrapolations to previous years can be made.

The dose rate data the analysis used were from TLD readings except for the offsite dose rates for 1990. In 1990 there were apparent problems with the TLD system because, for most dosimeter locations, there was only one non-zero quarterly value (MHSMC 1991). Because the TLD data appeared to be in error, for 1990 only, the offsite dose rate data were obtained from bulb dosimeters at the same sampling locations [32].

Figure 4-11 shows the average of the onsite and offsite radiation doses. In 1986, the Chernobyl incident released sufficient radioactive materials so that a spike in environmental dose rates was observed in locations far removed from the Pantex site (e.g., Oklahoma City and Austin, Texas) (TDH 1999). The dose rates in Figure 4-11 for 1986 could have been elevated solely due to the Chernobyl incident.

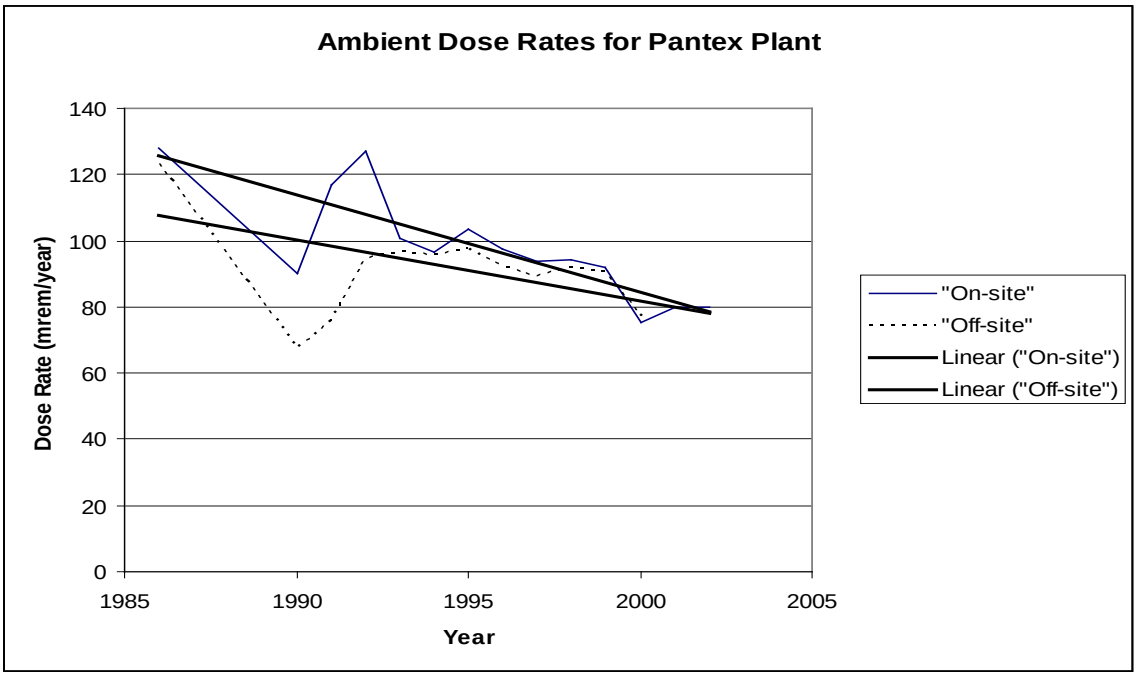

Figure 4-11. Ambient dose rates for Pantex Plant (based on continuous occupancy, 8760 hours per year).

Linear regression, as depicted in Figure 4-11, was performed on the reported dose rates for 1986 through 2000, and the trend lines for offsite and onsite doses were found to converge. According to the trend lines, convergence occurs between 1998 and 2000, depending on which data set is used. According to the trend lines, as time goes backward to 1955, the difference in onsite and offsite dose rates increases. Of course, this trend cannot go on forever in the past, but this analysis can well serve the purpose of estimating ambient doses on the Pantex Plant site that are favorable to claimants. The difference in the slopes of the trend lines were used to estimate onsite ambient environmental doses back to 1955 (Table 4-5).

Based on the data in Table 4-5 and to be favorable to claimants, it is suggested that onsite ambient occupational dose for 1955 through 1974 be added to a person's dose record at the rate of 30 mrem/yr, and the onsite ambient occupational dose for 1975 through 2000 be added to a person's dose record at the rate of 15 mrem/yr. These values are based on a 2500 hour work year. This would result in a maximum ambient dose of about 1,110 mrem for the 50-year period between 1955 and 2000 [33].

Table 4-5. Calculated difference between onsite and offsite annual doses for the Pantex Plant [34].

Year	Difference between onsite and offsite radiation dose rates (mrem/yr)(adjusted to account for a 2500 hour work-year)
1955	28
1960	25
1965	22
1970	19
1975	15
1980	12
1985	9
1990	6
1995	2
2000	1

The Pantex historical personnel external dose monitoring program was reviewed and determined to have been properly managed in relation to storage of control badges and accounting for environmental exposures [35]. Therefore, doses of record properly include occupational environmental doses and no adjustments of recorded doses need be made for monitored workers [36].

4.4 UNCERTAINTY

As discussed in the previous sections, estimates of annual intakes were based on air monitoring data and their sampling and analytical uncertainties. Where needed, the analysis made conservative (i.e., favorable to claimant) assumptions. The estimated annual concentrations based on monitoring data precluded the use of calculated meteorological conditions that could introduce large, additional uncertainties.

In instances where more detailed information is known about a particular individual or job classification, dose reconstruction should account for other modifying factors. For example, if (for a particular job classification) there is reason to believe that the actual ventilation rate for the worker might vary markedly from the average of 2,400 m^3/yr of exposure, the dose reconstructor should use professional judgment to adjust the estimated intakes as necessary, according to whether the individual was engaged in light or heavy work. The respiration rate is 1.2 m^3/hr for light work and 1.7 m^3/hr for heavy work (Shleien 1992). In these cases, dose reconstructors should estimate the annual intake by summing the products of the fractional annual period for each job-dependent level of work and the corresponding ventilation rate to determine the total ventilation volume for the year in cubic meters. The annual intake is the product of the annual ventilation volume and the annual average concentration for the location of interest.

Based on TLD measurements of ambient external dose, the annual mean external gross dose (not net dose) on the site was 0.910 mSv with a standard deviation of 0.140 mSv. However, additional bias and uncertainty has been identified in TLD dosimeters. Biases and uncertainties for typical TLD systems have been identified as described by Fix and Stewart (ORAUT 2006).

The factors to be applied to various dosimeters are:

- Based on the distribution of energy levels and geometry judged most likely, recorded dose divided by the table's bias value to calculate deep dose.

- Range of overall bias factors based on alternative distributions of energy levels and geometry.
- Systematic uncertainty resulting from lack of knowledge of actual distributions of energy levels and geometry.
- Random uncertainty resulting from variation among workers in energy levels and geometry.

Overall, these biases and uncertainties in external personnel dosimeters could lead to an additional factor-of-2 increase in the recorded dose.

For this document, no attempt has been made to quantify other uncertainties.

4.5 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).

Dillard B. Shipler served as the initial Document Owner of this document. Mr. Shipler was previously employed at the Pantex site and his work involved management, direction or implementation of radiation protection and/or health physics program policies, procedures or practices related to atomic weapons activities at the site. This revision has been overseen by a new Document Owner, who is fully responsible for the content of this document, including all findings and conclusions.

[1] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
Detailed source terms for the Pantex Plant are classified and were not made available.

[2] Winslow, Robert C. ORAU Team. Senior Health Physicist. April 2007.
DU contains about 99.8% ^{238}U, 0.2% ^{235}U, and 0.001% ^{234}U by mass. Application of the specific activities of 1.24×10^{-8} TBq/g for ^{238}U, 8.00×10^{-8} TBq/g for ^{235}U, and 2.31×10^{-4} TBq/g for ^{234}U results in 1.24×10^{-6} TBq for ^{238}U, 1.60×10^{-8} TBq for ^{235}U, and 2.31×10^{-7} TBq for ^{234}U and a total activity of 1.49×10^{-6} TBq.

[3] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
Pantex internal dosimetry manuals do not address ^{233}U at all.

[4] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
Because few devices were disassembled before 1980, releasable uranium oxide was available only in old devices and releases of tritium occurred only during disassembly. Airborne radioactive materials were not deemed a potential concern until 1980.

[5] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
Uranium oxide that was released when old devices were disassembled was known and dispersion was controlled within the cells. Only small amounts of tritium were released when the container was disconnected from its assembly.

[6] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
Tritium reservoirs came as sealed containers and the seal was not broken during insertion.

[7] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
From review of documents and interviews of personnel (see ORAUT 2004, ORAUT 2007b), metal came as formed items, so no activities were performed that would generate oxides.

[8] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
From review of documentation and interview of personnel (see ORAUT 2004, ORAUT 2007b), no materials containing metals were burned during this period, so no oxides were formed or released.

[9] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
Once tritium reservoirs were in place (inserted), valves were opened. When the device was disassembled, the valve was closed and the reservoir was removed. A small amount of tritium was released from between the reservoir and the device. These amounts are summarized in Table 4-1.

[10] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
Specific releases of radioactive materials from Pantex facilities are classified and not available. Summaries are provided in annual reports except for a few historical incidents.

[11] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
This is based on review of plant documents, interviews with plant personnel, and personal and professional judgment.

[12] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
Considering time-related production, time-related availability of radioactive materials on the site, and the small concentrations of radioactive materials in the air and soil when releases of radioactive materials could have occurred after 1980, initial analyses of potential intakes and resulting doses led the authors to believe that potential doses from intakes would be negligible.

[13] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
The team reviewed a number of “General Radiation Survey Forms for Bays/Cells” related to surveys of gland nut removals when disassembling tritium reservoirs. Most were 0 µCi, many were 10 µCi, and only a few were more than 10 µCi. The statement is a general statement of the reviews.

[14] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
The factor was derived based on review of many years of Pantex documentation, professional judgment, and favorability to claimants.

[15] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
The factor was derived based on review of Pantex documentation, professional judgment, and favorability to claimants.

[16] Shipler, Dillard B. ORAU Team. Principal Health Physicist. August 2006.
Uranium oxide that was released when old devices were disassembled was known and dispersion was controlled in the cells.

[17] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
Plutonium pits that were removed during disassembly are still sealed and, therefore, no releases of plutonium occur.

[18] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
This is the form of thorium that was monitored when monitoring did occur for thorium.

[19] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
"Negligible doses" will not contribute to doses deemed necessary to produce cancers.

[20] Winslow, Robert C. ORAU Team. Senior Health Physicist. March 2007.
A distribution of the environmental air samples taken outside the facility would represent the entire facility. While working at a facility, workers, in general, will move around and therefore receive exposures to different concentrations. However, a worker might spend a longer period in higher concentrations; the distribution would be diluted by the lower concentration areas. Therefore, the 95% confidence of the mean is assumed to be bounding to account for a worker spending the majority of the time in the higher concentration.

[21] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
This equation is a mathematical expression of the statement preceding the equation and referenced above.

[22] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The Pantex Plant monitored concentrations of radionuclides in air at the site boundary and at selected offsite locations (outside the site boundary). However, concentrations of radionuclides were not monitored regularly at locations within the site boundary. Areas within the site boundary (outside facilities) were monitored on an as-needed basis depending on the activities.

[23] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The argument is presented in case the form of ^{232}Th can be shown to be type M. The possibility is remote but the subject is covered.

[24] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The argument is presented to clarify the situation that involves bone surface cancer versus red bone marrow cancer where ^{232}Th might be thought to be a contributor.

[25] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The statement means that pure thorium metal particulates could not be released to the air. Only particulates of thorium oxide could be released.

[26] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The authors compared the maximum concentrations at various locations, which were all less than the concentrations used to demonstrate negligible doses in Section 4.2.2.

[27] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The history of radiation monitoring of external dose to workers is covered in ORAUT-TKBS-0013-6 (ORAUT 2007c), particularly in Table 6-15 and Figure 6-1.

[28] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The history of radiation monitoring of external dose to workers is covered in ORAUT-TKBS-0013-6 (ORAUT 2007c), particularly in Table 6-15 and Figure 6-1.

[29] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
After reviewing annual environmental reports and their predecessor documents and talking with Plant personnel, it is evident that radioactive materials were sampled in environmental media but direct radiation was not monitored at all locations.

[30] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
After reviewing annual environmental reports and their predecessor documents and talking with Plant personnel, it is evident that radioactive materials were sampled in environmental media but direct radiation was not monitored at all locations.

[31] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
After reviewing annual environmental reports and their predecessor documents and talking with Plant personnel, it is evident that radioactive materials were sampled in environmental media but direct radiation was not monitored at all locations.

[32] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
According to Pantex personnel and early site environmental and external monitoring data, bulb dosimeters were used before other dosimeters but were kept in the system as backup as new dosimetry was implemented.

[33] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The evaluation was based on the data in the spreadsheet and professional judgment in defining the factor and rounding it to a number that is favorable to the claimant and easy for the dose reconstructor to use.

[34] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The calculations were performed in a spreadsheet and the results of interest were included in the table and the figure to demonstrate the point.

[35] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
All Pantex external dosimetry program documents, including BWXT Pantex (2002a), were reviewed along with implementation reports and databases, and long-time employees were interviewed, as indicated in the several memoranda to file. The evidence seemed to justify the statements of credibility and reliance on the result of the programs as they grew and matured.

[36] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
All Pantex external dosimetry program documents, including BWXT Pantex (2002a), were reviewed along with implementation reports and databases, and long-time employees were interviewed, as indicated in the several memoranda to file. The evidence seemed to justify the statements of credibility and reliance on the result of the programs as they grew and matured.

[37] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
Section 4.2.2.5 discusses the potential for a small cumulative dose to bone surface because of dose factors and solubility factor selection.

[38] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
Because the lines converge noticeably to modern times and because the doses are relatively small, judgment concludes that single conservative values that are favorable to the claimant would be adequate rather than the imposition of a function for year-by-year doses.

[39] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
From the graph, the lines might be interpreted to converge in 2002. However, for conservatism and favorability to claimants, the convergence is not considered an end point and the proposed doses should be applied to current years.

[40] Shipler, Dillard B. ORAU Team. Principal Health Physicist. September 2006.
The storage of control badges in places where environmental doses as well as work-related doses do not exist means that differences between badges worn by workers and control

badges account for all exposures. Note in the paragraph above that unmonitored workers must have dose added to their total.

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GLOSSARY

annual dose equivalent
Dose equivalent received in a year in units of rem or sievert.

becquerel (Bq)
International System unit of radioactivity equal to 1 disintegration per second; 1 curie equals 37 billion (3.7×10^{10}) Bq.

beta radiation
Charged particle emitted from some radioactive elements with a mass equal to 1/1,837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is a positron.

committed effective dose equivalent (CEDE)
Sum of the effective dose equivalents to various tissues or organs in the body each multiplied by the appropriate tissue weighting factor and committed for a 50-year period following an acute intake or the onset of chronic intake. It does not include contributions from external dose.

curie (Ci)
Traditional unit of radioactivity equal to 37 billion (3.7×10^{10}) becquerels, which is approximately equal to the activity of 1 gram of pure ^{226}Ra.

depleted uranium (DU)
Uranium with a percentage of ^{235}U lower than the 0.7% found in natural uranium. As examples, spent (used) fuel elements, byproduct tails, residues from uranium isotope separation, and some weapons materials contain DU. DU can be blended with highly enriched uranium to make reactor fuel or used as a raw material to produce plutonium. Pantex lists the isotope activity fractions for use in nuclear weapons components as:

Isotope	Activity fraction
^{234}U	0.0840
^{235}U	0.0145
^{238}U	0.9015

dose equivalent (*H*)
In units of rem or sievert, product of absorbed dose in tissue multiplied by a weighting factor and sometimes by other modifying factors to account for the potential for a biological effect from the absorbed dose.

dosimeter
Device that measures the quantity of received radiation, usually a holder with radiation-absorbing filters and radiation-sensitive inserts packaged to provide a record of absorbed dose received by an individual.

dosimetry
Measurement and calculation of internal and external radiation doses.

dosimetry system
System for assessment of received radiation dose. This includes the fabrication, assignment, and processing of external dosimeters, and/or the collection and analysis of bioassay samples, and the interpretation and documentation of the results.

effective dose equivalent (EDE)

Average of the dose equivalents weighted for the susceptibility of harm to different tissues or organs in units of rem or sievert.

exposure

(1) In general, the act of being exposed to ionizing radiation. See *acute exposure* and *chronic exposure*. (2) Measure of the ionization produced by X- and gamma-ray photons in air in units of roentgens.

gamma ray

Electromagnetic radiation (photons) originating in atomic nuclei and accompanying many nuclear reactions (e.g., fission, radioactive decay, and neutron capture). Physically, gamma rays are identical to X-rays but have higher energy; the only essential difference is that X-rays do not originate in the nucleus.

gray

International System unit of absorbed radiation dose, which is the amount of energy from any type of ionizing radiation deposited in any medium; 1 gray equals 1 joule per kilogram or 100 rads.

ionizing radiation

Radiation of high enough energy to remove an electron from a struck atom and leave behind a positively charged ion. High enough doses of ionizing radiation can cause cellular damage. Ionizing particles include alpha particles, beta particles, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, photoelectrons, Compton electrons, positron/negatron pairs from photon radiation, and scattered nuclei from fast neutrons.

radiation

Subatomic particles and electromagnetic rays (photons) with kinetic energy that interact with matter through various mechanisms that involve energy transfer. See *ionizing radiation*.

radioactivity

Property possessed by some elements (e.g., uranium) or isotopes (e.g., ^{14}C) of spontaneously emitting energetic particles (electrons or alpha particles) by the disintegration of their atomic nuclei.

rem

Traditional unit of radiation dose equivalent that indicates the biological damage caused by radiation equivalent to that caused by 1 rad of high-penetration X-rays multiplied by a quality factor. The sievert is the International System unit; 1 rem equals 0.01 sievert. The word derives from roentgen equivalent in man; rem is also the plural.

thermoluminescence

Property that causes a material to emit light as a result of heat.

thermoluminescent dosimeter (TLD)

Device for measuring radiation dose that consists of a holder containing solid chips of material that, when heated, release the stored energy as light. The measurement of this light provides a measurement of absorbed dose.

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.

whole-body (WB) dose

Dose to the entire body excluding the contents of the gastrointestinal tract, urinary bladder, and gall bladder and commonly defined as the absorbed dose at a tissue depth of 10 millimeters (1,000 milligrams per square centimeter). Also called penetrating dose.

X-ray radiation

Electromagnetic radiation (photons) produced by bombardment of atoms by accelerated particles. X-rays are produced by various mechanisms including bremsstrahlung and electron shell transitions within atoms (characteristic X-rays). Once formed, there is no difference between X-rays and gamma rays, but gamma photons originate inside the nucleus of an atom.

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RADIONUCLIDE INTAKE AND OCCUPATIONAL EXPOSURE
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A.1 RADIONUCLIDE INTAKE

Based on the information in Section 4.2.2 of this Technical Basis Document, all potential doses from occupational environmental intakes on the Pantex Plant are considered negligible and should be assigned zero dose. Some attention might be paid to claims based on bone surface cancers relative to the time the worker spent at the Pantex Plant [37]. As stated in Section 4.2.2, the committed dose from ^{232}Th conservatively might be 117 µSv (1.17 mrem). In addition, for individuals who were employed at the Pantex Plant in 1989 and 1990, an acute dose of 0.015 rem applied as <15-keV electrons should be assigned for 1989 and a chronic dose of 0.001 rem applied as <15-keV electrons should be assigned for 1990 based on Section 4.2.1.1.

A.2 EXTERNAL EXPOSURE

Ambient external doses on the Pantex site have been monitored by TLDs since 1986. Based on trend analysis of onsite and offsite TLD measurements, as described in Section 4.3.1, the extrapolated difference in offsite and onsite doses in 1955 could be as much as 100 mrem/yr for continuous occupancy on the site (8,760 hr/yr) [38]. The trend lines converge in about 2000 [39]. Therefore, to account for the dose that a worker would receive in a 50-hour work week (2,600 hr/yr), it is recommended that 30 mrem/yr be added to unmonitored workers for 1955 through 1974 and 15 mrem/yr be added to unmonitored workers for 1975 through the present.

The Pantex historical personnel external dose monitoring program was reviewed and determined to have been properly managed in regard to storage of control badges and accounting for environmental exposures (BWXT Pantex 2002). It is concluded that doses of record properly include occupational environmental doses and no adjustments of recorded doses need be made for monitored workers [40].

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Tables A-1 and A-2 provide supporting data for the analyses described in this TBD.

Table A-1. References for maximum air concentrations for tritium (oxidized), thorium, uranium, and plutonium used in Section 4.2.2 dose analyses (BWXT Pantex 2001).

Radionuclides	Tables in DOE (2001a)
Tritium (oxidized)	Table 5.1, page 5-8, location PA-AR-06
Thorium-232	Table 5.3, page 5-11, location FL-AR-05
Uranium-234/234 & 238	Table 5.4, page 5-12, location FL-AR-05 Table 5.5, page 5-14, location FL-AR-05
Plutonium 239/240	Table 5.7, page 5-18, location FL-AR-08

Table A-2. Upwind "control" (location OA-AR-13) average annual air concentrations.

Isotopes/elements	Number of samples	Concentration (μBq/m^3) (mean ±standard deviation)	Previous 3-yr mean
Tritium oxide	-	-	-
Uranium	12	2.32 ±1.08	1.26
Plutonium	-	-	-
Thorium	12	2.17 ±1.37	1.85

A.3 ONSITE AMBIENT DOSE ASSIGNMENT

For cases in which doses can be overestimated, onsite ambient doses should be assigned based on Table A-3 using a constant distribution.

Table A-3. Maximizing onsite ambient doses

Year	Onsite ambient dose (rem)
1955–1974	0.030
1975–2015	0.015

For cases in which the dose cannot be overestimated, onsite ambient doses should be assigned based on Table A-4 using a normal distribution with the specified values for Parameters 1 and 2. Note that the primary mission at Pantex from 1952 through 1954 was to precision-machine HE castings and send them to Sandia National Laboratory in Albuquerque, New Mexico, for assembly (ORAUT, 2007b). Therefore, no on-site ambient doses are assigned for the years of 1951 through 1954.

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Table A-4. Best-estimate onsite ambient doses (rem).

Year	Parameter 1	Parameter 2	Year	Parameter 1	Parameter 2
1955	0.0280	0.0170	1985	0.0091	0.0055
1956	0.0273	0.0166	1986	0.0084	0.0051
1957	0.0267	0.0162	1987	0.0078	0.0047
1958	0.0261	0.0158	1988	0.0072	0.0044
1959	0.0254	0.0155	1989	0.0065	0.0040
1960	0.0248	0.0151	1990	0.0059	0.0036
1961	0.0242	0.0147	1991	0.0053	0.0032
1962	0.0235	0.0143	1992	0.0047	0.0028
1963	0.0229	0.0139	1993	0.0040	0.0024
1964	0.0223	0.0136	1994	0.0034	0.0021
1965	0.0217	0.0132	1995	0.0028	0.0017
1966	0.0210	0.0128	1996	0.0021	0.0013
1967	0.0204	0.0124	1997	0.0015	0.0009
1968	0.0198	0.0120	1998	0.0010	0.0005
1969	0.0191	0.0116	1999	0.0010	0.0001
1970	0.0185	0.0113	2000	0.0010	0.0001
1971	0.0179	0.0109	2001	0.0010	0.0001
1972	0.0172	0.0105	2002	0.0010	0.0001
1973	0.0166	0.0101	2003	0.0010	0.0001
1974	0.0160	0.0097	2004	0.0010	0.0001
1975	0.0154	0.0093	2005	0.0010	0.0001
1976	0.0147	0.0090	2006	0.0010	0.0001
1977	0.0141	0.0086	2007	0.0010	0.0001
1978	0.0135	0.0082	2008	0.0010	0.0001
1979	0.0128	0.0078	2009	0.0010	0.0001
1980	0.0122	0.0074	2010	0.0010	0.0001
1981	0.0116	0.0070	2011	0.0010	0.0001
1982	0.0109	0.0067	2012	0.0010	0.0001
1983	0.0103	0.0063	2013	0.0010	0.0001
1984	0.0097	0.0059	2014 forward	0.0010	0.0001