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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

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## PUBLICATION RECORD

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| 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. |

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AMAD | activity median aerodynamic diameter |
| ASER | Annual Site Environmental Report |
| Bq | Becquerel |
| Ci | curie |
| CDC | Centers for Disease Control and Prevention |
| CEDE | committed effective dose equivalent |
| CY | calendar year |
| DOE | U.S. Department of Energy |
| DU | depleted uranium |
| EEOICPA | Energy Employees Occupational Illness Compensation Program Act of 2000 |
| EH | environment, safety, and health (DOE) |
| EDE | effective dose equivalent |
| EPA | U.S. Environmental Protection Agency |
| FD | fenceline dosimeter |
| FL | fenceline |
| FS | firing site |
| g | gram |
| GM | Geiger-Mueller |
| h | hour |
| $^{3}H$ | tritium |
| HE | high explosive |
| ICRP | International Commission on Radiological Protection |
| IMBA | Integrated Modules for Bioassay Analysis (program) |
| m | meter |
| mrem | millirem |
| mL | milliliter |
| mph | miles per hour |
| NCRP | National Council on Radiation Protection and Measurements |
| NIOSH | National Institute for Occupational Safety and Health |
| OCAS | Office of Compensation and Support |
| OD | onsite dosimeter |
| OS | off-site |
| PD | onsite dosimeter |
| POC | probability of causation |
| RBM | red blood marrow |
| rem | unit of radiation dose |

| | |
|---|---|
| Sv | sievert |
| TBD | to be determined |
| TBq | terabecquerel |
| TLD | thermoluminescent dosimeter |
| U.S.C. | United States Code |
| yr | year |
| μ | micro, $10^{-6}$ |
| § | 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 historic 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) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute 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 contains an exclusion with respect to the Naval Nuclear Propulsion Program, 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 dosimetry monitoring results are considered valid for use in 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:

- Radiation from naturally occurring radon present in conventional structures
- Radiation from diagnostic X-rays received in the treatment of work-related injuries

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

### 4.1.1 Purpose

The purpose of this 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 present at the Pantex Plant include 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. The following sections discuss radionuclides present at Pantex.

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.

## 4.2 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 (EPA)-approved CAP88-PC computer model to evaluate the radiological dose that a member of the public could receive during the year (BWXT Pantex 2001, pp. 4-5). 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 release 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].

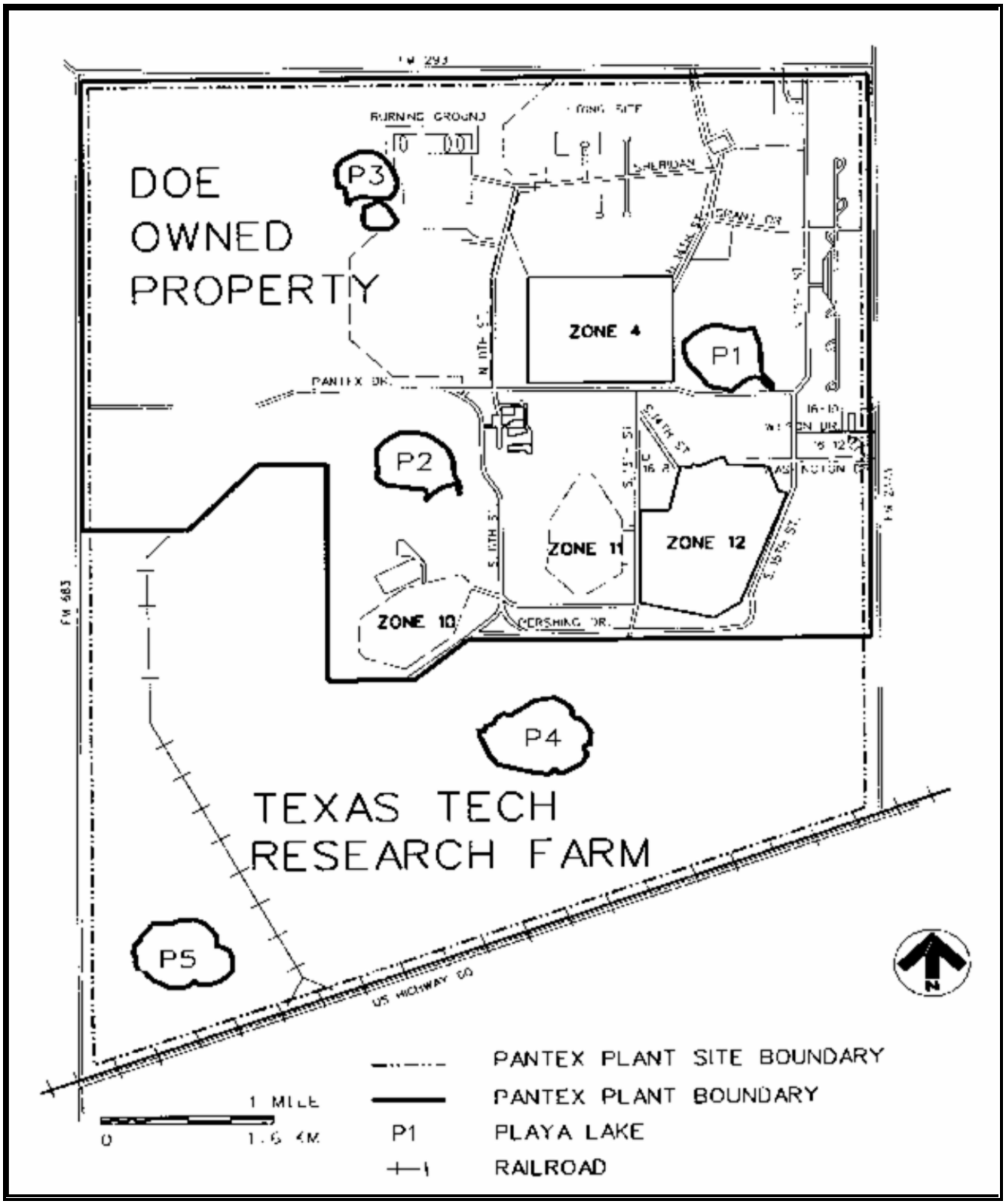


Figure 4-1. Pantex Plant site (BWXT Pantex 2001).

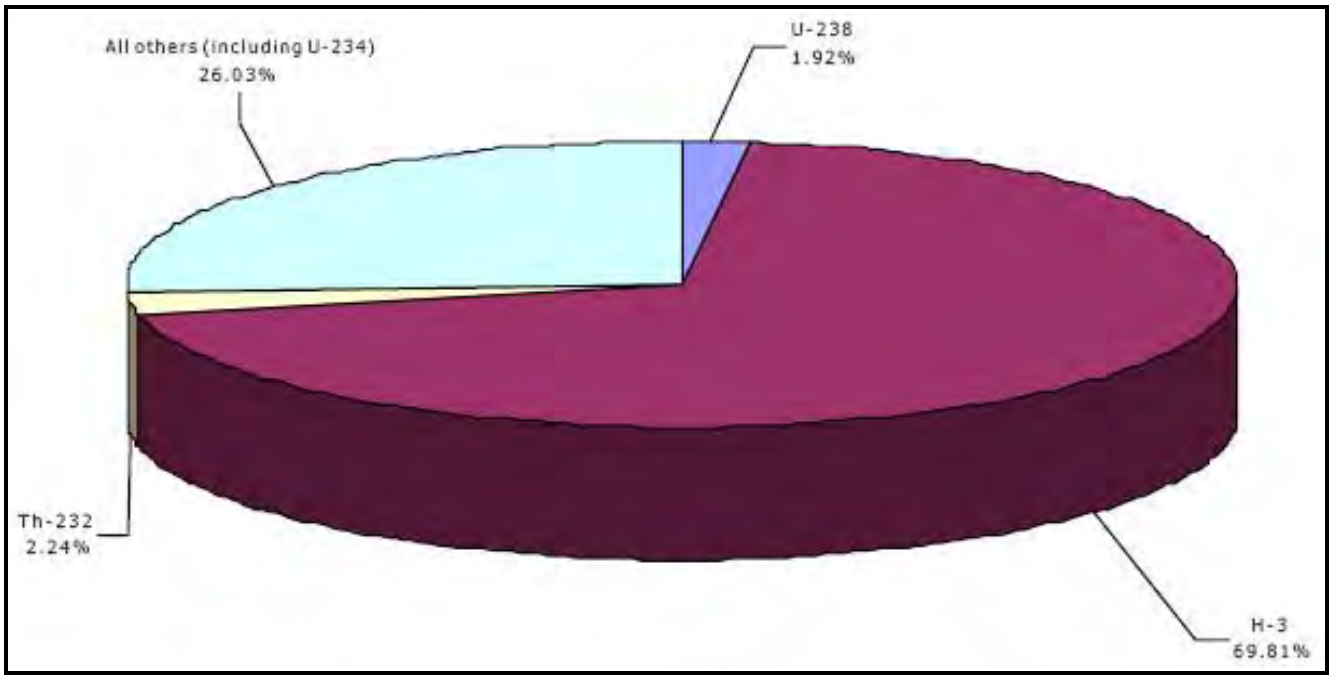


Figure 4-2. Isotopic contributions to offsite dose from Pantex operations in 2000 (BWXT Pantex 2001).

### 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 several sources, including Environmental Monitoring Reports (EMRs), 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; BP and MHMSC 1992, 1993, 1994, 1995; DOE 1996, 1997; BP and MHC 1998; DOE 1999, 2000; BWXT Pantex 2001, 2002, 2003), annual summaries of radiological doses and releases reported to DOE (DOE 1982, 1984, 1992, 1994; BMI 1985, 1988, 1990a,b; PNL 1993; PNNL 1997a,b), radiation safety department incident records (MHSMC 1986), and radiation safety department technical basis manuals (Pantex 2002). Table 4-1 summarizes releases to the atmosphere from plant vents. EMRs and ASERs contain air release and soil monitoring data, and thermoluminescent dosimeter (TLD) monitoring data from on and off the site. 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 (BP 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). Total employment on the site is shown in Figure 4-4. Many employees in early years were not badged indicating the need for assessing missed or unmonitored dose (Prather 2003).

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 | -- | -- | -- | BP and MHSMC 1994 |
| 1994 | 4.46E-01 | -- | -- | -- | BP 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 | BP 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, particularly air monitoring data would be appropriate for dose reconstruction and account for resuspension of radionuclides in soil, particularly, monitoring data would 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 was time-related, as follows:

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.

Radioactive materials began arriving at Pantex 1951 (Martin 2004).

- In 1951, DU began arriving as new, bare metal forms (Martin 2004).
- In 1956, tritium began arriving in sealed containers (Martin 2004).
- In 1958, plutonium began arriving in sealed metal forms (Martin 2004).
- Thorium began arriving at the plant as new, bare metal forms in the 1960s (Martin 2004).

- From 1952-1958, the only operation at Pantex was weapons assembly (Martin 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].

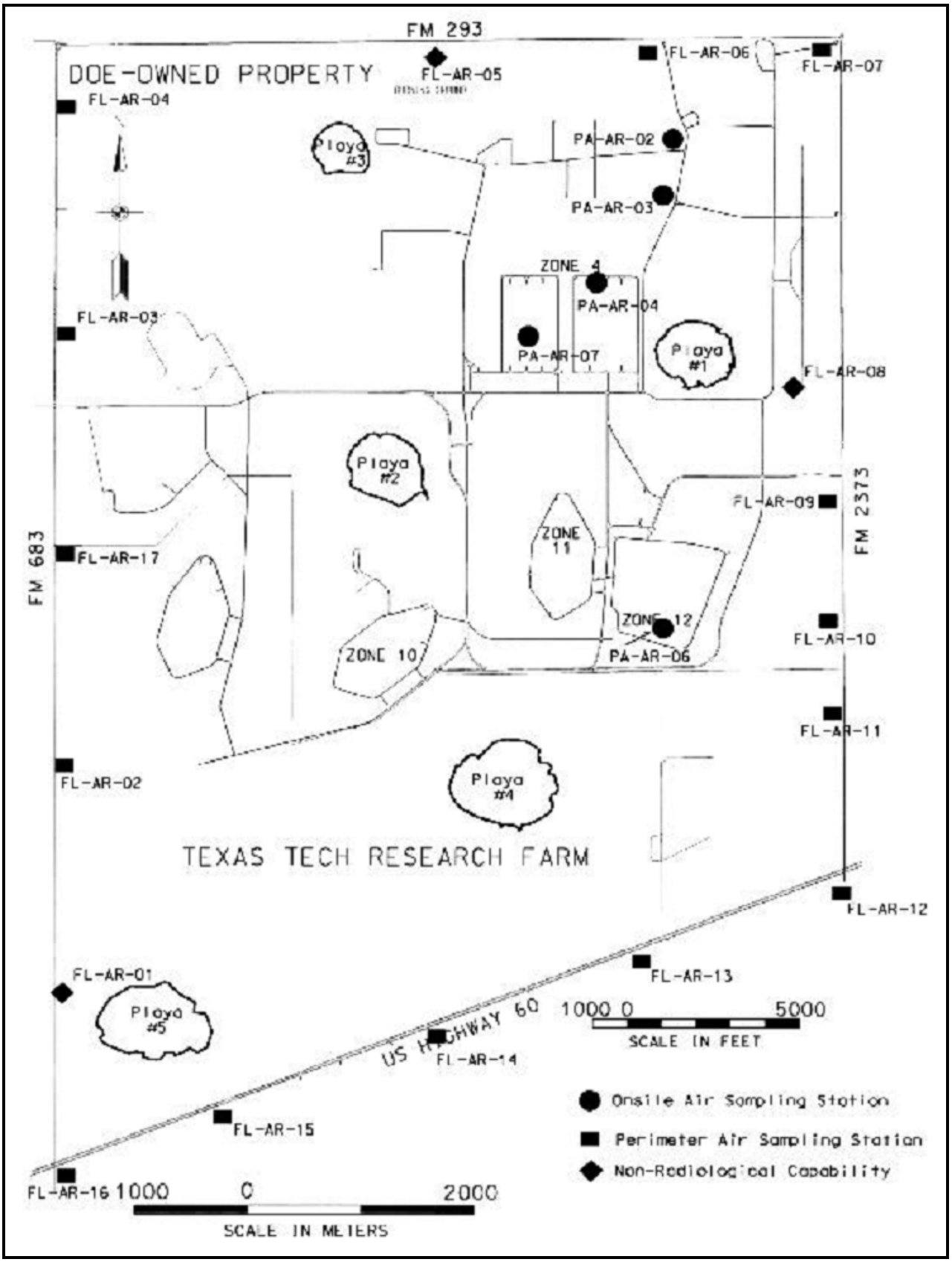


Figure 4-3. Air monitoring stations in 2000 (BWXT Pantex 2001).

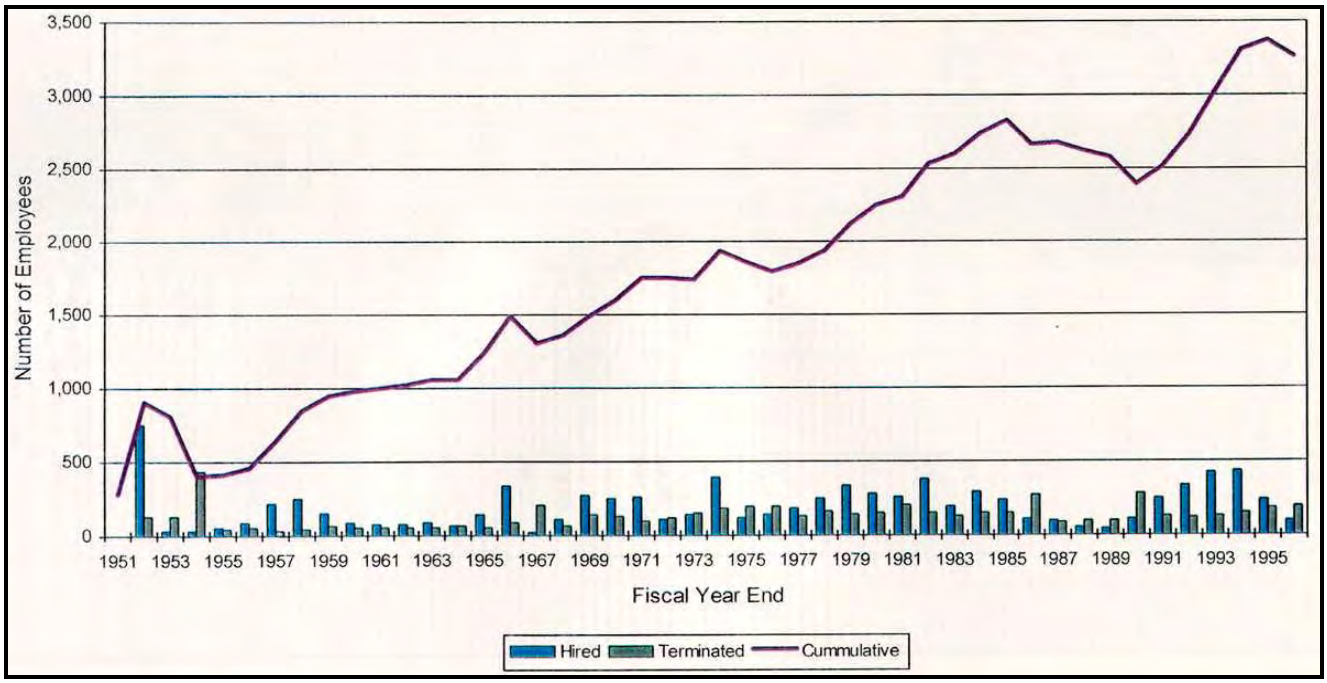


Figure 4-4. Employment history (Mitchell 2003).

  - Some DU was released at the burning grounds with the burning of high-explosive (HE) components (ORAUT 2006a).

  - Some DU was released at the firing sites when HE firings involved DU components (ORAUT 2006a).

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

- 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).

- Though $^{238}$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 $^{238}$Pu was never on the Pantex Plant (Griffis 2004).

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 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 [12]. Additional guidance for evaluation of potential intake based on the type of worker and location is provided in the Occupational Internal Dose section of the Pantex site profile (ORAUT 2007).

#### 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 2007). 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, NNE, was about 10 times the fenceline dose (MHSMC 1990). Therefore, use 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 tritium residual 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 (NNE) was 1.0 mrem. Use this value 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 (Martin 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 of type of part is HE that generally is destroyed by burning. During the burning, associated powdered uranium is released to the atmosphere (ORAUT 2007).

The alpha-emitting radionuclides of this uranium represent a potential radiological risk if inhaled. Isotopes measured to be present include $^{233/234}$U and $^{238}$U. For dose reconstruction, assume that $^{234}$U, the isotope that results in the maximum organ dose, is present at 100%. This assumption would result in a small, but favorable to claimant, overestimation of the actual dose (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 following a test detonation at Firing Site 23. This action resulted in the release of particulate material containing depleted uranium (BWXT Pantex 2004). All personnel in the area were upwind (NE 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 0.01-0.02 $\mu Bq/m^3$) and 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 Pantex Plant 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) clearance 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 airborne concentrations of radionuclides measured 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 radionuclides measured 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 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 are strongly correlated 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 released by 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 4-5 and 4-6, respectively.

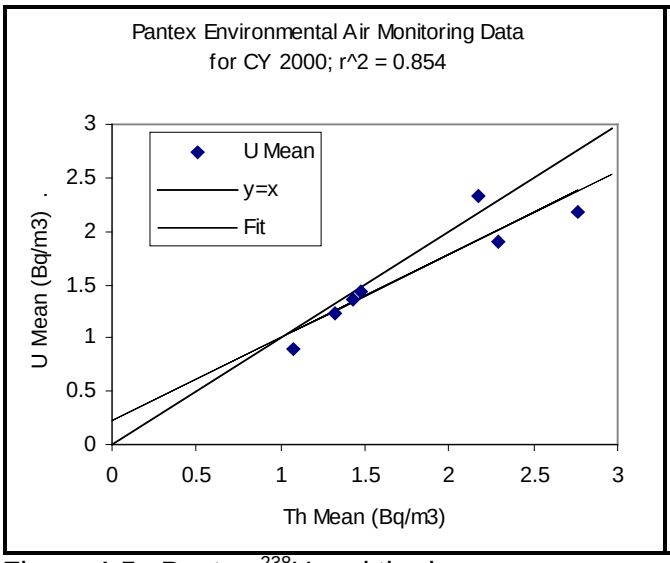


Figure 4-5. Pantex $^{238}$U and thorium mean environmental air monitoring data for 2000 at seven locations (BWXT Pantex 2001).

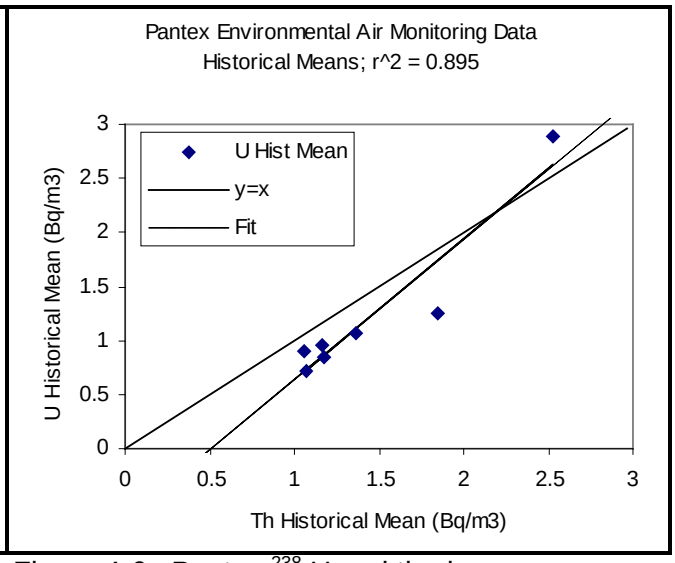


Figure 4-6. Pantex $^{238}$ U and thorium mean environmental air monitoring data (historic) at seven locations (BWXT Pantex 2001).

A further argument that all or virtually all of the uranium on 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 $\pm$0.037 (1 standard deviation), and for the historical data it is 0.981 $\pm$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]:

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

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 thus

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

#### 4.2.2.3 Upper 95% Confidence of the Mean Net Concentration

Environmental data for Pantex referenced in Attachment 4A, Table 4A-1, was used to calculate the values in Equation (1). The standard error of a value is related to the standard deviation by the reciprocal of the square root of the number of measurements:

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

The upper 95% confidence level of the mean 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

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

The upper 95% confidence level of the mean net concentration (assuming the same number of measurements was made of each) is

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

The maximum values for thorium and uranium, the two elements for which net concentrations are needed, are listed in Table 4A-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 2000 and for historical means. For the latter, it was necessary to estimate the standard error of the mean 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 Sv/Bq. These coefficients are the committed equivalent dose[2], $H_T(\tau)$, in organ or tissue $T$ per unit intake $h_T(\tau)$, where $\tau$ is the integration time in years following the intake. The integration time $\tau$ 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), transportability class (e.g., S, M, F), as well as the selection of biokinetic models. The most favorable to claimant assumptions 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

$$I(D) = \frac{D}{dose\,coefficient} = \frac{H_T(\tau)}{h_T(\tau)}. \quad (6)$$

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

[1]NIOSH does not use committed equivalent dose in its dose reconstructions for probability of causation 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.

$$C(D) = \frac{I(D)}{2{,}400m^3} = \frac{D}{(2{,}400m^3)(dose\,coefficient)} = \frac{H_T(\tau)}{(2{,}400m^3)(h_T(\tau))}. \quad (7)$$

Substituting 10 μSv for $H_T$ in the above equation gives

$$C(10\mu Sv) = \frac{10\mu Sv}{(2{,}400m^3)(h_T(\tau))}. \quad (8)$$

Selecting the greatest value of $h_T(\tau)$ for each element, for example, thorium, uranium, or plutonium, intakes results in specifying values of particle size, transportability class, 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 committed equivalent dose to an organ or tissue following a year's breathing of that concentration in air.

If the observed $\overline{C}_{net,95}$ 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 $\overline{C}_{net,95}$ 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.

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

Table 4-3, Dose conversion coefficients and air concentrations leading to 10 μSv for $^{3}$H, $^{232}$Th, $^{234}$U, and $^{239}$Pu, lists the air concentrations that would lead to 10 μSv committed equivalent dose, 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 95%ile concentrations are below these values, the resulting 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 95%ile concentrations are below 1 mrem for all but $^{232}$Th Type M. 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 1995).

| Nuclide | Details | Organ with highest $H_T(\tau)$ | Air concentration breathed for 2,000 hours leading to 10-μSv committed equivalent dose (μBq/m3) | Dose from breathing 95%ile 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 thorium Type M (the largest upper 95% confidence level of net mean air concentration = 2.21 μBq/m$^3$), indicating that a committed equivalent dose 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 = 14.4

µBq/m$^3$), indicating that a committed equivalent dose of 1.5 µSv (0.15 mrem) to bone surfaces would accumulate for each year of exposure. For thorium intakes, committed equivalent dose 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 committed equivalent dose 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 prior year. Figure 4-8 shows the annual contribution to equivalent dose to bone surfaces per unit intake for inhalation of a 1-µm AMAD Type M $^{232}$Th aerosol. The greatest value occurs in year 22 following intake, and the peak value is 2.41% of the average. Figure 4-9 shows the equivalent dose rate to bone surfaces for 10, 20, 30, 40, and 50 years of intakes of 1 Bq per year of the same aerosol. Figure 4-8 is derived from the results shown in Figure 4-7 by summing contributions to annual equivalent dose in a given year over the various years of intake. Figure 4-8 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 differing intervals (18, 15, 13, 9, and 0 years, respectively) after intake ends for the different intake durations.

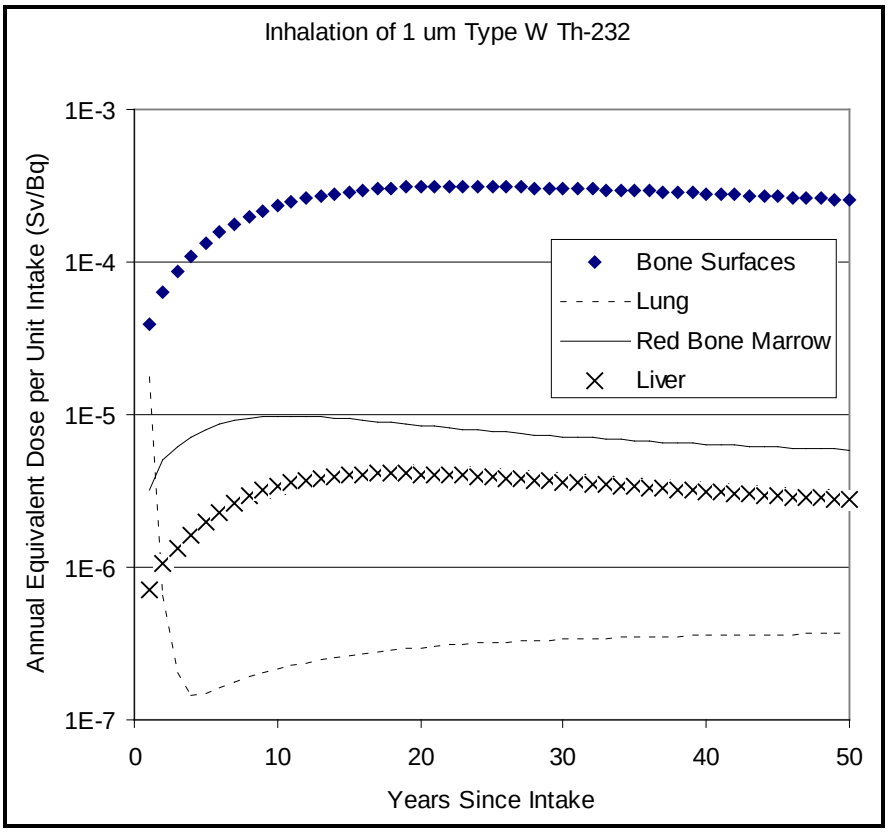


Figure 4-7. IMBA equivalent dose to four tissues or organs per unit intake (Sv/Bq) during each year for 1-µm AMAD Type W $^{232}$Th inhalation.

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 shown in

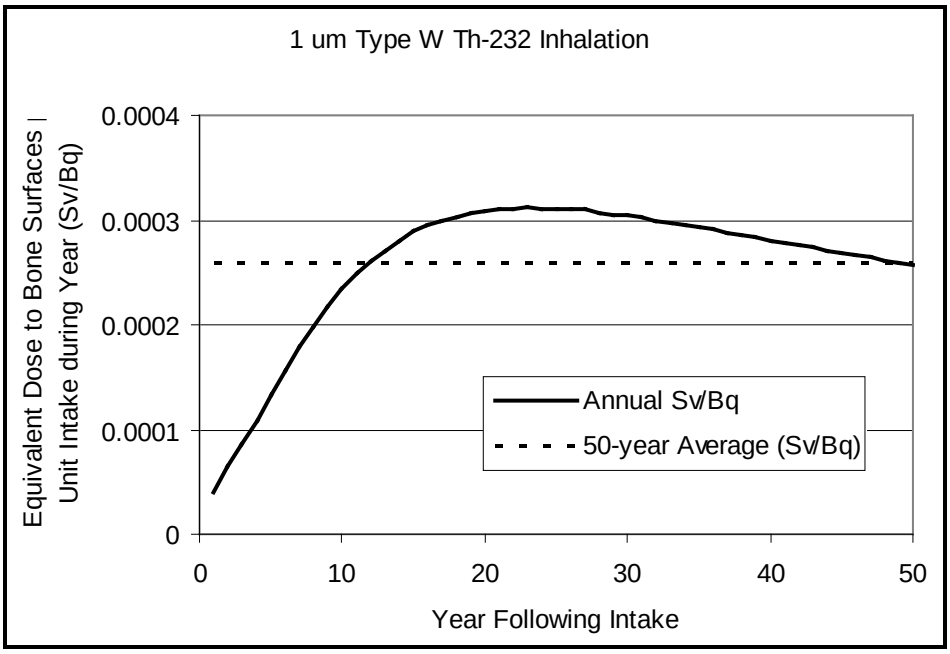


Figure 4-8. IMBA equivalent dose and average equivalent dose to bone surfaces per unit intake (Sv/Bq) during each year for 1 µm AMAD Type W $^{232}$Th inhalation.

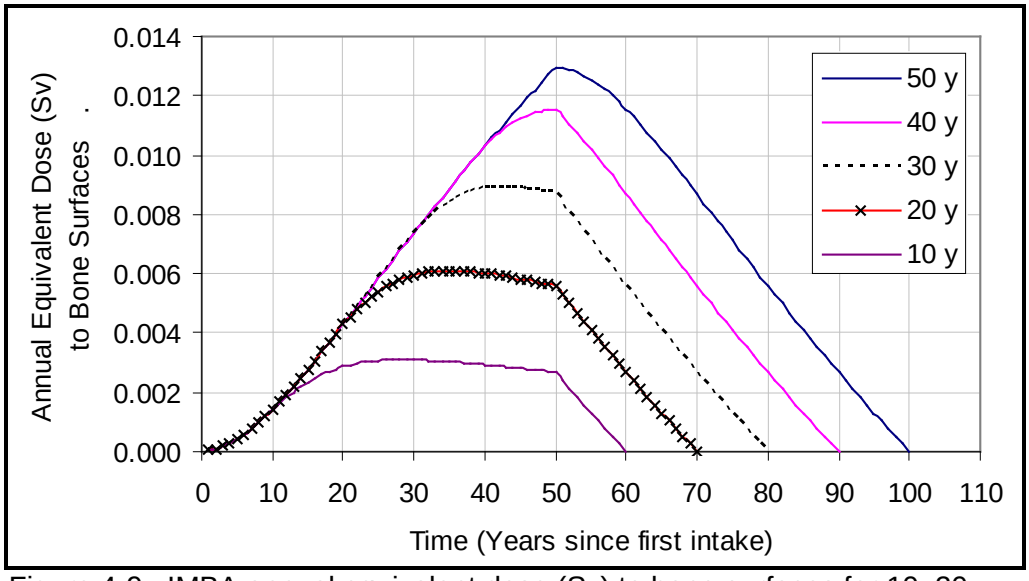


Figure 4-9. IMBA annual equivalent dose (Sv) to bone surfaces for 10, 20, 30, 40, and 50-year inhalation intakes of 1 Bq per year of 1 µm Type W $^{232}$Th.

Figure 4-8. 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. Thus, 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.

As a further measure of how this calculation tends to overestimate the dose, it is implausible that thorium released from Pantex operations could be Type M, because thorium was not machined or cut, only assembled or disassembled. Thus, 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 $2.5 \times 10^{-5}/4.5 \times 10^{-5} = 55\%$ 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 radionuclides combined never exceeds 10 μSv in any calendar year, even for 50 years continuous exposure.

### 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 air monitored 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 4-10 and Table 4-5) (BWXT Pantex 2001).

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

## 4.3 EXTERNAL DOSE

Before 1989, radiation workers were the only employees 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 are subjected to 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 reference section for citations by year) included ambient TLD radiation

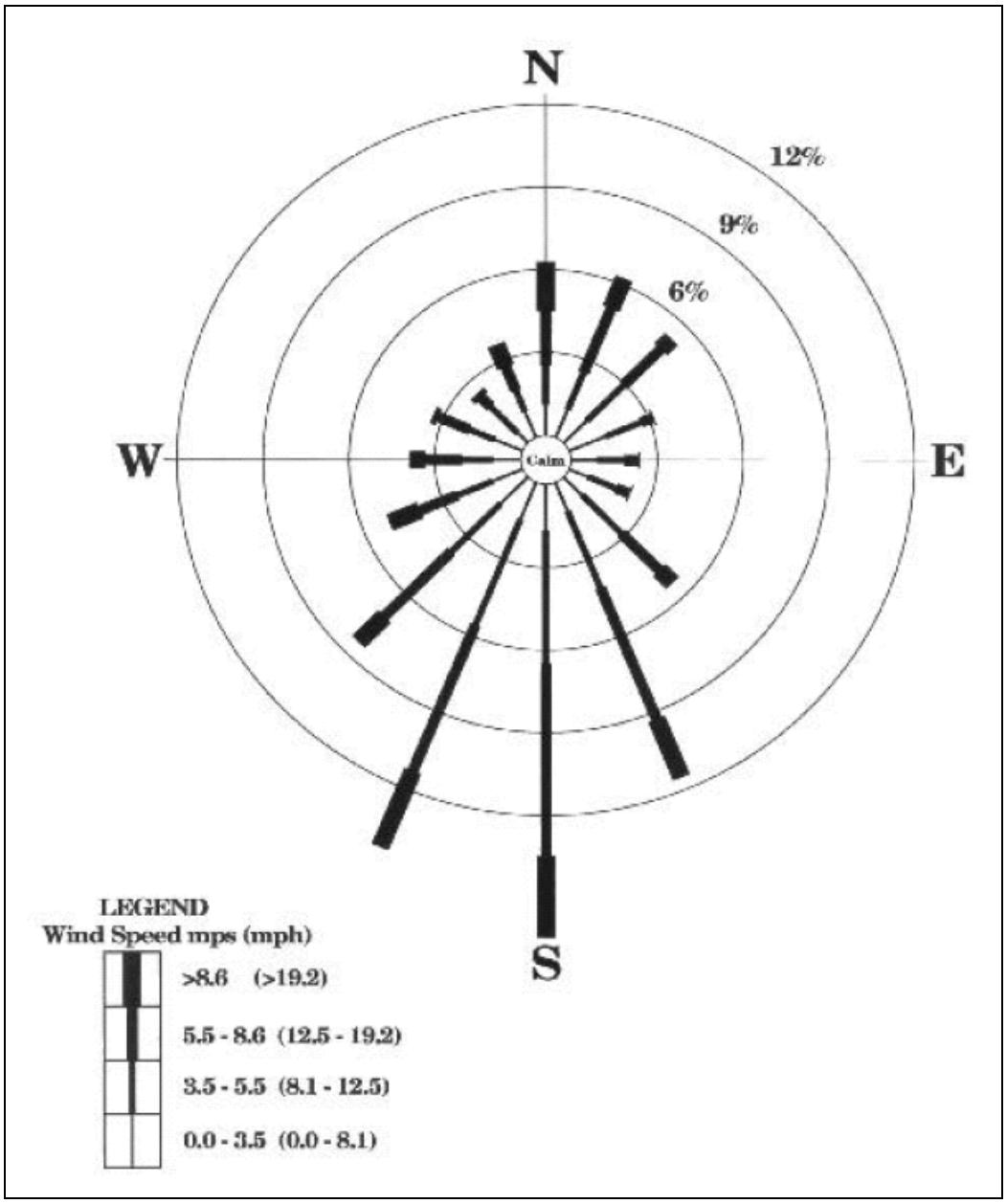


Figure 4-10. Wind rose for 2000 (BWXT Pantex 2001).

measurements. An ambient radiation level program was initiated and reported beginning in 1986. Figure 4-11 shows the locations of the monitors and TLD dosimeters in 2000 (Laseter 1987).

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 the plant site and off site.

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

Table 4-5. Climatological data for 2000 by month (BWXT Pantex 2001).

| Month | Temperature °C (°F) | | | Mean relative humidity (%) | Precipitation[a] millimeters (inches) | Wind speed meters per second (miles per hour) | |
|---|---|---|---|---|---|---|---|
| | 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.

The dose rate data used for the analysis was 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 located at the same sampling locations [32].

Figure 4-12 shows the average of the on-site and off site 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 shown in Figure 4-12 for 1986 may have been elevated solely due to the Chernobyl incident.

Linear regression, as depicted in Figure 4-12, was performed on the dose rates reported from 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 1950, 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, favorable to claimant wise, ambient missed dose on the Pantex Plant Site. The difference in the slopes of the trend lines were used to estimate onsite ambient environmental doses back to 1950. See Table 4-6.

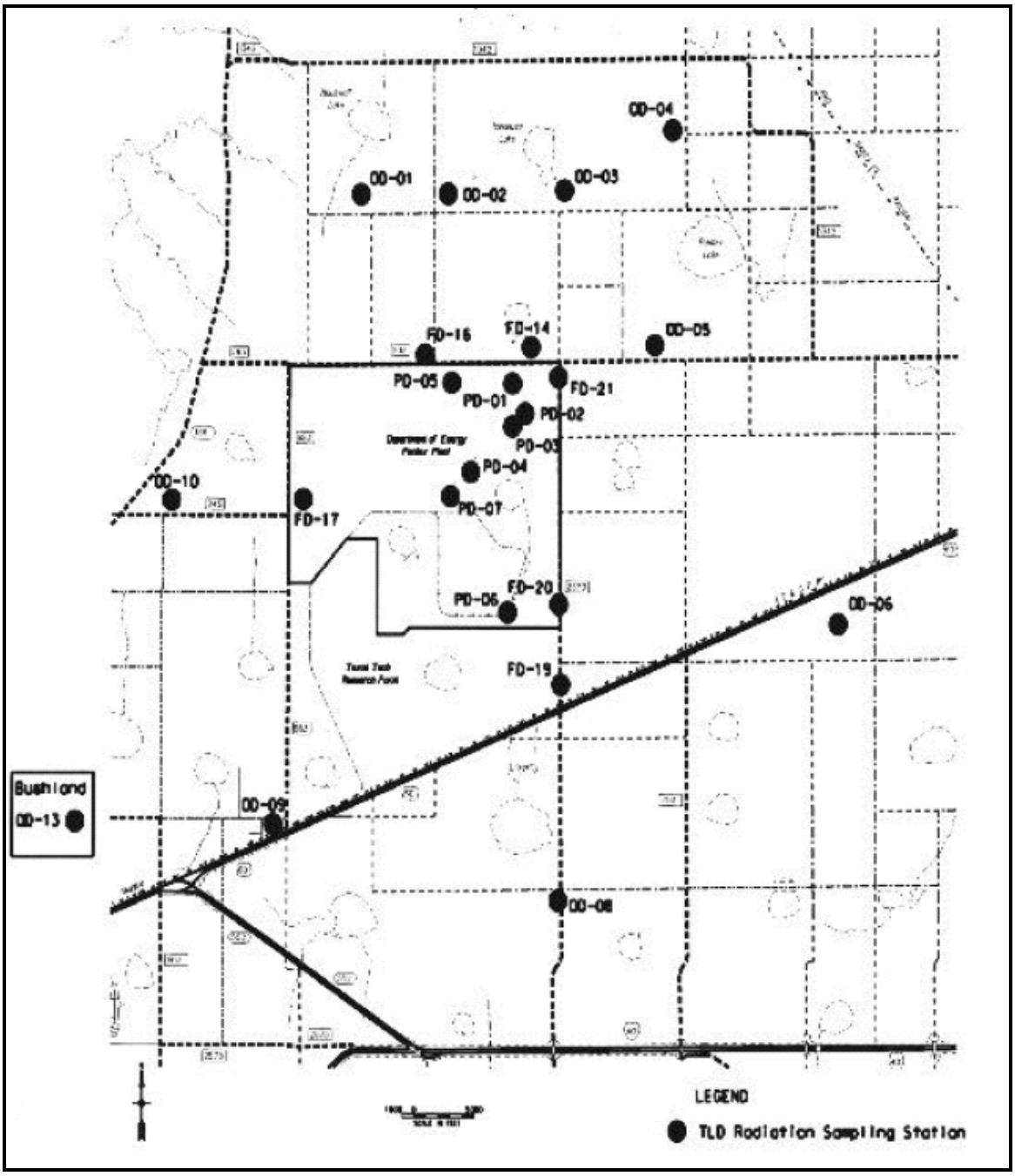


Figure 4-11. Locations of thermoluminescent dosimeters in 2000 (BWXT Pantex 2001).

Based on the data in Table 4-6 and to be favorable to claimants, it is suggested that unmonitored or missed onsite ambient occupational dose for the years from 1951 through 1974 be added to a persons dose record at the rate of 100 mrem/year, and the unmonitored or missed onsite ambient occupational dose for the years from 1975 through 2000 be added to a persons dose record at the rate of 50 mrem/year. This would result in a maximum unmonitored or missed ambient dose of about 3750 mrem for the 50-year period [33].

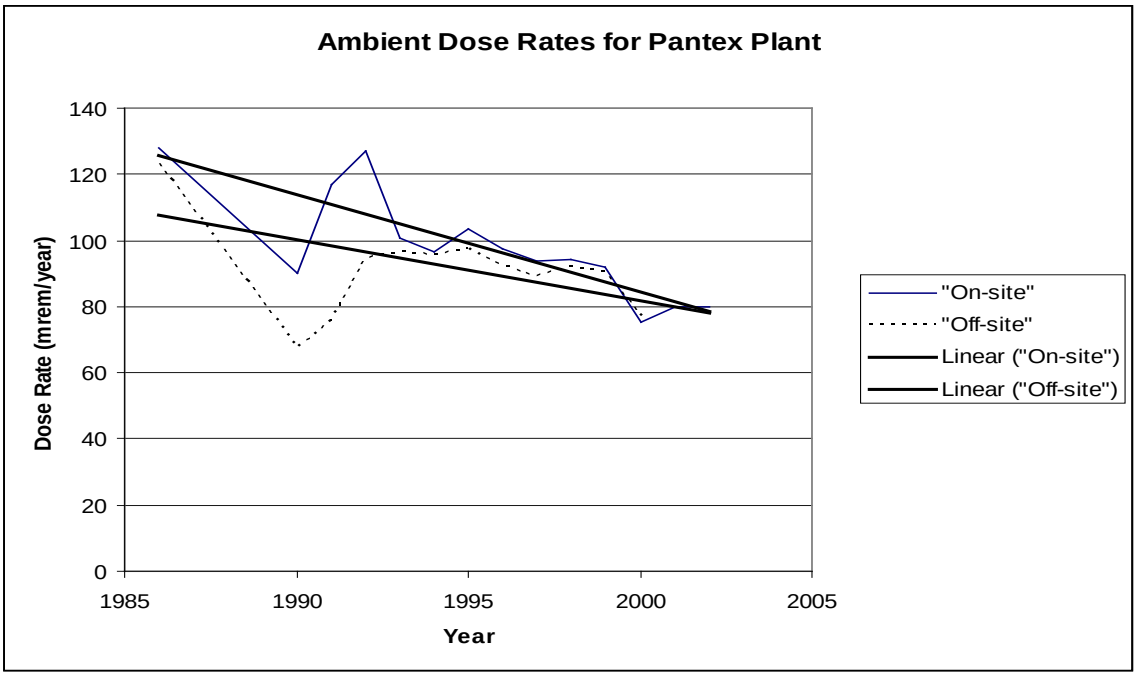


Figure 4-12. Ambient dose rates for Pantex Plant.

Table 4-6. Calculated difference between onsite and offsite annual doses for the Pantex plant [34].

| Year | Difference between on-site and offsite radiation dose rates (mrem/year) |
|---|---|
| 1950 | 110 |
| 1955 | 98 |
| 1960 | 87 |
| 1965 | 76 |
| 1970 | 65 |
| 1975 | 53 |
| 1980 | 42 |
| 1985 | 31 |
| 1990 | 20 |
| 1995 | 8 |
| 2000 | 2 |

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 [35]. It is concluded that 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, to estimate annual intake, sum 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 2006b).

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 the preceding text, bracketed callouts have been inserted to indicate information, conclusions, and recommendations to assist in the process of worker dose reconstruction. These callouts are listed in this section with information that identifies the source and justification for each item. Conventional references are provided in the next section that link data, quotations, and other information to documents available for review on the Oak Ridge Associated Universities (ORAU) Team servers.

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. Pacific Northwest National Laboratory. 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 1.24E-8 TBq/g for $^{238}U$, 8.00E-8 TBq/g for $^{235}U$, and 2.31E-4TBq/g for $^{234}U$ results in 1.24E-6 TBq for $^{238}U$, 1.60E-8 TBq for $^{235}U$, and 2.31E-7TBq for $^{234}U$ and a total activity of 1.49E-6 TBq.

[3] Shipler, Dillard B. Pacific Northwest National Laboratory. Principal Health Physicist. August 2006.
Pantex internal dosimetry manuals do not even address $^{233}U$.

[4] Shipler, Dillard B. Pacific Northwest National Laboratory. Principal Health Physicist. August 2006.
Since few devices were disassembled prior to 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. Pacific Northwest National Laboratory. Principal Health Physicist. August 2006.
Uranium oxide 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. Pacific Northwest National Laboratory. Principal Health Physicist. August 2006.
Tritium reservoirs came as sealed containers and the seal was not broken during insertion.

[7] Shipler, Dillard B. Pacific Northwest National Laboratory. Principal Health Physicist. August 2006.
From review of documents and interviews of personnel (see Martin 2004, ORAUT 2006a), metal came as formed items, so no activities were performed that would generate oxides.

[8] Shipler, Dillard B. Pacific Northwest National Laboratory. Principal Health Physicist. August 2006.
From review of documentation and interview of personnel (see Martin 2004, ORAUT 2006a), no materials containing metals were burned during this period, so no oxides were formed or released.

[9] Shipler, Dillard B. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. Principal Health Physicist. August 2006.
Uranium oxide released when old devices were disassembled was known and dispersion was controlled in the cells.

[17] Shipler, Dillard B. Pacific Northwest National Laboratory. Principal Health Physicist. September 2006.
Plutonium pits removed during disassembly are still sealed and, therefore, no releases of plutonium occur.

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

[19] Shipler, Dillard B. Pacific Northwest National Laboratory. 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, thus receiving 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. Pacific Northwest National Laboratory. Principal Health Physicist. September 2006.
This equation is a mathematical expression of the statement preceding the equation and referenced above.

[22] Shipler, Dillard B. Pacific Northwest National Laboratory. Principal Health Physicist. September 2006.
The Pantex Plant monitored concentrations of radionuclides in air at the site boundary and at select 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. Principal Health Physicist. September 2006.
The paragraph seems self-evident. 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. Pacific Northwest National Laboratory. Principal Health Physicist. September 2006.
The history of radiation monitoring of external dose to workers is covered in ORAUT-TKBS-0013-6, Rev. 00 (ORAUT 2006c), particularly in Table 6-15 and Figure 6-1.

[28] Shipler, Dillard B. Pacific Northwest National Laboratory. Principal Health Physicist. September 2006.
The history of radiation monitoring of external dose to workers is covered in ORAUT-TKBS-0013-6, Rev. 00 (ORAUT 2006c), particularly in Table 6-15 and Figure 6-1.

[29] Shipler, Dillard B. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. Principal Health Physicist. September 2006.
All Pantex external dosimetry program documents, including Pantex (2002), 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. Pacific Northwest National Laboratory. Principal Health Physicist. September 2006.
All Pantex external dosimetry program documents, including Pantex (2002), 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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. Pacific Northwest National Laboratory. 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, expressed in units of rem (sievert).

**Atomic Energy Commission**
Original agency established for nuclear weapons and power production; a predecessor to the U.S. Department of Energy.

**becquerel**
SI unit of radioactivity equal to one transformation per second.

**beta (β) dose**
Designation (i.e., beta) on some Pantex external dose records referring to the dose from less-energetic beta, X-ray, and/or gamma radiation.

**beta radiation**
Radiation consisting of charged particles of very small mass (i.e., the electron) emitted spontaneously from the nuclei of certain radioactive elements. Physically, the beta particle is identical to an electron moving at high velocity.

**committed dose equivalent ($H_{T,50}$)**
Dose equivalent to organs or tissues received from an intake of radioactive material by an individual during the 50-year period following the intake.

**committed effective dose equivalent ($H_{E,50}$)**
Sum of the products of the weighting factors applicable to each organ or tissue that are irradiated and the committed dose equivalent.

**curie**
A special unit of activity. One curie (1 Ci) exactly equals $3.7 \times 10^{10}$ nuclear transitions per second.

**deep absorbed dose ($D_d$)**
Absorbed dose at the depth of 1.0 cm in a material of specified geometry and composition.

**deep dose equivalent ($H_d$)**
Dose equivalent at the respective depth of 1.0 cm in tissue.

**depleted uranium (DU)**
Used as components in nuclear weapons; isotopic activity fractions (NOTE: this is not the mass fraction) listed by Pantex as:

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

**detection limit (lower)**
Minimum quantifiable exposure or neutron flux that can be detected.

**depleted uranium analysis**
Indicates that the chemical properties of uranium were used for analysis, not necessarily that the material in question was depleted uranium

**dose equivalent (H)**
Product of the absorbed dose (D), the quality factor (Q), and any other modifying factors. The special unit is the rem. When D is expressed in Gy, H is in sieverts (Sv). (1Sv = 100 rem).

**dose of record**
Dose files provided by DOE to NIOSH as part of the individual worker files.

**dosimeter**
Device used to measure the quantity of radiation received. A holder with radiation-absorbing elements (filters) and an insert with radiation-sensitive elements packaged to provide a record of absorbed dose or dose equivalent received by an individual. (See *film dosimeter*, *neutron film dosimeter*, *thermoluminescent dosimeter*).

**dosimetry**
Science of assessing absorbed dose, dose equivalent, effective dose equivalent, etc., from external and/or internal sources of radiation.

**dosimetry system**
System used to assess dose equivalent from external radiation to the whole body, skin, and/or extremities. This includes the fabrication, assignment, and processing of dosimeters as well as interpretation and documentation of the results.

**effective dose equivalent**
Sum of the products of dose equivalent to the organ or tissue ($H_T$) and the weighting factor ($W_T$) applicable to each organ or tissue.

**exchange period (frequency)**
Period (weekly, biweekly, monthly, quarterly, etc.) for routine exchange of dosimeters.

**exposure**
In the technical sense, a measure expressed in roentgens (R) of the ionization produced by photons (gamma and X-rays) in air.

**extremity**
That portion of the arm extending from and including the elbow through the fingertips, and that portion of the leg extending from and including the knee and patella through the tips of the toes.

**film**
In general, a "film packet" that contains one or more pieces of film in a light-tight wrapping. The film when developed has an image caused by radiation that can be measured using an optical densitometer. (See *nuclear track emulsion*).

**film dosimeter**
Small packet of film within a holder that attaches to a wearer.

**flux (n/cm$^2$-sec)**

Measure of the intensity of neutron radiation in neutrons/cm2-sec. It is the number of neutrons passing through a sphere with a cross-sectional area of 1 cm2 of a given target in 1 second. Expressed as nv, where n = the number of neutrons per cubic centimeter and v = their velocity in cm/sec. In this sense, flux is the same as "fluence rate" as defined by the International Commission on Radiation Units and Measurements.

**gamma ray (γ)**

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**

SI unit of absorbed dose. Unit symbol, Gy. 1 Gy = 100 rad.

**ionizing radiation**

Electromagnetic or particulate radiation capable of producing charged particles through interactions with matter.

**neutron**

Basic particle that is electrically neutral weighing nearly the same as the hydrogen atom.

**neutron, fast**

Neutron with energy equal or greater than 10 keV.

**neutron, intermediate**

Neutron with energy between 0.5 eV and 10 keV.

**neutron, thermal**

Strictly, neutrons in thermal equilibrium with surroundings; in general, neutrons with energy less than about 0.5 eV.

**neutron film dosimeter**

Film dosimeter that contains an Neutron Track Emulsion, type A, film packet.

**nuclear track emulsion, type A (NTA)**

Film that is sensitive to fast neutrons. The developed image has tracks caused by neutrons that can be seen by using an appropriate imaging capability such as oil immersion and a 1000X power microscope or a projection capability.

**personal dose equivalent $H_p(d)$**

Dose equivalent in soft tissue below a specified point on the body at an appropriate depth d. The depths selected for personnel dosimetry are 0.07 mm and 10 mm for the skin and body, respectively. These are noted as $H_p(0.07)$ and $H_p(10)$, respectively.

**photon**

Unit or "particle" of electromagnetic radiation consisting of X- and/or gamma rays.

**photon - x-ray**
Electromagnetic radiation of energies between 10 keV and 100 keV whose source can be an X-ray machine or radioisotope.

**quality factor, Q**
Modifying factor used to derive dose equivalent from absorbed dose.

**radiation**
Alpha, beta, neutron, and photon radiation.

**radioactivity**
Spontaneous emission of radiation, generally alpha or beta particles, gamma rays, and neutrons from unstable nuclei.

**rem**
Unit of dose equivalent, which is equal to the product of the number of rad absorbed and the "quality factor."

**roentgen (R)**
Unit of exposure to gamma (or X-ray) radiation. It is defined precisely as the quantity of gamma (or X-) rays that will produce a total charge of $2.58 \times 10^{-4}$ coulomb in 1 kg of dry air. An exposure of 1 R is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher (>100 keV) energy photons.

**shallow absorbed dose ($D_s$)**
Absorbed dose at a depth of 0.007 cm in a material of specified geometry and composition.

**shallow dose equivalent ($H_s$)**
Dose equivalent at a depth of 0.007 cm in tissue.

**shielding**
Material or obstruction that absorbs (or attenuates) radiation and thus tends to protect personnel or materials from radiation.

**skin dose**
Absorbed dose at a tissue depth of 7 $mg/cm^2$.

**thermoluminescent**
Property of a material that causes it to emit light as a result of being excited by heat.

**thermoluminescent dosimeter (TLD)**
Holder containing solid chips of material that when heated will release the stored energy as light. The measurement of this light provides a measurement of absorbed dose.

**whole-body dose**
Absorbed dose at a tissue depth of 1.0 cm (1,000 $mg/cm^2$); also used to refer to the recorded dose.

**X-ray**
Ionizing electromagnetic radiation that originates external to the nucleus of an atom.

**ATTACHMENT 4A**
**RADIONUCLIDE INTAKE AND OCCUPATIONAL EXPOSURE**
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### 4A.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).

### 4A.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 1951 could be as much as 100 mrem/year [38]. The trend lines converge in about 2000 [39]. So it is recommended that 100 mrem/year be added to unmonitored workers for the years 1951 through 1975 and 50 mrem/year be added to unmonitored workers for the years 1975 through 2000. This would result in a maximum unmonitored or missed ambient dose of about 3750 mrem for the 50 year period.

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 (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].

The following tables provide supporting data for the analyses described in the TBD:

**ATTACHMENT 4A**
**RADIONUCLIDE INTAKE AND OCCUPATIONAL EXPOSURE**
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Table 4A-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<br>Table 5.5, page 5-14, location FL-AR-05 |
| Plutonium 239/240 | Table 5.7, page 5-18, location FL-AR-08 |

Table 4A-2. Upwind "control" (location OA-AR-13) average annual air concentrations.

| Isotopes/elements | Number of samples | Concentration ($\mu$Bq m$^{-3}$) (mean ±standard deviation) | Previous 3 y mean |
|---|---|---|---|
| Tritium oxide | - | - | - |
| Uranium | 12 | 2.32 ± 1.08 | 1.26 |
| Plutonium | - | - | - |
| Thorium | 12 | 2.17 ± 1.37 | 1.85 |