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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
09/15/2005	00	New Technical Basis Document for Pinellas – Site External Dose. First approved issue. Training required: As determined by the Task Manager. Initiated by Mark D. Notich.
08/03/2006	00 PC-1	Approved page change revision to incorporate changes according to the public outreach meetings in 09/2004 and 11/2005 and claimant communications. Updated required language on pages 6 and 7 in Section 6.1. Added Purpose and Scope Sections on page 7. Changes occurred on page 10, in Section 6.1.4, page 27 in Section 6.4.2, and on pages 29 - 32 in the Reference Section. As a result of internal formal review, changes were made to Tables 6-4, 6-5, 6-11, and 6-12 on pages 16, 17, 25, and 27, respectively in Sections 6.2.3 and 6.4.1.1 and 6.4.2. Wording was added or changed on pages 10, 15, 19, 23, 24, and 27, in Sections 6.1.1, 6.2.3, 6.2.4, 6.3, and 6.4.2.1. No sections were deleted. This revision results in a reduction in assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Paul J. Demopoulos. Approval: Signature on File 07/25/2006 Paul J. Demopoulos, TBD Team Leader Signature on File 07/25/2006 John M. Byrne, Task 3 Manager Signature on File 07/24/2006 Edward F. Maher, Task 5 Manager Signature on File 07/27/2006 Kate Kimpan, Projector Director Signature on File 08/03/2006 James W. Neton, Associate Director for Science
11/08/2006	00 PC-2	Approved page change revision to incorporate changes according to Task 5 comment and Task 7 amendment to page 27 and 28 in Section 6.4.1.1. Corrects table numbering on page 28 and 29. Adds two references to page 34. Corrects references on pages 20, 24, and 32. No sections were deleted. Incorporates internal formal review comments. Incorporates NIOSH formal review comments. Minor editorial changes were made on pages 24 and 29. Deletes Task 7 amendment to page 27 and 28 in Section 6.4.1.1. Corrects Table 6-5 rows 2 and 3 on page 18. This revision results in an

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
11/08/2006 (continued)	00 PC-2 (continued	increase in assigned dose and a PER is required. Training required: As determined by the Task Manager. Initiated by Paul J. Demopoulos. Approval: Signature on File 10/19/2006 Paul J. Demopoulos, Document Owner Signature on File 10/20/2006 John M. Byrne, Task 3 Manager Signature on File 10/24/2006 Edward F. Maher, Task 5 Manager Signature on File 10/23/2006 Kate Kimpan, Projector Director Brant A. Ulsh Signature on File for 11/08/2006 James W. Neton, Associate Director for Science
04/28/2011	01	This technical basis document was predominantly revised to address SC&A's issues with the document, as identified in SCA-TR-TASK1-0015. Adjustments to certain photon dosimeter results now need to be made per Section 6.3.1.1. Photon LOD values specific to the Mound dosimeters are now provided in Table 6-10. Significant changes were also made on how neutron doses are assessed, and the new approaches are described in Section 6.3.2. The applicability dates for the various types of neutron dosimeters used at the site were changed, and are now in Table 6-11. In addition, a number of editorial changes were made to this document. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Brian P. Gleckler.
12/11/2017	02	Revision initiated to address update the missed dose tables in Section 6.4 to provide consistent LOD data for dose reconstruction. In addition, the following changes were also made: editorial changes, information updated, redundant information eliminated, and several sections were reorganized. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Brian P. Gleckler.

TRADEMARK INFORMATION

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
AWE	atomic weapons employer
Bq	becquerel
CFR	Code of Federal Regulations
Ci	curie
cm	centimeter
D	deuterium (^{2}H)
DCAS	Division of Compensation Analysis and Support
DCF	dose conversion factor
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
DOELAP	U.S. Department of Energy Laboratory Accreditation Program
DU	depleted uranium
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
ft	foot
g	gram
GE	General Electric Company
GEND	GE Neutron Devices
GENDD	GE Neutron Devices Department
GEPP	GE Pinellas Plant
GEXF	GE X-Ray Division in Florida
GEXM	GE X-Ray Division in Milwaukee, Wisconsin
hr	hour
HSR	Health and Safety Record (system)
ICRP	International Commission on Radiological Protection
in.	inch
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt, 1,000 electron-volts
Landauer	R. S. Landauer Jr. & Co.
LOD	limit of detection
MeV	megaelectron-volt, 1 million electron-volts
mR	milliroentgen
mrem	millirem
n	neutron
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH-OCAS Claims Tracking System
NDD	Neutron Devices Department
NTA	nuclear track emulsion, type A

ORAU	Oak Ridge Associated Universities
ORAUT	Oak Ridge Associated Universities Team
OW	open window
PER	Program Evaluation Report
PAO	Pinellas Area Office
POC	probability of causation
RBE	relative biological effectiveness
RTG	radioisotopically-powered thermoelectric generator
SEC	Special Exposure Cohort
SNL	Sandia National Laboratories
SRDB	Site Research Database
SRDB Ref ID	Site Research Database Reference Identification (number)
T	tritium (^{3}H)
TBD	technical basis document
TLD	thermoluminescent dosimeter
U.S.C.	United States Code
yr	year
μCi	microcurie
α	alpha particle
§	section or sections

6.1 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 Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities or categories of DOE or AWE facilities. They will be revised in the event additional relevant information is obtained about the affected DOE or AWE facility(ies). These documents may be used to assist NIOSH staff in the evaluation of Special Exposure Cohort (SEC) petitions and the completion of the individual work required for each dose reconstruction.

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

Accordingly, a Part B claim for benefits must be based on an energy employee’s eligible employment and occupational radiation exposure at a DOE or AWE facility during the facility’s designated time period and location (i.e., covered employee). After DOL determines that a claim meets the eligibility requirements under EEOICPA, DOL transmits the claim to NIOSH for a dose reconstruction. EEOICPA provides, among other things, guidance on eligible employment and the types of radiation exposure to be included in an individual dose reconstruction. Under EEOICPA, eligible employment at a DOE facility includes individuals who are or were employed by DOE and its predecessor agencies, as well as their contractors and subcontractors at the facility. Unlike the abovementioned statutory provisions on DOE facility definitions that contain specific descriptions or exclusions on facility designation, the statutory provision governing types of exposure to be included in dose reconstructions for DOE covered employees only requires that such exposures be incurred in the performance of duty. As such, NIOSH broadly construes radiation exposures incurred in the performance of duty to include all radiation exposures received as a condition of employment at covered DOE facilities in its dose reconstructions for covered employees. For covered employees at DOE facilities, individual dose reconstructions may also include radiation exposures related to the Naval Nuclear Propulsion Program at DOE facilities, if applicable. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

NIOSH does not consider the following types of exposure as those incurred in the performance of duty as a condition of employment at a DOE facility. Therefore these exposures are not included in dose reconstructions for covered employees (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

6.1.1 Purpose

The purpose of this technical basis document (TBD) is to document the external dosimetry program and practices at the Pinellas Plant, and to provide the technical basis to be used to evaluate the external occupational radiation dose for EEOICPA claims.

6.1.2 Scope

This TBD provides supporting documentation to assist in the evaluation of occupational external doses in accordance with the guidelines described in External Dose Reconstruction Implementation Guideline (NIOSH 2007). NIOSH considers the available data and methods for performing external dose reconstruction to be adequate for estimating with sufficient accuracy the external doses at the Pinellas Plant throughout its entire history.

This TBD describes the external dosimetry program at the Pinellas Plant. It discusses dose reconstruction, practices and policies at the Pinellas Plant, and dosimeter types and technologies for measuring dose from the different types of radiation in the work environment. It also discusses the specific details of the evaluation of doses that were measured from exposures to electron (beta particles), photon (X-rays and gamma rays), and neutron radiation; sources of bias; workplace radiation field characteristics; responses of different dosimeters in the workplace radiation fields; and adjustments to the recorded dose measured by these dosimeters during specific years.

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 6.7.

6.1.3 Overview

This TBD is Part 6 of the Pinellas Plant Site Profile. A site profile provides a summary of information about a site that is relevant to the dose reconstruction process.

The Pinellas Plant has been known by several names throughout its history. Those names include: 908 Plant, Pinellas Peninsula Plant, General Electric (GE) X-ray Division-Florida (GEXF), GE Neutron Devices Department (GENDD), GE Neutron Devices (GEND), GE Pinellas Plant (GEPP), and the Pinellas Plant. This document uses the latter for convenience.

The General Electric Company built and operated the Pinellas Plant for DOE from its initial startup in January 1957 until June 1992. In June 1992, Martin Marietta Specialty Components (MMSC) took over as the managing and operating contractor for the Pinellas Plant. In 1994, Lockheed merged with Martin Marietta and the managing and operating contractor for the Pinellas Plant was renamed Lockheed Martin Specialty Components (LMSC). The Pinellas Plant completed its war reserve fabrication of neutron generators at the end of September 1994, and began the transition from a defense mission to an environmental management mission. That transition included a number of decontamination and decommissioning activities that allowed the Plant to be turned over for commercial uses. LMSC continued as the managing and operating contractor until decontamination and decommissioning activities ended in 1997 (ORAUT 2011b).

The Plant was built to manufacture neutron generators, a principal component in nuclear weapons. The neutron generators consisted of a miniaturized linear ion accelerator with pulsed electric power supplies. The ion accelerator, or neutron tube, required ultraclean, high-vacuum technology; hermetic seals between glass, ceramic, glass-ceramic, and metal materials; and high-voltage generation and measurement technology. The Plant manufactured only neutron generators for its first 10 years of operation. It later manufactured other products including neutron detectors, radioisotopically-powered thermoelectric generators (RTGs), high-vacuum switch tubes, specialty capacitors, and specialty batteries (Weaver 1990). As part of its program to promote commercial uses of the site, DOE sold most of the Plant to the Pinellas County Industry Council in March 1995 and leased back a portion through September 1997 to complete safe shutdown and transition activities (MMSC 1996).

6.2 DOSE RECONSTRUCTION PARAMETERS

6.2.1 Radiation Sources

The manufacture of Pinellas Plant products required the use of radioactive materials and radiation generating devices. A variety of radioactive materials and radiation generating devices were used at the Pinellas Plant. The following sub-sections identify the major sources of radioactivity and/or radiation at the plant.

6.2.1.1 Radioactive Materials

The predominant radioactive materials used at the Plant included tritium, ^{85}Kr, depleted uranium (DU), and plutonium. A wide variety of other radionuclides were used at the Pinellas Plant; however, the uses of these radionuclides were mostly limited to sealed and plated check sources, static meter sources, explosive meter sources, heat sources, calibration sources, thickness gauges, gas chromatograph sources, dew point measurement sources, and static eliminator sources (Author unknown undated b).

The predominant source of electron radiation at the Pinellas Plant was tritium, but this radionuclide emits only a low-energy beta particle with an average energy of 5.7 keV. Because electrons below 15 keV do not have sufficient energy to penetrate the epidermal layer of the skin (NIOSH 2007), tritium is not considered to be an external radiation hazard.

Krypton-85, a beta and gamma emitter, was used in two leak detection systems (Radiflo and TRACER-flo systems) as part of the Pinellas Quality Control Program. The leak detection systems were housed in separate rooms and surrounded by ventilation shrouds. Each shroud was connected to ductwork that exhausted to the east main exhaust stack. Because it is a noble gas, ^{85}Kr can deliver a whole-body dose with the possibility of a significant skin dose from electron radiation. Because of engineering controls such as shielding and ventilation, significant external exposures to ^{85}Kr gas at the Pinellas Plant were unlikely, but did occur during some accidents (MMSC 1993, Author unknown, undated d, ORAU 2007). The ^{85}Kr was first introduced into one of the leak detection systems on September 24, 1963 (GE 1957–1967, p. 253). By the end of 1996, all ^{85}Kr had been removed from the site (LMSC 1997, p. 12).

Beginning in the late-1970’s, portable radiation dose rate instruments were calibrated in Building 800 using a Model 81-12 Beam Calibrator manufactured by J. L. Shepard and Associates (GE 1977, Author unknown undated e). The Model 81-12 Beam Calibrator contained a 120-Ci ^{137}Cs source, which was in the form of a sealed source (GE 1977, Author unknown undated e). The ^{137}Cs was in a sealed source in a shielded cabinet in the concrete Building 800, so the probability of a worker receiving electron radiation exposures from ^{137}Cs was remote.

In either 1965 or 1968, the Pinellas Plant started using depleted uranium (DU), consisting mainly of ^{238}U, for its tritium storage beds (Phillips 1975, GE 1979). According to one document, the tritium storage beds using DU were 14 years old in 1979, indicating that they were first used in 1965 (GE 1979). Whereas, another document stated that the tritium storage beds using DU were 7 years old in 1975, indicating that they were first used in 1968 (Phillips 1975). In the new tritium storage beds, DU metal was used to store tritium as uranium tritide (UT_3). The DU metal in the tritium storage beds was sealed in stainless steel canisters (GE 1979; Ward 1973). The DU inside the tritium storage beds presents no significant external radiation hazard, due to the relatively small quantities used, low specific activity for DU, and its non-penetrating radiation.

The first plutonium that was received at the Pinellas Plant was a 7 g Pu source (predominately ^{239}Pu), which was received in September 1957. The source was an encapsulated plutonium-beryllium (Pu-Be) neutron source that was used for calibrating health physics monitoring equipment (Author unknown undated b, GE 1957–1973). In December 1978, this Pu-Be neutron source was shipped offsite for disposal (Author unknown undated c, Various authors 1961–1990). In August 1979, the 7 g Pu-Be neutron source was replaced with a Pu-Be source containing 32 g of Pu, which was also predominately ^{239}Pu (Author unknown undated c, Various authors 1961–1990). In October 1990, the 32 g Pu-Be neutron source was shipped offsite for disposal (Author unknown undated c, Various authors 1961–1990).

The thimble size triply encapsulated plutonium oxide ($^{238}PuO_2$) heat sources that were used for the radioisotopically-powered thermoelectric generators (RTGs) did not start arriving at the Pinellas Plant until November 1975 (Author unknown undated b, GE 1982). In November 1975, the site received seven plutonium heat sources (Author unknown undated b). The radionuclide composition of each sealed plutonium heat source was approximately 80% ^{238}Pu, 16% ^{239}Pu, 3% ^{240}Pu, and 1% of other radionuclides by mass (GE 1982). There were two different types of plutonium heat sources, 8.75 g sources and 10 g sources (GE 1982). Between 1975 and 1991, monthly inventories of the RTG heat sources ranged from 31.2 g to 4,397.5 g of Pu (Author unknown undated c). The Pinellas Plant also had several small plutonium sources that were as alpha check sources for checking instruments (Author unknown undated b), but those were insignificant from an external exposure perspective. All plutonium, with the exception of calorimeter sources and very small instrument calibration check sources, was removed from the Plant by February 1991 (Author unknown undated c, MMSC 1992).

In approximately 1988, the Pinellas Plant acquired a 10 Ci ^{241}Am source for unknown reasons. The source was an encapsulated americium-beryllium (Am-Be) neutron source, which was likely used as a calibration source. By October 1991, the Am-Be neutron source was inactive and in the process of being excessed (Author unknown undated b).

6.2.1.2 Radiation Generating Devices

Radioactive materials were not the only source of ionizing radiation at the Pinellas Plant. Many pieces of equipment produced and used at the Plant were capable of generating radiation. Unlike radioactive materials, radiation-generating devices emit radiation only when they are connected to a power supply and are activated. When not in use, these devices did not emit radiation.

The most common type of radiation-generating device at the Pinellas Plant was its primary product, the neutron generator. Neutron generators are miniaturized linear ion accelerators (DOE 1987). A pulsed electric power supply accelerates deuterons (i.e., deuterium nuclei) into either a tritium or deuterium target, depending on the type of neutron generator, to create a controlled source of neutrons (DOE 1987; NCRP 1983; Weaver 1994a). The neutrons are generated by either a $T(d,n)^4He$ or $D(d,n)^3He$ fusion reaction. Most units produced at the Pinellas Plant were the $T(d,n)^4He$ type that produced 14-MeV neutrons; however, a few were constructed to produce 2.5-MeV neutrons from the $D(d,n)^3He$ reaction (Weaver 1994a; NCRP 1983). The neutron generators also produce some X-rays by other interactions within the accelerator (NCRP 1983). This radiation was generated by testing either the neutron tubes (a component in the neutron generators) or the completed neutron generators.

An ion accelerator, a Model 200 HP Ion Implanter that was manufactured by Accelerator Inc., was also used at the Pinellas Plant (Malbrough 1983). It was a Cockroft-Walton-type linear ion accelerator and was first installed in 1975 in Area 161 of Building 100 for use by the Chemistry Laboratory (GE

1977a, p. 23; Malbrough 1983). The accelerator was originally used for ion implantation work and eventually for target assessment work prior to being relocated (GE 1977a; Malbrough 1983). In 1979, the accelerator was relocated to Building 800. After the accelerator's relocation, it was used for a larger variety of activities that included target assessment; material analysis; low-energy nuclear, solid-state, and atomic physics; and material science (Malbrough 1983). Personnel working with this accelerator were required to wear dosimeters that measured both photon and neutron doses (Weaver 1994a).

Table 2-1 of the Pinellas Plant – Site Description (ORAUT 2011b) provides a listing of the other radiation generating devices and their locations at the Pinellas Plant. These devices were not a radiation concern under normal operating conditions, because of engineering controls (e.g. shielding, access controls, system interlocks, etc...). However, there were recorded incidents at the Pinellas Plant involving these types of devices that resulted in external radiation exposures to a few of its workers. The listing of unusual events and incidents provided in Table 2-4 of the Pinellas Plant – Site Description (ORAUT 2011b) includes several radiation exposure incidents involving radiation generating devices. Based on a review of the available claim records, the Pinellas Plant appears to have assessed any potential doses from those incidents and included them in the workers' dosimetry records.

6.2.2 Workplace Radiation Fields

Potential sources for workplace radiation fields at Pinellas can be placed in two categories, radionuclide sources and machine-generated sources. The only open-area radiation fields to be routinely encountered by workers were from the testing of neutron tubes and neutron generators, the use of machine-generated X-rays, and areas where work was performed with the RTG heat sources. During some accidents involving either of the two leak detection systems (Radiflo and TRACER-flo systems), open-area radiation fields were temporarily present in the rooms that housed those systems due to ^{85}Kr gas leaks (MMSC 1993, Author unknown, undated d, ORAU 2007). During those incidents, non-routine external exposures to ^{85}Kr gas occurred, but those exposures were limited to personnel working in the rooms that housed the two leak detection systems due to the engineering controls for those systems.

6.2.2.1 Photon and Electron Radiation Fields

The NIOSH Interactive RadioEpidemiological Program (IREP) uses three photon energy groups (below 30 keV, 30 to 250 keV, and above 250 keV) (NIOSH 2007). For electron exposures, there are two electron energy groups (equal to or below 15 keV and above 15 keV); however, only the above 15 keV group is applicable to external dose.

The majority of the photon radiation exposures in the neutron generator production areas were from the testing of neutron tubes and neutron generators. In the RTG production areas (Building 400), the majority of the photon radiation exposures were from the plutonium oxide ($^{238}PuO_2$) heat sources.

The only potentially significant sources of electron radiation with sufficient energy to penetrate the skin are ^{85}Kr that is used with the two leak detection systems (Radiflo and TRACER-flo systems). Electron radiation exposures were also possible for X-ray diffraction and electron beam devices if containment of the beams was compromised. However, it was more probable that any exposures from these devices would have been from X-rays or bremsstrahlung production and not from a free electron beam. The exposures, if diffuse, would have been monitored by film badge or TLD.

Table 6-1 lists electron and photon energies and percentages for the various locations at the Pinellas Plant. For most locations, specific photon energy distribution information was not available. Therefore, with the exception of one location, 100% of the photons were assumed to be 30 to 250 keV photons, which is the most favorable photon energy interval. For exposures to ^{85}Kr gas in the area housing the two leak detection systems (Radiflo and TRACER-flo systems), a different photon energy distribution was used, based on the X-rays and gamma-rays being emitted from ^{85}Kr.

Table 6-1. Electron and photon radiation energies and percentages.

Location	Process type	Radiation type, energy group, and percentage
Buildings 100, 200, 300	Neutron generator production areas	Photon, 30–250 keV, 100%
Building 100, Area 109[a]	Leak detection systems area with ^{85}Kr (Radiflo and TRACER-flo systems area)	Electron, >15 keV, 100%; Photon 30–250 keV, 86%; Photon, >250 keV, 14%
Building 400	RTG production	Photon, 30–250 keV, 100%
Building 800[b]	Calibration and ion accelerator	Electron, >15 keV, 100%; Photon, 30–250 keV, 100%

a. The location of the two leak detection systems may have changed during their use at the Pinellas Plant. Because exposure to ^{85}Kr gas only occurred during accidents with these leak detection systems, the parameters for the leak detection systems area are only applicable to accidental exposures to ^{85}Kr gas.

b. Electron doses would not normally be assessed for this location. The assessment of electron dose for Building 800 would only be performed for workers accidentally exposed to the 120 Ci ^{137}Cs calibration source, if any such exposure ever occurred.

6.2.2.2 Neutron Radiation Fields

The NIOSH Interactive RadioEpidemiological Program (IREP) uses five neutron energy groups (below 10 keV, 10 to 100 keV, 0.1 to 2.0 MeV, 2.0 to 20.0 MeV, and above 20.0 MeV) (NIOSH 2007).

There were two distinct sources of neutrons at the Pinellas Plant. The first distinct sources of neutrons, were the neutrons produced by neutron generator sources, such as those generated by the testing of neutron tubes, testing of neutron generators, and operation of ion accelerator in Building 800. Those sources generated neutrons by either a $T(d,n)^4He$ or $D(d,n)^3He$ fusion reaction (also notated as D-T and D-D reactions), and only produce neutrons when electrically activated. Most of these sources produced 14-MeV neutrons from the $T(d,n)^4He$ reaction; however, a few produced 2.5-MeV neutrons from the $D(d,n)^3He$ reaction (Weaver 1994a; NCRP 1983). Note that these energy values are approximate and vary slightly from one reference to the next. This is mostly due to the fact that these sources actually produce a distribution of neutrons at various energies versus neutrons at a single discrete energy. This is illustrated in Figures 6-1 and 6-2, which are neutron spectrums for each of these reactions (Ing, Cross, and Tymons 1977).

The second distinct source of neutrons, were the sealed PuO_2 heat sources used for the RTGs. The RTG PuO_2 heat source neutron spectrum is illustrated in Figure 6-3 (Greene 1984b). The spectrum was probably from the Mound Laboratory and used to analyze the effectiveness of various Landauer Neutrak TLDs by the Pinellas Health Physics Department (Burkhart 1987a). It was determined that the Landauer dosimeters responded to only about 67% of the dose equivalent for the RTG PuO_2 heat source spectrum.

Table 6-2 lists the IREP neutron energy groups and fractions (as percentages) that are applicable to the various locations at the Pinellas Plant.

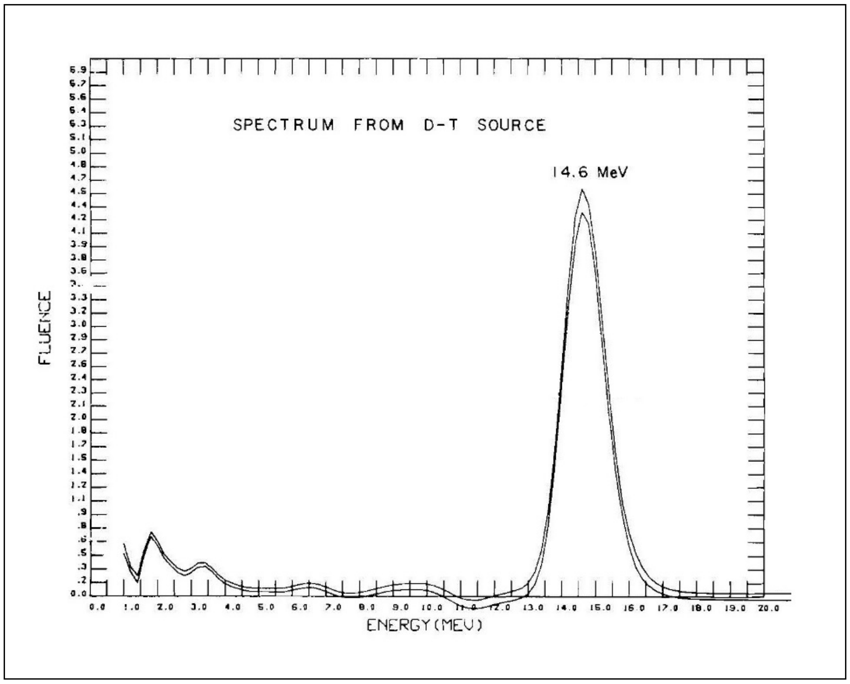

Figure 6-1. Neutron energy spectrum for a D-T reaction (Ing, Cross, and Tymons 1977).

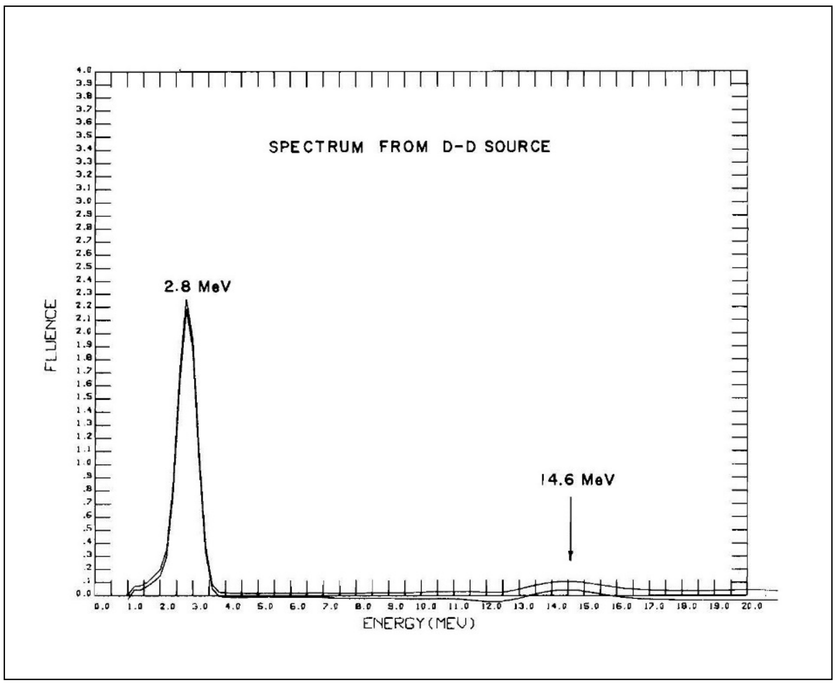

Figure 6-2. Neutron energy spectrum for a D-D reaction (Ing, Cross, and Tymons 1977).

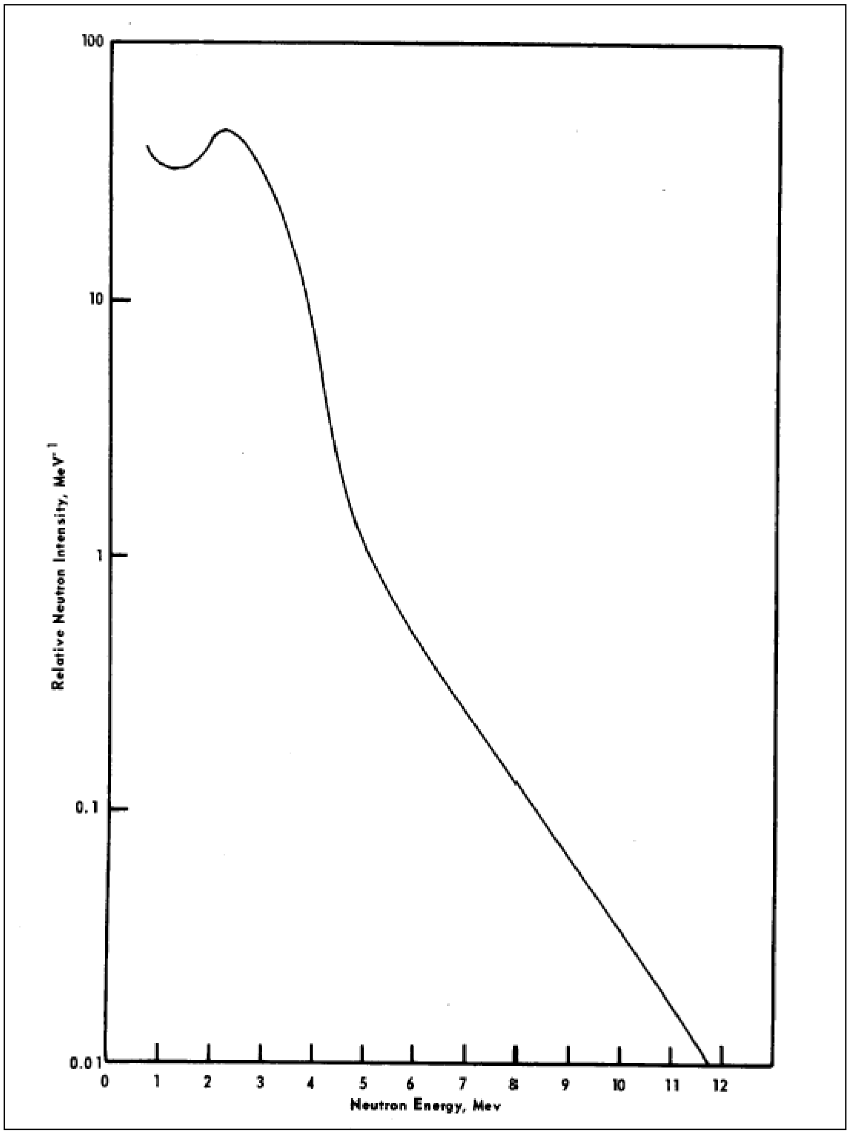

Figure 6-3. RTG plutonium source neutron energy spectrum – PuO_2 microspheres (Greene 1984b).

Table 6-2. Neutron radiation energies and percentages.

Location	Process type	Energy groups and percentage
Building 100	Neutron generator production areas	Neutron, 2–20 MeV, 100%
Building 400	RTG production	Neutron, 0.1–2 MeV, 50% Neutron, 2–20 MeV, 50%
Building 800[b]	Ion accelerator	Neutron, 2–20 MeV, 100%

6.2.3 Dosimetry Technology

For the period of 1957–June 1974, GEND-Health Physics conducted radiation dosimetry management and analysis through in-plant processing of X-ray and neutron-sensitive photographic films (Burkhart 1987b). For that period, no information regarding the specific design parameters for the film dosimeters used at the Pinellas Plant (e.g. film type, filters used, dosimeter holder design, etc…) could be found. During the period that the Pinellas Plant read its own dosimeters (1957–June 1974), the available film work sheets indicate that only the open window (OW) film was read from the film dosimeters and the OW result was reported as photon dose (GE 1957–1990, pages 67 and 99). Because the OW portions of the early film dosimeters typically over-responded to photons with energies <500 keV (ORAUT 2005c, 2006) and because a significant portion of the Pinellas Plant's photon doses were attributable to low energy photons, this practice likely resulted in the reported photon doses for the period of 1957–June 1974 being overestimates of the workers actual photon doses. Because specific information on dosimeter design and dosimeter calibration could not be confirmed for the period of 1957– June 1974, no adjustments to the reported photon doses are recommended, to account for the over-response that the dosimeters likely had to the photon radiation at the Plant. The practice of only reading the OW film and reporting the result as photon dose would also explain why non-penetrating doses such as electron doses were not reported during this era. In addition, any potential electron doses received by the workers would have been accounted for and reported as photon doses by this practice.

An unsigned note in a collection of highly varied examples of dosimetry records, which include a number of records from GEXM, indicates that personnel monitoring for neutrons might not have begun at the Pinellas Plant until 1960, and neutron doses for the period from 1957 through May 1960 might have been estimated from area monitors (GE 1957–1990). Even if the note is accurate about neutron monitoring at the Plant, it should not have an adverse effect on the neutron dose calculations for that period. Because the same whole-body dosimeters were used for personnel and area monitoring, the neutron dose calculations would be the same regardless of whether the worker's neutron doses were based on a personnel dosimeter or a dosimeter used to monitor an area.

Beginning in July 1974, the Plant began using dosimetry provided exclusively by Landauer. The original Landauer dosimetry was based on film badge technology (Ward 1974). Landauer processed the dosimetry and provided exposure reports to GEND for review after badge processing. Figure 6-4 is an example of a Landauer dosimetry report from 1978, with all personal information redacted (GE 1974–1980). Information in the Landauer reports included personnel data (identification number, name, social security number, and birth date), dosimeter type, deep and shallow exposure for the reporting period (i.e., monthly), and cumulative totals for deep and shallow exposures for the calendar quarter, year to date, and permanent exposure (lifetime exposure at the Pinellas Plant). The exposure information was entered in each person's exposure history by hand or into a Pinellas-based computer system and GE's Corporate Health and Safety Record (HSR) system (Richards 1986). The Landauer records are not provided by the DOE for the EEOICPA claims, examples of those records are provided in Attachment A.

Starting in mid-1978, the Plant began using the Landauer polycarbonate plastic dosimeter for 14-MeV neutrons, and continued to use photographic film processing for 2.5-MeV neutrons, X-ray, beta, and gamma exposures, and Landauer thermoluminescent dosimeter (TLD) rings for hand monitoring (Burkhart 1987b).

From October 1979 through September 1987, the Plant used dosimeters from Mound Laboratory for evaluating exposures to X-rays and 2-MeV average neutrons from the handling of sealed $^{238}PuO_2$ sources during the production of RTG units in Building 400, and continued to use the Landauer dosimetry discussed above for exposures from all other radiation sources, including 14-MeV neutrons. Problems related to the DOE Laboratory Accreditation Program (DOELAP) testing with the Mound dosimetry and the equivalent performance of Landauer neutron dosimetry led GEND to discontinue use of the Mound dosimetry in October 1987 (Burkhart 1987b). Beginning in 1990, earlier dosimetry technology was replaced with Landauer TLD dosimetry that was used until the end of nuclear development and testing operations in 1994. Table 6-3 summarizes the significant historical events for the dosimetry program at the Pinellas Plant.

Table 6-3. Pinellas Plant historical dosimetry events.

Date	Event	Reference
1957	In-plant processing of gamma and neutron film dosimeters initiated.	Burkhart 1987a
April 1957	New employee orientation in radiation safety offered.	Burkhart 1990
October 1957	Measured neutron dose rates at all test positions.	Burkhart 1990
November 1957	Measured neutron output of neutron generators, and was determined to be equivalent to 10 mrem/pulse at 1 in.	Burkhart 1990
December 1957	SNL asked to provide film badges. However, there is no indication that SNL ever provided any film badges for the Pinellas Plant.	Burkhart 1990
January 1960	Full-time Health Physics representative assigned to Area 108.	Burkhart 1990
November 1963	Began use of wrist badges in place of ring badges for limited number of employees.	Burkhart 1990
February 1965	GEXM memorandum comparing performance of two types of neutron badges and two types of gamma badges.[a]	Szedziewski 1965
Late 1969	Film badge fading study.	Author unknown ca. 1969
January 1973	Memorandum on dose rate for stress test facility.	Holliday 1973
July 1974	Began using Landauer as source of film badges.	Ward 1974
April 1978	Memorandum on personnel neutron dosimetry recommending use of new Landauer neutron badge using polycarbonate plastic.	Holliday 1978
October 1979	Began using Mound neutron dosimeters.	Burkhart 1987b
1986	Landauer switched from reporting photon doses as exposures to reporting them as deep doses.	Yoder 2005
October 1986	Memorandum on estimated doses to GEND personnel handling unmarked neutron generator units.	Burkhart 1986
October 1987	End use of Mound neutron dosimeters.	Burkhart 1987b
October 1988	Memorandum on radiation dose rates from RTG heat sources.	Weaver 1988
April 1990	Changed from Landauer film to thermoluminescent dosimetry.	Hall 1989
February 1991	All plutonium, with the exception of calorimeter sources and very small instrument calibration check sources, was removed from the Pinellas Plant by February 1991.	Author unknown undated c, MMSC 1992
1971–1993	Various determinations for doses from testing of sealed neutron generators.	GE 1971–1996
October 1994	The primary Defense Program mission for the Pinellas Plant ended on October 1, 1994. The Pinellas Plant's new mission was to clean up the facility from the past DOE mission and transition the site to an alternate use.	MMSC 1994

a. The Pinellas Plant was the progeny of GEXM. Because the radiological control programs for these two sites were closely linked and because the available information indicates that the Pinellas Plant managed the radiological programs at GEXM after its startup, the information in this evaluation is considered to be applicable to the Pinellas Plant dosimeters.

GENERAL ELECTRIC CO
ATTN [redacted]
ENVIRONMENTAL HLTH
PO BOX 11508
ST PETERSBRG FL 33733

RADIATION DOSIMETRY REPORT

ACCOUNT NO.	SERIES CODE
70463	

EXPOSURE PERIOD	PROCESS NO.	PREPARATION DATE	QUARTERLY SUMMARY PLAN *	NO. COP.		OVEX LEV.	NOTIF.	PAGE NO.
1 MONTH M	J8139	30978	2. CAL. QUARTER TO DATE 3. NO SUMMARY 5. COMB. 2 AND 3 ABOVE 2	1		33333	CP	1

R. S. Landauer, Jr. & Co.
Division of Technical Operations, Incorporated

Glenwood Science Park
Glenwood, Illinois 60425
Telephone (312)755-7000

tech/ops
Landauer

PR 772 – 2886

FOR EXPOSURE PERIOD 02/01/78 TO 02/28/78 0101 0331 1978

PARTICIPANT IDENT. NO.	PARTICIPANT NAME	SOCIAL SECURITY NO.	NOTE (SEE REVERSE SIDE)	EXPOSURE TYPE		EXPOSURE TO BADGE (IN MILLIREMS) FOR THE PERIOD OR PERIODS INDICATED BELOW: GAMMA & X-RAY	* BETA / THERMAL NEUTRON	FAST NEUTRON	TOTAL	ENERGY RANGE	CUMULATIVE TOTALS - IN MILLIREMS: CALENDAR QUARTER OR 13 WEEKS	YEAR-TO-DATE	PERMANENT	ADJUSTMENTS	PERMISSIBLE ACCUMULATED DOSE (IN MILLIREMS)	UNUSED PART OF PERMISSIBLE ACCUMULATED DOSE (IN MILLIREMS)	SEX	BIRTH DATE (MO. DAY YR.)	NO. OF BADGE REPORTS TO DATE	NO. OF REPORTS THIS QUARTER	NO. OF ADJUSTMENTS TO DATE	INCEPTION DATE OF PERMANENT TOTAL (MO. YR.)
00000	CONTROL			P	1	M		M	M		M	M	60						57	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		20	20	40				M	[redacted]	25	2		276
[redacted]	[redacted]	[redacted]		P	1	M		40	40		40	40	80				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		40	40		40	40	140				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		M	M	500				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]			2	M	M		M		M	M	550				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		20	20		40	40	160				F	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		M	M	280				F	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		40	40		80	80	160				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		60	60		60	60	240				M	[redacted]	44	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		20	20	130				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		M	M	140				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		M	M	100				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		20	20		20	20	160				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		20	20	80				F	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		M	M	100				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		20	20		20	20	160				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		40	40		60	60	140				F	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		40	40		60	60	210				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	40		M	40		60	60	280				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		40	40		80	80	160				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		20	20	80				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		100	100		100	100	180				M	[redacted]	44	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		M	M	40				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		G	1	M			M		M	M	60				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		20	20		20	20	240				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		40	40		80	80	80				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		20	20		20	20	100				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		40	40		40	40	180				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		20	20		20	20	80				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		100	100		180	180	220				M	[redacted]	45	2		674
[redacted]	[redacted]	[redacted]		P	1	M		M	M		20	20	20				M	[redacted]	45	2		674
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) / (9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)

(COLUMN 6) EXPOSURE TYPE
1-TOTAL BODY 2-SKIN DOSE 3-RIGHT FINGER 4-LEFT FINGER 5-RIGHT WRIST 6-LEFT WRIST 7-OTHER EXTREMITY 8-OTHER TOTAL BODY 9-MONITOR

IMPORTANT — SEE REVERSE SIDE FOR ADDITIONAL EXPLANATIONS

* COLUMN 8/9 IS USED TO SEPARATELY REPORT BETA DOSAGE AND THERMAL NEUTRON DOSAGE. IF EXPOSURE TYPE (COLUMN 6) IS 2, BETA DOSAGE IS BEING SHOWN. IF EXPOSURE TYPE (COLUMN 6) IS 1, THERMAL NEUTRON DOSAGE IS BEING SHOWN.

Figure 6-4. Redacted example of a Landauer dosimetry report from 1978.

Tables 6-4 through 6-9 summarize the monitoring techniques and describe the suspected and known Pinellas Plant dosimeters.

Table 6-4. Whole body beta-gamma dosimeters used at Pinellas Plant.[a]

Period	Dosimeter type	Dosimeter description
1957–Jun 1974	Photographic film (beta-gamma)	Photographic film dosimeters during this period were processed in-house (Burkhart 1987a). Based on the early film worksheets that are available, the early beta-gamma dosimeters consisted of only an open window (OW) dosimeter and a single shielded dosimeter. Additionally, those records also indicate that only the OW dosimeter was normally read, unless a significant OW reading was recorded. By December 1970, the beta-gamma dosimeters appear to have consisted of an open window dosimeter and three shielded dosimeters. The shielded dosimeters appear to have utilized an aluminum (Al) filter and two cadmium (Cd) filters of different thicknesses. Based on the records for the area dosimeters, the filters were likely 0.040 in Al, 0.014 in Cd, and 0.040 in Cd. However, it still appears that only the OW dosimeter was normally read (GE 1957–1990, 1958–1973, and 1972).
Jul 1974–Mar 1990	Landauer Type G[b,c] (beta-gamma)	The Type G dosimeter was a film emulsion package placed in standard Gardray holder/badge for monitoring beta, X-ray, and gamma exposures. It was insensitive to neutron radiation. Required in areas where Kr-85 was used. Required for radiation-generating equipment and accelerator operators. Gamma and X-ray: 30 keV to 20 MeV; beta: over 1.5 MeV.
Apr 1990–1997	Landauer Type Z/F[c] (beta-gamma)	The Type Z dosimeter was comprised of 3 TLD-700 chips for monitoring beta, X-ray and gamma exposures. It was insensitive to neutron radiation. After 1994, the Type Z dosimeter was renamed the Type F dosimeter.

a. Sources: Landauer 1956–2002; Burkhart 1987b; GE 1986–1988, GE 1990, Burkhart 1990; Greene 1985a; Hall 1989; Holliday 1978; GE 1974–1980, Landauer 2005–2006; Ingle 1991; Weaver 1987, 1991, 1995 , 1996; ORAUT 2004a.

b. A June 1974 memorandum indicates that the Pinellas Plant ordered Landauer Type J (beta-gamma) and Type K (beta-gamma and neutron) dosimeters (Burkhart 1987b); however, the actual dosimetry records indicate that Landauer Type G (beta-gamma) and Type P (beta-gamma and neutron) dosimeters were actually received and used (Landauer 1974–1980).

c. The use of the Landauer dosimeters is indicated by exposure type codes in the earlier years and use codes in the later years. The following are the dosimeter exposure type or use codes: 1 - whole body, 2 – skin/lens of eye, 3 - right finger, 4 – left finger, 5 – right wrist, 6 – left wrist, 7 – other extremity, 8 – other whole body, 9 – monitor.

Table 6-5. Whole body neutron and beta-gamma-neutron dosimeters used at Pinellas Plant.[a]

Period	Dosimeter type	Dosimeter description
1957– Jun 1974	NTA film (neutron only)	Photographic film dosimeters to measure beta-gamma radiation were also equipped with NTA film to measure neutron radiation. As with the early beta-gamma dosimeters, these dosimeter were also processed in-house (Burkhart 1987a). Fast neutrons undergoing elastic collision with content of emulsion or cellulose acetate base material produced recoil protons, which were recorded as photographic tracks in the NTA film emulsion. Track density was a linear function of dose. Developed images exhibited tracks caused by neutrons, which could be viewed and counted using appropriate imaging method (typically using a microscope or a magnified projector). Initially, total neutron tracks per 100 fields were counted. By January 1968, the total neutron tracks per 10 fields and sometimes neutron tracks per 50 fields were counted (GE 1957–1990, 1958–1973, and 1972).
Jul 1974–May 1978	Landauer Type P[b,c] (beta-gamma-neutron)	The Landauer Type P dosimeter appears to have been used in all areas with a potential for neutron exposures (GE 1974–1980). The Type P dosimeter was a combination beta-gamma and fast neutron dosimeter. The fast neutron dosimeter was an NTA film dosimeter and the beta-gamma dosimeter was likely a Landauer Type G film dosimeter.
Jun 1978–1997	Landauer Type E[c] (neutron only)	The Landauer Type E neutron dosimeter was used in all areas at the Pinellas Plant until October 1979 when the site started to use the Mound dosimeters in areas with RTG operations. After October 1979, the Type E dosimeter was used only in the neutron generator areas at the Plant. The Type E dosimeter is a polycarbonate (Lexan) neutron recoil track registration device used to monitor fast neutron interactions. Neutrak 144 has a dosimeter element for response to fast neutrons. Neutrak E1 has a polyethylene radiator over CR-39 chip that would monitor for fast neutrons; only Lexan responded to neutrons by recording ionization damage caused by neutrons interacting with carbon and oxygen atoms, which leaves a track. It had uniform energy response from 3 to over 14 MeV with threshold of about 1 MeV (Weaver 1987). The Type E dosimeter was combined with the Type G dosimeter (and later with the Type Z/F dosimeter) (Weaver 1987, 1996). Workers were required to wear an E/G dosimeter combination when working around neutron generators. Accelerator operators were also required to wear an E/G dosimeter combination. An E/G dosimeter combination or a G dosimeter was required when working with calibration sources (Weaver 1987).
Oct 1979–Sep 1987[d]	Mound TLD (gamma-neutron)	The Mound TLD was used in areas with RTG operations (i.e., where PuO_2 was handled). It was used to measure exposures to the X-rays and 2-MeV average neutrons from the handling of the sealed PuO_2 sources during the production of RTG units in Building 400. This dosimeter utilized a Harshaw 8810 TLD package that included an albedo neutron monitoring capability. The Harshaw 8810 TLD package utilized a combination of TLD-600 and TLD-700 dosimeter chips, which were encased in a plastic holder made of Cycolac.

Period	Dosimeter type	Dosimeter description
Sep 1987[d]–Feb 1991	Landauer Type R/I[c] (beta-gamma-neutron)	The Landauer Type R dosimeter arrangement was used in areas with RTG operations (i.e., where PuO_2 was handled), and replaced the Mound TLD. The Type R dosimeter package consisted of a Type G dosimeter for measuring beta, X-ray, and gamma radiation and a Type I dosimeter for measuring neutron radiation. The Type I dosimeter combined a TLD albedo neutron monitor with a track recoil device (CR-39 [allyl diglycol carbonate]) that responds to proton recoil events. Neutron energy range was approximately 1 x 10^{-6} to 10 MeV. Albedo response to thermal neutron radiation was subtracted to yield fast neutron dose. The “Neutrak ER” has an albedo element with the above-described elements. A qualitative relationship was derived to determine ratios of neutrons of various energies. When first used at the Pinellas Plant, the Type I dosimeters did not meet all DOELAP requirements during performance testing (Weaver 1991). After the Type G dosimeter was replaced by the Type Z dosimeter, the combined dosimeter unit was known as the Type I dosimeter. After production of RTGs was halted in October 1991, the Type R/I dosimeter was used only as an area monitor for the americium-beryllium (AmBe) source (Weaver 1991).

a. Sources: Landauer 1956–2002; Burkhart 1987b; GE 1986–1988, GE 1990, Burkhart 1990; Greene 1985a; Hall 1989; Holliday 1978; GE 1974–1980, Landauer 2005–2006; Ingle 1991; Weaver 1987, 1991, 1995 , 1996; ORAUT 2004a.
b. A June 1974 memorandum indicates that the Pinellas Plant ordered Landauer Type J (beta-gamma) and Type K (beta-gamma and neutron) dosimeters (Burkhart 1987b); however, the actual dosimetry records indicate that Landauer Type G (beta-gamma) and Type P (beta-gamma and neutron) dosimeters were actually received and used (Landauer 1974–1980).
c. The use of the Landauer dosimeters is indicated by exposure type codes in the earlier years and use codes in the later years. The following are the dosimeter exposure type or use codes: 1 - whole body, 2 – skin/lens of eye, 3 - right finger, 4 – left finger, 5 – right wrist, 6 – left wrist, 7 – other extremity, 8 – other whole body, 9 - monitor.
d. Dual Mound and Landauer Type R neutron dosimeters were used to monitor RTG workers during the month of September 1987 (Burkhart 1987b).

Table 6-6. Wrist beta-gamma dosimeters used at Pinellas Plant[a].

Period	Dosimeter type	Dosimeter description
Jul 1974–1990	Landauer Type G[b,c] (beta-gamma)	The Type G wrist dosimeter was a film emulsion package placed in a standard Gardray holder/badge for monitoring beta, X-ray, and gamma exposures. It was insensitive to neutron radiation. The Type G wrist dosimeter was used to monitor extremity doses in areas with RTG operations (i.e., where PuO_2 was handled) (Weaver 1987); extremity dosimetry was assigned in other areas as needed (Weaver 1996).
1991–1997	Landauer Type K[b] (beta-gamma)	The Landauer Type K wrist dosimeters assigned during this period utilized three TLD-100 chips.

a. Sources: Landauer 1956–2002; Burkhart 1987b; GE 1986–1988, GE 1990, Burkhart 1990; Greene 1985a; Hall 1989; Holliday 1978; GE 1974–1980, Landauer 2005–2006; Ingle 1991; Weaver 1987, 1991, 1995 , 1996; ORAUT 2004a.
b. The use of the Landauer dosimeters is indicated by exposure type codes in the earlier years and use codes in the later years. The following are the dosimeter exposure type or use codes: 1 - whole body, 2 – skin/lens of eye, 3 - right finger, 4 – left finger, 5 – right wrist, 6 – left wrist, 7 – other extremity, 8 – other whole body, 9 - monitor.
c. A June 1974 memorandum indicates that the Pinellas Plant ordered Landauer Type M (beta-gamma) wrist dosimeters (Burkhart 1987b); however, the actual dosimetry records indicate that Landauer Type G (beta-gamma) wrist dosimeters were actually received and used (GE 1974–1980).

Table 6-7. Ring beta-gamma dosimeters used at Pinellas Plant[a].

Period	Dosimeter type	Dosimeter description
1957–1974	Photographic film (beta-gamma)	Outside of the fact that the photographic film dosimeters during this period were processed in-house (Burkhart 1987a), no other details about these dosimeters are known.
1975–1983	(unknown)	This analysis found no information regarding the type of ring dosimeters used during this period. If ring dosimeters were used during this period, they might have included the in-house film dosimeters or Landauer Type L ring dosimeters. Because the type of ring dosimeter that might have been used is uncertain, extremity doses based on ring dosimeters from this period will need to be assessed on a case-by-case basis.
About 1983[b]–1997	Landauer Type U[c] (beta-gamma)	The Landauer Type U ring dosimeters assigned during this period utilized one LiF TLD chip for monitoring beta (>1.5 MeV), X-ray, and gamma exposures. It was insensitive to neutron radiation. The Type U ring dosimeter was used to monitor extremity doses in areas with RTG operations (i.e., where PuO_2 was handled) (Weaver 1987); extremity dosimetry was assigned in other areas as needed (Weaver 1996).

a. Sources: Landauer 1956–2002; Burkhart 1987b; GE 1986–1988, GE 1990, Burkhart 1990; Greene 1985a; Hall 1989; Holliday 1978; GE 1974–1980, Landauer 2005–2006; Ingle 1991; Weaver 1987, 1991, 1995 , 1996; ORAUT 2004a.
b. This analysis found no documentation that shows the start of use for the Landauer Type U finger ring dosimeters.
c. The use of the Landauer dosimeters is indicated by exposure type codes in the earlier years and use codes in the later years. The following are the dosimeter exposure type or use codes: 1 - whole body, 2 – skin/lens of eye, 3 - right finger, 4 – left finger, 5 – right wrist, 6 – left wrist, 7 – other extremity, 8 – other whole body, 9 - monitor.

6.2.4 Dosimetry Performance and Calibration

6.2.4.1 Performance Testing

During 1965, the GE X-Ray Division in Milwaukee (GEXM) compared the performance of the gamma and neutron dosimeters being used at GEXM to dosimeters with commercial services from R. S. Landauer Jr. & Company (Landauer), which showed essentially equivalent performance (Szedziewski 1965). Because the gamma and neutron dosimeters being used at GEXM were being processed by the Pinellas Plant (Burkhart 1987a), this performance comparison is also applicable to the Pinellas Plant's dosimeter performance.

As indicated in Table 6-5, NTA film was used for the neutron dosimeters from 1957–May 1978 (Author unknown ca. 1969; ORAUT 2004a). As stated in the Hanford Site, Idaho National Laboratory, and Nevada Test Site Occupational External Dose TBDs (ORAUT 2010, 2011a, and 2012a), NTA film was basically the only common dosimeter method available to measure neutron dose in AEC facilities prior to the use of TLDs. The neutron spectra at Pinellas were known to be dominated by higher energy 14-MeV deuterium-tritium and 2.5 MeV deuterium-deuterium fusion neutrons due to the unique designs of the neutron generators. These higher-energy neutron fields tend to minimize errors from fading or energy response reported at the first AEC Neutron Dosimetry Workshop in 1969 which indicated that Savannah River Site calibration laboratory dose measurements made with NTA film were about one-half to one-fourth of those measured with other methods, including the neutron TLD (Vallario, Hankins, and Unruh 1969).

A circa 1969 study, indicated that the NTA film neutron dosimeters experienced track fading during use, which caused a loss of information (Author unknown ca.1969, Holliday 1978). The maximum errors associated with the use of this factor occurred when a worker received a majority of the neutron exposure at the beginning or the end of a dosimeter monitoring period. The assigned dose to a worker receiving a total exposure on the first day of a dosimeter period would be 20% of the true dose per week; while the dose assigned to a worker receiving a total exposure on the last day of the monitoring period would be 40% of the true dose for a monthly wear period (Author unknown ca. 1969). As a result of that study, GEND Health Physics started applying a factor of 3 to correct for the track fading in January 1970 (Author unknown ca. 1969). The Landauer polycarbonate badge that replaced these badges in May 1978 were not subject to track fading, so no correction factor was applied after May 1978 (Holliday 1978).

The GEND Health Physics Group determined that the Neutrak ER portions of the Landauer Type R/I neutron dosimeter recorded only 67% of total neutron dose because of the dosimeter's poor energy response to low-energy neutrons from the RTG PuO_2 heat sources (Burkhart 1987a).

6.2.4.2 Calibration

Pinellas conducted dosimetry calibration as part of its external dosimetry audit program. This type of performance testing occurred every 6 months using radiation sources with known strengths. Tests used the DOE *Standard for the Performance Testing of Personnel Dosimetry Systems* (DOE 1986) and American National Standards Institute ANSI/HPS13N.11, *Personal Dosimetry Performance – Criteria for Performance* (HPS 1993). Each test used approximately six to nine badges.

The photon calibration of the Landauer Type G dosimeters was performed by exposing the dosimeters to the Shepherd Model 81-12 ^{137}Cs beam irradiator in Building 800 (a gamma check for 662-keV photons). For beta calibration, the dosimeters were exposed by placing them on a bare uranium slab for exposure to the resulting radiation. A covering with a known density thickness was placed on the dosimeters to keep them free from uranium contamination (GE 1990).

Calibration of the Landauer Type E polycarbonate dosimeters was performed by exposing them to a D-T fast neutron source with known source strength. The badges were placed on a Lexan "jig" and set at a known distance from the source of neutrons (GE 1990).

The Landauer Type R dosimeter, which consisted of a beta-gamma film dosimeter, an albedo neutron monitoring TLD, and a CR-39 neutron dosimeter, was placed on a water phantom and exposed to a Shepherd Model 149 calibrator equipped with an $^{241}AmBe$ source. The phantom was level with (and at known distances from) the source on a moveable metal rack about 4 ft above the floor to minimize scattering effects (GE 1990).

However, even though there is Pinellas Plant documentation showing such calibration studies occurred, the results of the studies and subsequent use in the radiation dosimetry program are not available.

Beginning in 1974, Landauer supplied all dosimetry badges and performed the necessary calibrations. Landauer used control film. The personnel monitoring reporting was normally in net exposure; the control film reading was deducted from the personnel film reading. If the control film appeared to have been exposed differently than the personnel packets, the densities on the personnel film were normalized to Landauer controls only and a nonminimal control reading was reported. A control packet reading was provided in arbitrary units, not necessarily in millirem. Minimal beta or soft X-ray skin dose readings were not reported until after a positive skin dose exposure was recorded. Ring badges were calibrated only for high-energy gamma (probably >0.662 MeV) and high-energy beta (1.5 MeV) unless special arrangements were made with the Plant (ORAUT 2004a). As indicated in Table 6-3, Landauer switched from reporting photon doses as exposures to reporting them as deep doses in 1986 (Yoder 2005).

Further details on the dosimetry used at the Pinellas Plant are provided in Sections 6.3 and 6.4.

6.2.5 Historical Administrative and Reporting Practices

6.2.5.1 Administrative Practices

The Pinellas Plant started an external dosimetry program in 1957 to monitor individual employees working in neutron generator production areas. Some Pinellas records on facility monitoring, safety evaluations, investigations, etc., exist; however, most of these records concern operations after 1970. Records of radiation dose to individual workers from personnel dosimeters are generally available for 1957 to 1994 for the workers' time of employment. The dose measured by dosimeters was recorded at the time of measurement, reviewed by Pinellas Plant health physicists, and routinely made available to workers. The guidance document *External Dose Reconstruction Implementation Guidelines*, OCAS-IG-0001 (NIOSH 2007), indicates that these records represent the highest quality record for a retrospective dose assessment. The information in this section pertains to the analysis of the available records.

Table 6-8 lists the total number of Pinellas Plant employees and the numbers of employees who were monitored for radiation exposure for years that this type of data was available. From 1960 to 1973, U.S. Atomic Energy Commission (AEC) annual exposure summary reports indicate that Pinellas had 27.5% of its labor force wearing external dosimetry. For the years through 1989, external dosimetry was exchanged and analyzed monthly. Beginning in January 1990, external dosimetry was exchanged and analyzed quarterly (Burkhart 1988; Weaver 1990).

As indicated in Table 6-8, not all Pinellas Plant employees were monitored for external dose. This was due to the fact that the Pinellas Plant was not required to monitor most employees, because the majority of the work performed at the Pinellas Plant did not involve exposures to external sources of radiation and because most personnel did not have routine access to radiation areas.

The following are some examples of the historical guidelines and regulations for radiation protection and worker dose monitoring requirements that were effective throughout the Pinellas Plant's operational history. One of the earliest guidelines on radiation protection was the 1958 *Addendum to National Bureau of Standards Handbook 59*, which recommended that it be made improbable for any individual outside of a controlled area to receive a dose of more than 0.5 rem/year from external radiation (NBS 1958). The first radiation protection regulation was the AEC's initial issue of 10 CFR 20 in 1960, which imposed external dose limits of 1.25 rem/quarter for restricted areas and no more than 0.100 rem in any seven consecutive days for unrestricted areas (AEC 1960). In 1974 the AEC was abolished and its functions were divided into the newly formed ERDA and NRC. After that transition, 10 CFR 20 became a regulation that was only applicable to NRC facilities. After ERDA was reorganized into the DOE in 1977, the requirements for DOE facilities were driven by DOE directives and orders. The 1981 version of DOE Order 5480.1 required workers to be monitored for external dose if they had the potential to receive more than 10% of the quarterly dose limit (i.e. more than 0.300 rem/quarter) (DOE 1981). Since 1988, DOE Order 5480.11 (DOE 1988) and later 10 CFR 835 have required workers with a potential to receive 0.100 rem/year of external dose to be monitored.

Table 6-8. Annual whole body radiation exposure information for the Pinellas Plant .[a,b]

Year	Number of Pinellas Plant employees	Number of monitored employees	Number of annual doses <1 rem	Number of annual doses 1–2 rem
1960	1,304	225	225	0
1961	1,395	251	251	0
1962	1,370	254	254	0
1963	1,597	545	545	0
1964	1,408	347	347	0
1965	1,319	301	301	0
1966	1,445	325	325	0
1967	1,405	585	584	1
1968	1,424	292	292	0
1969	1,323	588	588	0
1970	1,311	442	441	1
1971	1,283	410	410	0
1972	1,402	346	346	0
1973	1,252	383	383	0
1974	Not available	Not available	Not available	Not available
1975	Not available	Not available	Not available	Not available
1976[c]	Not available	317	317	0
1977	Not available	300	300	0
1978	Not available	298	298	0
1979	Not available	334	334	0
1980	Not available	376	376	0
1981	Not available	389	389	0
1982	Not available	408	408	0
1983	Not available	378	378	0
1984	Not available	405	405	0
1985	Not available	391	391	0

a. Source: ORAUT 2017a.
b. The values in this table include all AEC/ERDA/DOE and GE employees. They do not include any data for Pinellas Plant visitors.
c. The values for 1976–1985 include the numbers of workers monitored for external dose and/or internal dose, and their reported annual doses. Whereas, the values for 1960–1973 are limited to only external dose information. Additionally, the reported information for 1976–1985 no longer included the numbers of unmonitored employees, so the total number of employees could not be determined.

General operating procedures for the Pinellas Plant from as early as 1967 indicate that dosimeters were assigned to all personnel with a potential to receive a measurable external dose. Pinellas Plant general operating procedure titled "*Film Badge Requirements*," dated May 10, 1967, states that it was management's responsibility to "Ascertain that film badges are worn by all personnel whose work assignments entail the potential for accumulating measurable radiation exposures; compliance with this procedure is a condition of employment in a Radiation Area." (GE 1957–1990 p. 127–128). All versions of a Pinellas Plant general operating procedure titled "*Assignment of Personnel to Work in Radioactive Material, Contamination, or Radiation Are*as," dated between January 17, 1968, and June 29, 1984, state that it was the Work Area Manager's responsibility to "Ensure that all employees having work assignments in Radiation Areas are provided with film badges." (GE 1957–1990 p. 122–125 and 129–130). In addition, a Pinellas Plant memorandum dated November 1, 1984, states that "All individuals with a potential of receiving measurable radiation dosage are included in our personnel monitoring program." (Greene 1984a). Based on a comparison of these procedures to the historical guidelines and regulations, the Pinellas Plant monitored significantly more workers for external dose than what was necessary.

The reported annual whole-body doses indicate that on average approximately 95% of the monitored workers at the Plant received an annual whole-body dose of less than or equal to 0.100 rem for any given year (see Table B-1 in Attachment B). Table B-1 also indicates that nearly 80% of those same workers actually received annual doses ≤ 0.020 rem on average. This confirms that the Pinellas Plant did monitor any personnel with the potential to receive a measurable external dose, which exceeded the worker monitoring requirements throughout its entire history.

A Pinellas Plant health physicist reviewed the reports and evaluated and resolved unusual or inconsistent results. The health physicist could modify the reports, documenting all investigations and reasons for such modifications. These reports were placed in the worker's dosimetry file. The health physicist checked the printed version of the Landauer reports against the electronic version. Until 1990, workers who reported lost or stolen badges were assigned an exposure that was an average from their previous dose histories (GE 1990).

If Landauer found that a badge exceeded 400 mrem whole body, 800 mrem skin, or 6,000 mrem extremity, it was required to call the responsible Pinellas health physicist (GE 1990). Analysis of the available worker records found no documentation that this reporting requirement was ever exceeded during the time Landauer provided dosimetry services to the Plant (1974 to 1997).

6.2.5.2 Reporting Practices

Based on the available claim records, the Pinellas Plant routinely recorded cumulative career dose totals, annual dose totals, and individual dosimeter results for the monitored workers. Attachment A contains examples of some of the external dosimetry records are provided by the DOE for the EEOICPA claims. The examples in Attachment A only include examples of the records that provided individual dosimeter results for the workers. It should be noted that the reported monthly, annual, cumulative, and lifetime dose totals for the Pinellas Plant were reported as whole body doses, which would include any internal tritium doses that the worker received.

By the late-1980's, the Pinellas Plant had begun an "As Low As Reasonably Achievable" (ALARA) Program, which provided another layer of tracking and reporting worker doses (Burkhart 1989, Weaver 1994b, LMSC 1996).

6.3 ADJUSTMENTS TO RECORDED DOSE

The following adjustments need to be made to the reported doses from certain dosimeters used at the Pinellas Plant, to account for biases that may have resulted in under-measurements of the workers' external doses.

The recorded Pinellas doses show that there is not a consistent relationship between recorded neutron and photon doses for work performed in the neutron generator areas at the Plant. This lack of a true neutron-to-photon dose ratio can be attributed to the nature of the Pinellas processes, during which neutron generator testing occurred in open rooms that, combined with the short period of the neutron pulse, relatively open test structure, virtually no photons from the neutron generator, and relatively low number of neutrons per test pulse (no significant quantities of activation products), would result in a corresponding photon dose. This result is supported in the individual dose records, which indicate that the timing of Pinellas personnel neutron and photon exposures varied greatly not only on a yearly but also on a monthly basis (a recorded value for 1 month and no recorded doses for the next several months). Thus, the assignment of a neutron-to-photon dose ratio to adjust for a missed neutron dose is not valid for the Pinellas Plant for neutron generators.

However, for RTG PuO_2 heat sources an approximate 3:1 neutron-to-photon ratio was measured based on neutron and photon exposure rates from the processing of the RTG PuO_2 heat sources as measured in 1987 (GE 1987). Exposure rates measured at another time were 0.37 mR/hr neutron and 0.18 mR/hr gamma at 24 in. Actual dose equivalent received from removal and processing of 15 units for one worker (apparently the typical workload was 50 generators per month for perhaps three personnel) amounted to a 20.9-mrem neutron and 7.1-mrem gamma dose equivalents or approximately a 3:1 neutron-to-photon ratio (GE 1983). Because the RTG radioisotopic ratios and activities remained unchanged and the workstations and processes consistent, this ratio can also be considered a constant for RTG work conducted from 1975 to 1990.

6.3.1 Photon Dose Adjustments

With the exception of the Mound TLDs, no adjustments to photon doses are necessary for dose reconstruction.

6.3.1.1 Signal Fading Adjustments

Prior to July 1981, the Mound TLDs were subject to signal fading, which could amount to 25 to 30% of the stored signal fading during a period of 4 weeks (Crain 1981a). Beginning with the third quarter of 1981, the Mound TLDs were annealed before being packed into the dosimeter holders/badges to reduce the signal fading problem to a negligible level (Crain 1981a, 1981b). As a result of this signal fading, the reported doses for the affected dosimeters were as little as 70% of the actual dose. To compensate for the signal fading, the Mound TLD results reported during the period from October 1979 through June 1981 should be multiplied by a signal fading correction factor of 1.43 (1/0.70). After June 1981, there was no significant signal fading for those dosimeters, and no corrections for signal fading are necessary.

6.3.2 Neutron Dose Adjustments

The following subsections provide the bases for the various neutron dose adjustments. The necessary neutron dose adjustments are summarized in Tables 6-9, 6-10, and 6-11 below.

6.3.2.1 Radiation Weighting Factor Adjustments

The Pinellas Plant used a relative biological effectiveness (RBE) weighting factor of 10.0 when calculating the effective dose for 14-MeV neutrons (Holliday undated), which is equivalent to the ICRP Publication 60 neutron weighting factor for neutron energies from 2 to 14 MeV (ICRP 1991). Because the weighting factor value used by the Pinellas Plant is higher than other values that could have been used (such as those in NCRP 1971), the ICRP Publication 60 correction factor is unity for neutron exposures in the neutron generator areas.

The plutonium in the RTGs emits neutrons with an average energy of 2 MeV and an energy range of thermal to 12 MeV (Figure 6-3) (Burkhart 1987a). Based on the average neutron energy being 2 MeV, 50% of the neutrons were assumed to be in the 2- to 20-MeV neutron energy group and the remaining 50% of the neutrons were assumed to be in the neutron energy group of 0.1- to 2-MeV, which is typically the most favorable-to-claimant neutron energy group. The available GEND documentation does not describe any separate processing of the dosimetry when Landauer dosimeters were used to monitor exposures from RTG operations. Therefore, it was assumed that an RBE of 10 was applied to the neutron doses from RTG operations when Landauer dosimeters were used for the RTG operations (i.e., 1975–September 1979 and September 1987–February 1991). When the Mound dosimeters were used to monitor exposures from RTG operations (i.e., October 1979–September 1987), a single RBE value of 7 was applied to the Pinellas Plant doses reported by the Mound Laboratory (ORAUT 2004). Because the RBE value used for the Landauer dosimeters is uncertain and because the RBE used for the Mound dosimeters is likely more favorable to claimants than what was used for the Landauer dosimeters, the radiation weighting factor adjustments for all neutron energy groups and all periods of RTG operations should be based on an RBE value of 7.

A summary of the ICRP Publication 60 correction factors (ICRP 1991) for the Pinellas Plant's reported neutron doses is provided in Table 6-9.

Table 6-9. Neutron radiation energies and ICRP 60 correction factors.

Process type	Neutron energy range	IREP energy group	Default dose fraction[a] (%)	ICRP 60/RBE ratio[b]	ICRP 60 correction factor[c]
Neutron generator operations	≤14 MeV	2–20 MeV	100%	10/10	1.00
RTG operations	0–2 MeV	0.1–2 MeV	50%	20/7	1.43
RTG operations	2–12 MeV	2–20 MeV	50%	10/7	0.71

a. Because no neutron dose values for the various neutron energies were available at the time of this assessment, the default dose fractions for the Pinellas Plant are actually just based on the expected neutron energy distributions.
b. The ICRP 60/RBE ratio is the appropriate radiation weighting factor in ICRP 60 (ICRP 1991) divided by the historical RBE value that was applied to the reported neutron doses.
c. The ICRP 60 correction factor is the ICRP 60/RBE ratio multiplied by the appropriate fraction/percentage for the neutron energy group.

6.3.2.2 Track Fading Adjustments

The NTA track film that was used at the Pinellas Plant from the start of operations in 1957 through June 1978 was susceptible to track fading. Track fading occurs between the time the tracks in the dosimeter were created and when the dosimeter film was analyzed. As this time interval increases, the amount of track fading increases.

A study was performed in 1969 to determine the amount of track fading on the NTA track film dosimeters that were used at the Pinellas Plant. Track fading was potentially significant because of the Plant's monthly dosimeter exchange frequency. The study determined that an average of 67% of the proton-recoil tracks had faded for a monthly dosimeter exchange. In other words, on average only 33% of the original tracks remained by the time the dosimeters were analyzed. The study recommended that a correction factor of 3 (i.e., 1/0.33) be incorporated into the dose calculations beginning in January 1970 to account for track fading (Author unknown ca. 1969). A 1974 memorandum from Landauer indicates that the correction factor of 3 was also being applied to the NTA film dosimeter results provided by Landauer for the period of July 1974 through May 1978 (Wheeler 1974).

Because there is no indication that the Pinellas Plant performed any track fading corrections to the reported neutron doses prior to 1970, the dose reconstructor should apply a track fading correction factor of 3.0 to the neutron doses reported for the years of 1957–1969. No track fading corrections need to be applied to the neutron doses reported after 1969, because the reported neutron doses have already been corrected.

6.3.2.3 Signal Fading Adjustments

Prior to July 1981, the Mound TLD was subject to signal fading, which could amount to 25% to 30% of the stored signal fading during a period of 4 weeks (Crain 1981a). Beginning with the third quarter of 1981, the Mound TLDs were annealed before being packed into the dosimeter holders/badges to reduce the signal fading problem to a negligible level (Crain 1981a, 1981b). As a result of this signal fading, the doses reported for the affected dosimeters were as little as 70% of the actual dose. To compensate for the signal fading, the Mound TLD results reported during the period from October 1979 through June 1981 should be multiplied by a signal fading correction factor of 1.43 (1/0.70). After June 1981, there was no significant signal fading for those dosimeters, and no corrections for signal fading are necessary.

6.3.2.4 Neutron Energy Response Adjustments

Because of the higher neutron energies associated with the neutron generator production activities, the reported neutron doses for workers in the neutron generator portions of the Pinellas Plant do not need to be adjusted for the dosimeters' poor response to lower neutron energies. However, reported neutron doses for the Plant's RTG workers need to be adjusted because of the limitations of some of the dosimeter responses to the lower energy neutrons that were encountered in the RTG areas.

NTA film has a neutron energy response threshold of 0.5 MeV. Because some of the neutrons associated with the RTG PuO_2 heat sources had neutron energies below 0.5 MeV, the reported neutron doses from the start of Pinellas operation through June 1978 require a correction for poor energy response. Based on the neutron energy distribution information for the RTG PuO_2 heat sources (Burkhart 1987a), 6.4% of the neutrons were in the 0–1 MeV energy range and were assumed to not have been detected by the NTA film dosimeters. Therefore, a neutron energy response correction factor of 1.07 [1/(1-0.064)] should be applied to all NTA film dosimeter results to account for any under-reported neutron doses due to the Nevada Test Site film dosimeter's energy response.

Because the Mound dosimeters utilized TLD chips that responded well to the neutron energies encountered by RTG workers, no adjustment for the neutron energy response of the Mound dosimeters is necessary (ORAUT 2004b).

The GEND Health Physics Group determined that the Neutrak ER portions of the Landauer Type R/I neutron dosimeter recorded only 67% of total neutron dose because of the dosimeter's poor energy response to low-energy neutrons from the RTG PuO_2 heat sources (Burkhart 1987a). In addition, there is no indication that the reported neutron doses for the RTG workers have been adjusted by the Pinellas Plant. Therefore, dose reconstructors should use a neutron energy response correction factor of 1.49 (1/(0.67) to account for the underreported neutron doses from the RTG PuO_2 heat sources.

Table 6-10. Summary of neutron dosimeter correction factors (CF) for neutron generator operations (1957–1997).[a,b]

Applicable period	Track Fading CF	Signal Fading CF	Energy Response CF	Total adjustment
1957–1969	3.00	N/A	N/A	3.00
1970–1997	N/A	N/A	N/A	1.00

a. N/A = not applicable.
b. This summary includes all of the neutron dosimeter correction factors except the ICRP Publication 60 correction factors, which are already summarized in Table 6-9

Table 6-11. Summary of neutron dosimeter correction factors (CF) for RTG operations (1975–1991).[a,b]

Applicable period	Track Fading CF	Signal Fading CF	Energy Response CF	Total adjustment
1975–Sep 1979	N/A	N/A	1.07	1.07
Oct 1979–Jun 1981	N/A	1.43	N/A	1.43
Jul 1981–Sep 1987	N/A	N/A	N/A	1.00
Oct 1987–Feb 1991	N/A	N/A	1.49	1.49

a. N/A = not applicable
b. This summary includes all of the neutron dosimeter correction factors except the ICRP Publication 60 correction factors, which are already summarized in Table 6-9.

6.3.3 <u>Electron Dose Adjustments</u>

Electron doses were monitored but not routinely recorded. The primary source of electron exposures was from the use of two ^{85}Kr leak detection systems (Radiflo and TRACER-flo systems) in Area 109 from about 1963 through 1994.

Beta dose monitoring for ^{85}Kr started before the DOELAP standard release, which used a calibration factor from a ^{90}Sr/^{90}Y source that tended to underestimate the dose from ^{85}Kr exposures. To compensate for the lower energy of ^{85}Kr in relation to that of ^{90}Sr/^{90}Y, a correction factor might have been used for the Pinellas Plant based on the more similar ^{204}Tl energy spectrum. Because it is not clear from the Plant records whether the ^{204}Tl energy calibration or equivalent was requested by Pinellas of Landauer or other vendors prior to 1986, a correction should be performed on the reported non-penetrating or electron doses prior to 1986 to ensure that the workers' doses are not underestimated. To compensate for the energy spectrum differences the reported nonpenetrating or electron doses should be multiplied by a correction factor of 3.5 for the years prior to 1986 (Poliziani 1985). From 1986 onwards, when DOELAP and National Voluntary Laboratory Accreditation Program standards included ^{204}Tl calibration criteria for ^{85}Kr exposures, it is not necessary to apply a correction factor.

6.4 MISSED DOSE

Missed external dose is the unrecorded or unmeasured external dose that is the result of either relatively high detection limits, short monitoring periods, high dosimeter exchange frequencies, or a combination of these three factors (NIOSH 2007). Missed doses are applicable to the Pinellas Plant workers that were monitored for external dose and had one or more reported dosimeter readings that were less than half the LOD for the dosimeter. Missed dose is primarily estimated based on dosimeter results, where the number of zero or < LOD/2 values for a given year is multiplied by the LOD/2 value for the dosimeters used during that year (NIOSH 2007).

At the Pinellas Plant, electron, photon, and neutron doses were possible. However, electron doses, including missed electron doses, were unlikely, as discussed in Section 6.2.2.1. Based on the available information for the Pinellas Plant, chronic external exposures to electrons did not occur and acute external exposures to electrons were unlikely. Therefore, missed electron doses do not normally need to be assessed for Pinellas Plant workers.

Tables 6-12 through 6-17 summarize the dosimetry parameters to be used for calculating missed doses for Pinellas Plant workers. For the calendar years that have more than one dosimeter LOD value, the highest LOD value should be used for the entire year, unless all of the dosimeter results are for the period with the lower LOD value.

Table 6-12. Whole-body beta-gamma dosimetry missed doses for Neutron Generator Operations (1957–1997).[a]

Dosimeter type	Period of use	LOD (rem)	Exchange frequency	Maximum annual missed dose (rem)[b]
Photographic film	Jan 1957–Jun 1974	0.040 photons[c] 0.040 electrons[c]	Monthly	0.240 photons 0.240 electrons
Landauer Type G/P[d]	Jul 1974–Apr 1990	0.010 photons[e] 0.040 electrons[e]	Monthly (1974–1989)	0.060 photons 0.240 electrons
Landauer Type G/P[d]	Jul 1974–Apr 1990	0.010 photons[e] 0.040 electrons[e]	Quarterly (after 1989)	0.020 photons 0.080 electrons
Landauer Type Z/F[f]	May 1990–Dec1997	0.010 photons[e] 0.040 electrons[e]	Quarterly	0.020 photons 0.080 electrons

a. Some of the beta-gamma dosimeters listed in this table included a component for monitoring neutron exposures; however, only the beta-gamma components of those dosimeters are addressed in this table.
b. The maximum annual missed dose assignments are calculated by multiplying half of the dosimeter's LOD value by the maximum number of dosimeters exchanged in a given year (NIOSH 2007).
c. Estimated LODs for commonly used photon dosimetry (ORAUT 2006b).
d. The Landauer Type P dosimeter was a beta-gamma-neutron dosimeter that likely utilized a Type G dosimeter or equivalent for its beta-gamma component.
e. The photon and electron LODs for this Landauer dosimeter are based on information in GE (1974-1980).
f. After 1994, the Landauer Type Z dosimeter was renamed the Type F dosimeter.

Table 6-13. Whole-body beta-gamma dosimetry missed doses for RTG Operations (1975–1991).[a]

Dosimeter type	Period of use	LOD (rem)	Exchange frequency	Maximum annual missed dose (rem)[b]
Landauer Type G/P[c]	Late-1975–Sep 1979	0.010 photons[d] 0.040 electrons[d]	Monthly	0.060 photons 0.240 electrons
Mound TLD[e]	Oct 1979–Jun 1981	0.029 photons[f,g]	Monthly	0.174 photons
Mound TLD[e]	Jul 1981–Aug 1987[h]	0.020 photons[f]	Monthly	0.120 photons
Landauer Type R/I	Oct 1987[h]–Feb 1991	0.010 photons[d] 0.040 electrons[d]	Monthly (1987–1989)	0.060 photons 0.240 electrons
Landauer Type R/I	Oct 1987[h]–Feb 1991	0.010 photons[d] 0.040 electrons[d]	Quarterly (after 1989)	0.020 photons 0.080 electrons

a. Some of the beta-gamma dosimeters listed in this table included a component for monitoring neutron exposures; however, only the beta-gamma components of those dosimeters are addressed in this table.
b. The maximum annual missed dose assignments are calculated by multiplying half of the dosimeter's LOD value by the maximum number of dosimeters exchanged in a given year (NIOSH 2007).
c. The Landauer Type P dosimeter was a beta-gamma-neutron dosimeter that likely utilized a Type G dosimeter or equivalent for its beta-gamma component.
d. The photon and electron LODs for this Landauer dosimeter are based on information in GE (1974-1980).
e. The Mound TLD was a gamma-neutron dosimeter.
f. The LOD for this Mound neutron dosimeter was 0.020 mrem (ORAUT 2004).
g. The LOD for this dosimeter has been adjusted to account for signal fading, in accordance with Section 6.3.1.1, and that adjustment is shown in ORAUT (2017b).
h. Dual Mound and Landauer Type R neutron dosimeters were actually used to monitor RTG workers during the month of September in 1987 (Burkhart 1987b). Because it is uncertain which dosimeters were used for the reported doses, the dosimeter with the most favorable-to-claimant LOD values was used and the period of use date has been adjusted to reflect that.

Table 6-14. Whole-body neutron dosimetry missed doses for Neutron Generator Operations (1957–1997).[a]

Dosimeter type	Period of use	LOD (rem)	Exchange frequency	Maximum annual missed dose (rem)[b]
NTA film	Jan 1957–Dec 1969	0.150 neutrons[c,d]	Monthly	0.900 neutrons
NTA film	Jan 1970–Jun 1974	0.050 neutrons[c]	Monthly	0.300 neutrons
Landauer Type P[e]	Jul 1974–May 1978	0.020 neutrons[f]	Monthly	0.120 neutrons
Landauer Type E	Jun 1978–Dec 1997	0.020 neutrons[f]	Monthly (1974–1989)	0.120 neutrons
Landauer Type E	Jun 1978–Dec 1997	0.020 neutrons[f]	Quarterly (after 1989)	0.040 neutrons

a. Some of the neutron dosimeters listed in this table included a component for monitoring beta-gamma exposures; however, only the neutron components of those dosimeters are addressed in this table.
b. The maximum annual missed dose assignments are calculated by multiplying half of the dosimeter's LOD value by the maximum number of dosimeters exchanged in a given year (NIOSH 2007).
c. NTA film dosimeters have an LOD of 0.050 rem for fast neutrons based on Wilson et al. (1990).
d. The LOD for this NTA film dosimeter has been adjusted to account for track fading, in accordance with Section 6.3.2.2, and that adjustment is shown in ORAUT (2017b).
e. The Landauer Type P dosimeter was a beta-gamma-neutron dosimeter that utilized NTA film for its neutron component.
f. The LOD for this Landauer neutron dosimeter was 0.020 mrem for fast neutrons GE (1974-1980).

Table 6-15. Whole-body neutron dosimetry missed doses for RTG Operations (1975–1991).[a]

Dosimeter type	Period of use	LOD (rem)	Exchange frequency	Maximum annual missed dose (rem)[b]
Landauer Type P[c]	Late-1975–Sep 1979	0.021 neutrons[d]	Monthly	0.126 neutrons
Mound TLD[e]	Oct 1979–Jun 1981	0.014 neutrons[f,g]	Monthly	0.084 neutrons
Mound TLD[e]	Jul 1981–Aug 1987[h]	0.010 neutrons[f]	Monthly	0.060 neutrons
Landauer Type R/I[i]	Sep 1987[h]–Feb 1991	0.030 neutrons[j]	Monthly (1987–1989)	0.180 neutrons
Landauer Type R/I[i]	Sep 1987[h]–Feb 1991	0.030 neutrons[j]	Quarterly (after 1989)	0.060 neutrons (quarterly)

a. Some of the neutron dosimeters listed in this table included a component for monitoring beta-gamma exposures; however, only the neutron components of those dosimeters are addressed in this table.
b. The maximum annual missed dose assignments are calculated by multiplying half of the dosimeter's LOD value by the maximum number of dosimeters exchanged in a given year (NIOSH 2007).
c. The Landauer Type P dosimeter was a beta-gamma-neutron dosimeter that utilized NTA film for its neutron component.
d. The LOD for this Landauer neutron dosimeter was 0.020 mrem for fast neutrons GE (1974-1980). The LOD for this dosimeter has been adjusted to account for its energy response to RTG neutrons, in accordance with Section 6.3.2.4, and that adjustment is shown in ORAUT (2017b).
e. The Mound TLD was a gamma-neutron dosimeter.
f. The LOD for this Mound neutron dosimeter was 0.010 mrem (ORAUT 2004).
g. The LOD for this dosimeter has been adjusted to account for signal fading, in accordance with Section 6.3.2.3, and that adjustment is shown in ORAUT (2017b).
h. During September 1987, dual Mound TLD and Landauer Type R/I neutron dosimeters were used to simultaneously monitor the RTG workers (Burkhart 1987b). Because it is uncertain which dosimeters were used for the reported doses, the dosimeter with the most favorable-to-claimant LOD values was used and the period of use date has been adjusted to reflect that.
i. The Landauer Type R/I dosimeter was a beta-gamma-neutron dosimeter. The neutron component to this dosimeter (i.e. the Type I part) utilized a TLD albedo neutron monitor with recoil device that responds to proton recoil events.
j. The LOD for this Landauer neutron dosimeter was 0.020 mrem Landauer (1956–2002). The LOD for this dosimeter has been adjusted to account for its energy response to RTG neutrons, in accordance with Section 6.3.2.4, and that adjustment is shown in ORAUT (2017b).

Table 6-16. Wrist beta-gamma dosimetry missed doses.

Dosimeter type	Period of use	LOD (rem)	Exchange frequency	Maximum annual missed dose (rem)[a]
Photographic film	1957–Jun 1974	0.040 photons[b] 0.040 electrons[b]	Monthly	0.240 photons 0.240 electrons
Landauer Type G	Jul 1974–1990	0.010 photons 0.040 electrons	Monthly (1974–1989)	0.060 photons 0.240 electrons
Landauer Type G	Jul 1974–1990	0.010 photons 0.040 electrons	Quarterly (after 1989)	0.020 photons 0.080 electrons
Landauer Type K	1991–1997	0.010 photons 0.040 electrons	Quarterly	0.020 photons 0.080 electrons

a. The maximum annual missed dose assignments are calculated by multiplying half of the dosimeter's LOD value by the maximum number of dosimeters exchanged in a given year (NIOSH 2007).
b. Estimated LODs for commonly used photon dosimetry (ORAUT 2006b).

Table 6-17. Finger ring beta-gamma dosimetry missed doses.

Dosimeter type	Period of use	LOD (rem)	Exchange frequency	Maximum annual missed dose (rem)[a]
Photographic film	1957–Jun 1974	0.040 photons[b] 0.040 electrons[b]	Monthly	0.240 photons 0.240 electrons
Unknown[c]	Jul 1974–Apr 1979	Unknown[c]	Unknown[c]	Unknown[c]
Landauer Type U	May 1979[d]–1997	0.030 photons 0.040 electrons	Monthly (1974–1989)	0.180 photons 0.240 electrons
Landauer Type U	May 1979[d]–1997	0.030 photons 0.040 electrons	Quarterly (after 1989)	0.030 photons 0.080 electrons

a. The maximum annual missed dose assignments are calculated by multiplying half of the dosimeter's LOD value by the maximum number of dosimeters exchanged in a given year (NIOSH 2007).
b. Estimated LODs for commonly used photon dosimetry (ORAUT 2006b).
c. Because the type of ring dosimetry used during this period was unknown at the time of this analysis, the assessment of any ring dosimeter results during this period will need to be handled on a case-by-case basis. Currently, there is no indication that ring dosimeters were ever assigned during this period.
d. May 1979 is the earliest indication of the Landauer Type U dosimeter being used (Holliday 1980).

6.5 UNMONITORED DOSE

6.5.1 Unmonitored Workers

The majority of the work performed at the Pinellas Plant did not involve exposures to external sources of radiation, which explains why a significant number of the workers were not monitored for external dose. Based on the review of the available dosimetry data, employees with any significant potential for external dose exposure appear to have been routinely monitored, as evidenced by the large number of monitored individuals that routinely had doses below the reporting levels. Therefore, it is reasonable to assume that unmonitored workers received less dose than monitored workers at the Pinellas Plant.

For the periods in which any Pinellas Plant worker was not monitored for external dose, an annual unmonitored external dose assignment of 100 mrem should be assigned. The basis for this unmonitored external dose assignment is in Attachment B of this document. For unmonitored periods that are less than 1 year in duration, the unmonitored dose assignment should be prorated, unless doses are being overestimated. For Plant workers who were likely exposed only to the onsite ambient levels of radiation, this more favorable-to-claimant unmonitored dose is assigned in lieu of the onsite ambient doses provided in the site's technical basis document on occupational environmental dose (ORAUT 2011c), for the reasons provided in the basis for the unmonitored external dose assignment. In addition, the unmonitored external dose assignment should be assigned only as 100% 30- to 250-keV photons, for the reasons provided in Attachment B.

6.5.2 Workers Whose Dosimetry Records Are Missing

DOE has not been able to find the dosimetry records for a significant number of the Pinellas Plant workers. This situation was identified by comparing the DOE responses found in the claim files with the dosimetry records contained in ORAUT's Site Research Database (SRDB). For a number of claims, DOE has indicated that no records were found, whereas NIOSH has located full or partial sets of dosimetry records for those claims in its SRDB.

Because a monitored Pinellas Plant worker had a higher potential to receive external dose than an unmonitored worker, special considerations need to be made for workers whose dosimetry records are missing:

- In the instances where sufficient records are found in the SRDB, which are identified as Personnel Exposure files in the claim files, no special considerations need to be made and the other sections of this document can be used to assess the worker's external doses.

- In instances where there is only an indication that a worker was monitored for dose (e.g. records of annual whole-body doses found for some years), the worker's job description should be carefully evaluated to determine if the worker was likely monitored for external dose, internal dose, or both. When records consisting of only annual whole-body doses are found for some years, the reported doses could consist of external photon doses, external neutron doses, internal tritium doses, or any combination of these three types of dose. If the worker was likely monitored for external dose, it also needs to be determined if the worker was likely monitored for external neutron doses and/or photon doses. Given that the available information for the Pinellas Plant indicates that in most instances neutron dose monitoring was performed in conjunction with photon dose monitoring, the default assumption is that the worker was monitored for both neutron doses and photon doses, when the type of dose monitoring is unknown. The appropriate annual missed doses should be assigned along with the annual unmonitored external dose assignment prescribed in Section 6.5.1, because missed doses were not accounted for in the unmonitored dose assignment for reasons indicated in Attachment B. For overestimating doses, the annual missed doses can be assigned based on the maximum zeros approach (the maximum dosimeters exchanged per year approach). For a reasonable, yet likely favorable-to-claimant estimate of a worker's missed doses, the annual missed doses should be based on the maximum potential number of dosimeter exchanges within a year minus 1 to account for the unmonitored dose assignment as being a single positive dosimeter reading.

6.6 UNCERTAINTY

When a reported external dose is based on a single measurement, the uncertainty associated with that individual measurement needs to be accounted for in the assigned dose. In contrast to individual dose measurements, the uncertainty associated with external doses based on multiple measurements for the same period has already been accounted for in the dose assignment. An example of this is unmonitored dose assignments, which are typically based on either average or upper bound annual doses for a population of worker doses. As a result, this section only addresses how the uncertainties for individual external dose measurements should be assessed.

6.6.1 Beta-Gamma Dosimeter Uncertainty

For film dosimeters, the LODs that are quoted in the literature range from about 30 to 50 mrem for electron and photon irradiation (Morgan 1961). These are not the expected uncertainties at larger electron and photon dose readings. For example, it was possible to read a photon dose of 100 mrem to within ±15 mrem (±15%) if the exposure involved photons with energies between several hundred keV and several MeV (Morgan 1961). If the exposure involved photons with energies less than several hundred keV, the uncertainty was at least twice that for the more energetic photons (Morgan 1961). Therefore, the standard error in the recorded film dosimeter doses from photons of any energy is estimated to be ±30%. The standard error for the recorded dose from electron irradiation was essentially the same as that for photon irradiation, but when an unknown mixture of electron and photon irradiation was involved, the standard error for the dose from beta irradiation was somewhat larger than ±30% (Morgan 1961). Therefore, the standard error in the recorded film dosimeter doses from >15 keV electrons is estimated to be ±30% for a known mixture of photon and electron irradiation, and higher if the mixture is unknown.

For TLDs, the uncertainty is generally lower than the uncertainty for film dosimeter results; however, the uncertainty is still somewhat dependent on the measured dose (NIOSH 2007). Based on that observation, the uncertainty associated with the Pinellas Plant's recorded electron and photon doses from TLDs will be assumed to be ±30%, which is potentially favorable to claimants for some reported dose values.

6.6.2 Neutron Dosimeter Uncertainty

The NTA film technology used to measure neutron doses at the Pinellas Plant was similar to the technology used at other AEC/DOE facilities. Based on a review of the available information for such facilities, a reasonable uncertainty for neutron dose measurements performed using NTA film dosimeters is ±50%.

For the Landauer Type E neutron dosimeters, which were a polycarbonate (Lexan) dosimeter, the sensitivity to fast neutron radiation was reported in 1978 as 30 ± 15 mrem (±50%) (Holliday 1978). It was also verified that the uncertainties of the dose determinations decrease as exposures increase (Holliday 1978). Therefore, a reasonable uncertainty for neutron dose measurements performed using the Landauer Type E dosimeters is ±50%.

For the Mound TLDs, an uncertainty of ±30% should be applied based on the site-specific information for the Mound Site (ORAUT 2004b).

For the Landauer Type R/I neutron dosimeters, an uncertainty of ±30% should be considered reasonable and likely favorable to claimants, based on a review of the available information for other AEC/DOE facilities.

6.7 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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GLOSSARY

absorbed dose

In external dosimetry, process in which radiation energy is imparted to material. In internal dosimetry, movement of material to blood regardless of mechanism.

accreditation

For external dosimetry, the assessment of whether or not a personnel dosimetry system meets specific criteria. The assessment includes dosimeter performance and the associated quality assurance and calibration programs.

accuracy

The characteristics of an analysis or determination that ensures that both the bias and precision of the resultant quantity will remain within the specified limits.

albedo dosimeter

Thermoluminescent dosimeter that measures the thermal, intermediate, and fast neutrons scattered and moderated by the body or a phantom from an incident fast neutron flux.

alpha radiation

Positively charged particle emitted from the nuclei of some radioactive elements. An alpha particle consists of two neutrons and two protons (a helium nucleus) and has an electrostatic charge of +2.

backscatter

Reflection or refraction of radiation at angles over 90 degrees from its original direction.

beta particle

See *beta radiation*.

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.

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.

densitometer

Instrument that uses a photoelectric cell to measure the transition of light through developed X-ray film to determine its optical density.

DOE Laboratory Accreditation Program (DOELAP)

Program for accreditation by DOE of DOE site personnel dosimetry and radiobioassay programs based on performance testing and the evaluation of associated quality assurance, records, and calibration programs.

dose

In general, the specific amount of energy from ionizing radiation that is absorbed per unit of mass. Effective and equivalent doses are in units of rem or sievert; other types of dose are in units of roentgens, rads, reps, or grays.

dose equivalent
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. See *dose*.

dose equivalent index
Historical measure for neutron source calibration defined by the International Commission on Radiation Units and Measurements as the sum of the maximum dose equivalents delivered within a sphere at any depth for the respective neutron energies even though the maximum dose occurred at different depths and discounting the outer 0.07-millimeter-thick shell. Also called unrestricted dose equivalent index.

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. See *albedo dosimeter*, *film dosimeter*, *neutron film dosimeter*, *pocket ionization chamber*, *thermoluminescent dosimeter*, and *track-etch dosimeter*.

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.

electron radiation
See *beta radiation*.

error
Difference between the correct, true, or conventionally accepted value and the measured or estimated value. Sometimes used to mean estimated uncertainty. See *accuracy* and *uncertainty*.

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

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

extremities
The arms from and including the elbow through the fingertips and the legs from and including the knee and patella through the toes.

fast neutron
Neutron with energy equal to or greater than 10 kiloelectron-volts. This type of neutron causes fission in some isotopes (e.g., ^{238}U, ^{239}Pu). See *intermediate neutron* and *slow neutron*.

favorable to claimants
In relation to dose reconstruction for probability of causation analysis, having the property of ensuring that there is no underestimation of potential dose. This often means the assumption of a value that indicates a higher dose than is likely to have actually occurred in the absence of more accurate information. See *probability of causation*.

film

In the context of external dosimetry, radiation-sensitive photographic film in a light-tight wrapping. See *film dosimeter*.

film dosimeter

Package of film for measurement of ionizing radiation exposure for personnel monitoring purposes. A film dosimeter can contain two or three films of different sensitivities, and it can contain one or more filters that shield parts of the film from certain types of radiation. When developed, the film has an image caused by radiation measurable with an optical densitometer. Also called film badge.

filter

Material used in a dosimeter to adjust radiation response to provide an improved tissue equivalent or dose response.

gamma radiation

Electromagnetic radiation (photons) of short wavelength and high energy (10 kiloelectron-volts to 9 megaelectron-volts) that originates in atomic nuclei and accompanies many nuclear reactions (e.g., fission, radioactive decay, and neutron capture). Gamma photons are identical to X-ray photons of high energy; the difference is that X-rays do not originate in the nucleus.

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. See *alpha radiation*, *beta radiation*, *gamma radiation*, *neutron radiation*, *photon radiation*, and *X-ray radiation*.

isotope

One of two or more atoms of a particular element that have the same number of protons (atomic number) but different numbers of neutrons in their nuclei (e.g., ^{234}U, ^{235}U, and ^{238}U). Isotopes have very nearly the same chemical properties.

kiloelectron-volt (keV)

Unit of particle energy equal to 1,000 (1×10^3) electron-volts.

luminescence

Emission of light from a material as a result of some excitation. See *thermoluminescence*.

limit of detection (LOD)

Minimum level at which a particular device can detect and quantify exposure or radiation. Also called lower limit of detection and detection limit or level. See *minimum detectable level*.

megaelectron-volt (MeV)

Unit of particle energy equal to 1 million (1×10^6) electron-volts.

monitoring

Periodic or continuous determination of the presence or amount of ionizing radiation or radioactive contamination in air, surface water, groundwater, soil, sediment, equipment surfaces, or personnel (for example, bioassay or alpha scans). In relation to personnel, monitoring includes internal and external dosimetry including interpretation of the measurements.

neutron (n)
Basic nucleic particle that is electrically neutral with mass slightly greater than that of a proton. There are neutrons in the nuclei of every atom heavier than normal hydrogen.

neutron film dosimeter
Film dosimeter with a nuclear track emulsion, type A, film packet.

neutron radiation
Radiation that consists of free neutrons unattached to other subatomic particles emitted from a decaying radionuclide. Neutron radiation can cause further fission in fissionable material such as the chain reactions in nuclear reactors, and nonradioactive nuclides can become radioactive by absorbing free neutrons. See *neutron*.

photon
Quantum of electromagnetic energy generally regarded as a discrete particle having zero rest mass, no electric charge, and an indefinitely long lifetime. The entire range of electromagnetic radiation that extends in frequency from 10^{23} cycles per second (hertz) to 0 hertz.

photon radiation
Electromagnetic radiation that consists of quanta of energy (photons) from radiofrequency waves to gamma rays.

probability of causation (POC)
For purposes of dose reconstruction for the Energy Employees Occupational Illness Compensation Program Act of 2000, the percent likelihood, at the 99th percentile, that a worker incurred a particular cancer from occupational exposure to radiation.

rad
Traditional unit for expressing absorbed radiation dose, which is the amount of energy from any type of ionizing radiation deposited in any medium. A dose of 1 rad is equivalent to the absorption of 100 ergs per gram (0.01 joules per kilogram) of absorbing tissue. The rad has been replaced by the gray in the International System of Units (100 rad = 1 gray). The word derives from <u>r</u>adiation <u>a</u>bsorbed <u>d</u>ose.

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.

radioisotopic thermoelectric generator (RTG)
Generator that obtains its power from passive (natural) radioactive decay using thermocouples to convert the heat of decay into electricity.

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.

roentgen

Unit of photon (gamma or X-ray) exposure for which the resultant ionization liberates a positive or negative charge equal to 2.58×10^{-4} coulombs per kilogram (or 1 electrostatic unit of electricity per cubic centimeter) of dry air at 0 degrees Celsius and standard atmospheric pressure. An exposure of 1 roentgen is approximately equivalent to an absorbed dose of 1 rad in soft tissue for higher energy photons (generally greater than 100 kiloelectron-volts).

scattering

Change in direction of radiation by refraction or reflection, often accompanied by a decrease in radiation due to absorption by the refracting or reflecting material.

shallow dose equivalent

Dose equivalent in units of rem or sievert at a depth of 0.07 millimeters (7 milligrams per square centimeter) in tissue equal to the sum of the penetrating and nonpenetrating doses.

shielding

Material or obstruction that absorbs ionizing radiation and tends to protect personnel or materials from its effects.

skin dose

See shallow dose equivalent.

thermal neutron

Neutron in thermal equilibrium with its surroundings having an average energy of 0.025 electron-volts.

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.

uncertainty

Standard deviation of the mean of a set of measurements. The standard error reduces to the standard deviation of the measurement when there is only one determination. See *accuracy* and *error*. Also called standard error.

whole-body 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. See *dose*.

X-ray

See *X-ray radiation*.

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.

ATTACHMENT A
EXAMPLES OF PINELLAS PLANT EXTERNAL DOSIMETRY RECORDS

LIST OF FIGURES

Attachment A provides examples of the Pinellas Plant's external dosimetry records that contain individual dosimeter results. These examples were obtained from EEOICPA claim records in the NOCTS database. All personal information in these examples has been blacked out. Note that some of the records formats used throughout the Pinellas Plant's history overlapped each other.

ATTACHMENT A
EXAMPLES OF PINELLAS PLANT EXTERNAL DOSIMETRY RECORDS (continued)

PERSONNEL EXPOSURE RECORD

Name [redacted]
Badge No. [redacted]
S. S. [redacted]

19 57

Accumulated Exposures

Month	mrad	mrem	mr	Total
January				
February				
March	<5.4 10.8	6.5	6.5	24
April	<5.2 10.4	6.5	6.5	23
May	<5.8 11.6	6.5	6.5	25
June	<2.2 4.4	6.5	6.5	17
July	<5.4 10.8	6.5	6.5	24
August	<1.9 3.8	6.5	6.5	17
September	8.2 16.4	6.5	6.5	29
October	<2.9 5.8	6.5	6.5	19
November	<2.0 4.0	6.5	6.5	17
December	<2.7 5.4	6.5	6.5	18

Total exposure at end of three months ______ mrem

Total exposure at end of six months ______ mrem

Total exposure at end of nine months ______ mrem

Total estimated exposure at end of twelve months 216 mrem

Figure A-1. Example of dosimetry records used during 1957–1959.

ATTACHMENT A
EXAMPLES OF PINELLAS PLANT EXTERNAL DOSIMETRY RECORDS (continued)

B

EXPOSURE RECORD

Period 1-61 to

Soc. Sec. No. [redacted]

Name [redacted]

No. [redacted]

MUL-334-R-1

Date	uc/1	mrem(B)	mr(F)	mrem(F)	Total	Date	uc/1	mrem(B)	mr(F)	mrem(F)	Total
1-3	0.10	<20			<20	DEC.			<5	17	17
2-2	0.04	<20			<20				<	17	17
		<			<						
3-2	0.20	<20			<20						
		<			<						
4-6	0.01	<20			<20						
		<			<						
5-4	0.04	<20			<20						
		<			<						
6-1	0.00	<20			<20						
		<			<						
7-7	<	<20			<20						
		<			<						
6-61			<5	<17	<22						
JUL			<5	<8	<13						
			<	<	<						
AUG.			<5	<8	<13						
			<	<	<						
SEPT.			<5	<14	<19						
			<	<	<						
OCT.			<5	<14	<19						
			<	<	<						
NOV.			<5	<8	<13						
			<	<	<						

Figure A-2. Example of dosimetry records used during 1959–1965.

G-211D GENERAL ELECTRIC CO. - PINELLAS PENINSULA PLANT 12 31

ANNUAL OCCUPATIONAL RADIATION EXPOSURE

EXPOSURE FOR CALENDAR YEAR 1969

[redacted] [redacted] [redacted]

FIRST DATE OF MONITOR PERIOD	X-RAY GAMMA REM	NEUTRON REM	TRITIUM REM	OTHERS REM	W B EXP PERIOD	TOT W B CUM PPP	TOT W B LIFE
01-69	.000	.000	.	.	.000	.053	.053
02-69	.000	.000	.	.	.000	.053	.053
03-69	.000	.000	.	.	.000	.053	.053
04-69	.000	.000	.	.	.000	.053	.053
05-69	.000	.000	.	.	.000	.053	.053
06-69	.000	.000	.	.	.000	.053	.053
07-69	.000	.000	.	.	.000	.053	.053
08-69	.000	.000	.	.	.000	.053	.053
09-69	.000	.000	.	.	.000	.053	.053
10-69	.000	.000	.	.	.000	.053	.053
11-69	.000	.000	.	.	.000	.053	.053
12-69	.000	.000	.	.	.000	.053	.053
TOTAL						.053	.053

Figure A-3. Example of dosimetry records used during 1964–1970.

ATTACHMENT A
EXAMPLES OF PINELLAS PLANT EXTERNAL DOSIMETRY RECORDS (continued)

FC-600(10-70)

PERSONNEL MONITORING RECORD

BADGE [redacted]

NAME [redacted]

S.S.No. [redacted]

SECTION ~~852~~ 652

ACCUMULATED WHOLE BODY (REM)

	1970	1971	1972
YEAR	.000	.000	.020
NDD	.053 .042	.053 .002	.073 .0
LIFE	.053	.055	.073

FILM BADGE

DATE	WHOLE BODY XRAY-GAMMA MR	WHOLE BODY NEUTRON MREM	EXTREMITY XRAY-GAMMA MR	EXTREMITY BETA MRAD	DATE	WHOLE BODY XRAY-GAMMA MR	WHOLE BODY NEUTRON MREM	EXTREMITY XRAY-GAMMA MR	EXTREMITY BETA MRAD
1/71	0	0			1/72	0	0		
2/71	0	0			2/72	0	0		
3/71	0	0			3/72	0	0		
4/71	0	0			4/72	0	0		
7/71	0	0			5/72	0	0		
8/71	0	0			6/72	0	0		
9/71	0	0			7/72	0	0		
10/71	0	0			8/72	0	0		
11/71	0	0			9/72	0	0		
12/71	0	0			10/72	0	20		
					11/72	0	0		
					12/72	0	0		

Figure A-4. Example of dosimetry records used during 1971–1980.

ATTACHMENT A
EXAMPLES OF PINELLAS PLANT EXTERNAL DOSIMETRY RECORDS (continued)

Badge No.	[redacted]	SS No.	[redacted]	Sex	PERSONNEL MONITORING RECORD NFC-1163
Name	[redacted]	Hire Date		M X	
Unit	982	Term Date		F	

041 G-1

Year 1984	WHOLE BODY N	G	T	Total YTD	EXTREMITY G	N	Total YTD	Year 1985	WHOLE BODY N	G	T	Total YTD	EXTREMITY G	N	Total YTD
JAN	m	m		m				JAN	m	m		m			
FEB	m	m		m				FEB	m	m		m			
MAR	m	m		m				MAR	m	m		m			
APR	m	m		m				APR	m	m		m			
MAY	m	m		m				MAY	m	m		m			
JUN	m	m		m				JUN	m	m		m			
JUL	m	m		m				JUL	m	m		m			
AUG	m	m		m				AUG	m	m		m			
SEP	m	m		m				SEP	m	m		m			
OCT	m	m		m				OCT	m	m		m			
NOV	m	m		m				NOV	m	m		m			
DEC	m	m		m				DEC	m	m		m			
TOTAL	m	m		m				TOTAL	m	m		m			

262	NDD TOTAL	262	NDD TOTAL	262
262	LIFETIME TOTAL	262	LIFETIME TOTAL	262

Neutron Exposure (N)	Tritium RBE = 1.0
X ray or Gamma Exposure (G)	Tritium Infinite Dose (0.422)(T_B)(μCi/ℓ)
Tritium Deposition Exposure (T)	T_B for Standard man = 12
Neutron Quality Factor 10	NOTE: All Exposures Are Recorded in Mrem

Figure A-5. Example of dosimetry records used during 1980–1987.

NAME: [redacted] [redacted] [redacted] BADGE#: [redacted]

EXTERNAL DOSIMETRY DATA (IN MREM)

NEUT	EXTREM	GAMMA	SHALLOW	SM	SD	SY	EM	ED	EY
0		0	0	1	1	88	1	31	88
0		0	0	2	1	88	2	29	88
0		0	0	3	1	88	3	31	88
0		0	0	5	1	88	5	31	88
0		0	0	6	1	88	6	30	88

INTERNAL DOSIMETRY DATA

START DATE	END DATE	LEVEL	DOSE (MREM)

1988 DOSE EQUIVALENT:	0 MREM
GE LIFETIME DE:	262 MREM
TOTAL LIFETIME DE:	262 MREM

Figure A-6. Example of dosimetry records used during 1988–1997.

ATTACHMENT B
BASIS FOR UNMONITORED EXTERNAL DOSE ASSIGNMENT

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ATTACHMENT B
BASIS FOR UNMONITORED EXTERNAL DOSE ASSIGNMENT (continued)

B.1 BACKGROUND

Based on an evaluation of the available dosimetry records for the Pinellas Plant, personnel who had any potential to receive significant external dose were likely monitored. In addition, the majority of the work performed at the Pinellas Plant was nonradiological, which explains why a significant number of the employees were not monitored. However, there was the potential to receive incidental external doses that were small (i.e., < 20 mrem/yr) but were much more significant than the highest onsite ambient doses for the plant [i.e., >> 3.66×10^{-13} mrem/yr, from the Plant's environmental dose TBD (ORAUT 2011c)]. One of the most common types of incidental radiation exposures was attributable to Plant tours, which included visits to the neutron generator testing areas. Based on information provided in the claimant telephone interviews, personnel on these tours were allowed to witness the neutron generators being tested without being provided with dosimetry. Pinellas Plant health physics records indicate that doses at the 3-ft exclusion boundary for the neutron generator tests were 9.9 mrem per test (Weaver 1996). Assuming that personnel on a Plant tour would not have likely stayed in the neutron generator testing area for more than two tests, these exposed personnel might have received an incidental dose of almost 20 mrem.

Because the incidental doses at the Pinellas Plant were likely much larger than the onsite ambient doses, it is not appropriate to assign onsite ambient doses to all unmonitored workers unless it can be established that there was no potential for incidental dose due to an employee's job. Because a determination that incidental doses were not received can rarely be defended, unmonitored external doses should be assigned for all workers in lieu of the onsite ambient doses for the Plant.

B.2 BASIS FOR UPPER-95TH PERCENTILE DOSE

A review of the available dosimetry data for the Pinellas Plant indicates that on average 95% of the monitored workers at the plant received annual doses ≤100 mrem. This determination is based on an evaluation of whole-body dose information that was available in the following documents: GE 1956–1980, 1957–1990, 1975; Greene 1985b, 1986; Holliday 1977, 1979, 1981, 1983; LMSC 1996; Schumacher 1982, 1983, 1984; and Weaver 1994b.

Whole-body dose information was used for the evaluation because it was the only form of data that was consistently available throughout the years the Pinellas Plant operated. Unfortunately, the Pinellas Plant's reported whole-body doses consist of external photon, external neutron, and internal tritium doses, and the contribution attributable to each of these components cannot be determined for most years. In addition, the doses evaluated represent population doses that do not account for potential missed doses. Table B-1 provides summarized results of the dosimetry data that were evaluated. The average percentage of annual whole-body doses below 100 mrem was 94.7% (95% when rounded to the nearest percent), for the years that were evaluated. However, for a select number of years, more detailed dose information was provided, and it was determined that a significant number of the annual whole-body doses were either entirely or mostly attributable to tritium dose. This is consistent with the types of operations performed at the Pinellas Plant. Therefore, the upper-95th-percentile external dose for monitored workers is likely to be less than 100 mrem/yr.

ATTACHMENT B
BASIS FOR UNMONITORED EXTERNAL DOSE ASSIGNMENT (continued)

Table B-1. Evaluation of Pinellas Plant doses available in the SRDB.

Year	Total number of annual doses checked	Number of annual doses ≥100 mrem	Percentage of annual doses below 100 mrem	Number of annual doses ≤20 mrem	Percentage of annual doses ≤20 mrem
1957	71	12	83.1	38	53.5
1958	142	4	97.2	102	71.8
1959	205	43	79.0	114	55.6
1960	232	40	82.8	147	63.4
1961	265	39	85.3	168	63.4
1962	259	36	86.1	159	61.4
1963	258	20	92.2	197	76.4
1964	292	13	95.5	212	72.6
1965	280	37	86.8	233	83.2
1966	320	17	94.7	277	86.6
1967	351	8	97.7	328	93.4
1968	355	3	99.2	340	95.8
1969	344	9	97.4	326	94.8
1970	293	9	96.9	258	88.1
1971	282	6	97.9	261	92.6
1972	292	7	97.6	267	91.4
1973	280	10	96.4	254	90.7
1974	303	8	97.4	265	87.5
1975	276	2	99.3	246	89.1
1976	255	5	98.0	195	76.5
1977	246	27	89.0	159	64.6
1978	262	20	92.4	176	67.2
1979	313	17	94.6	244	78.0
1980	383	23	94.0	249	65.0
1981	388	18	95.4	324	83.5
1982	418	4	99.0	286	68.4
1983	396	11	97.2	263	66.4
1984	428	13	97.0	296	69.2
1985	395	15	96.2	253	64.1
1986	322	Not applicable	Not applicable	Not applicable	Not applicable
1987	248	Not applicable	Not applicable	Not applicable	Not applicable
1988	263	4	98.5	245	93.2
1989	285	5	98.2	270	94.7
1990	284	4	98.6	258	90.8
1991	288	1	99.7	274	95.1
1992	280	0	100.0	275	98.2
1993	245	0	100.0	242	98.8
1994	NA	Not applicable	Not applicable	Not applicable	Not applicable
1995	215	0	100.0	Not applicable	Not applicable
1996	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
1997	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
1998	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Averages	Not applicable	Not applicable	**94.7**	Not applicable	**79.6**

ATTACHMENT B
BASIS FOR UNMONITORED EXTERNAL DOSE ASSIGNMENT (continued)

Upon review of the dosimetry data in the referenced documents listed above and in Table 6-1 of this document, many discrepancies regarding the numbers of individuals monitored were noted. Therefore, it is not recommended that the 95th-percentile doses for individual years be tabulated unless a better data set is located. By averaging the data over several years, the potential for incurring a significant error for a given year would be minimized. In addition, including the dose contribution attributable to tritium helps to compensate for any potential errors and helps to ensure that the 95th-percentile dose is favorable to claimants. Because the majority (>79% each year on average) of the annual whole-body doses reported for Pinellas Plant workers were ≤20 mrem, which is an individual dosimeter's limit of detection for some of the dosimeters used at the Plant, it appears that the Plant monitored workers if they had any potential to receive dose. As a result, it is unlikely that any unmonitored workers would have received doses approaching the upper-95th percentile doses. Therefore, it is very unlikely that any errors in the 95th-percentile dose calculation attributable to these discrepancies would result in an underestimate of an individual's actual unmonitored dose.

B.3 COMPARISON OF MAXIMUM LIKELIHOOD DOSES TO UNMONITORED DOSE ASSIGNMENT

Area dosimeter results with their placement locations identified in relation to the external radiation source terms are very limited. However, detailed area dosimeter results were available for the period from 1984 through June 1986 in GE (1984–1986).

The area dosimeter results available for Areas 128, 131, and 183 were evaluated. These areas represent photon and neutron exposure areas, which are in the neutron generator operational areas of the Plant. Area 131 was the final testing area of the neutron generators. Area 128 was represented by dosimeter locations 9000, 9001, 9003, 9004, 9008, and 9019. Area 131 was represented by dosimeter locations 9026 and 9038. Area 183 was represented by dosimeter location 9020. All of these dosimeter locations were reported as being within 24 to 65 in. of the closest radiation source. For the period from 1984 through June 1986, only a single photon dosimeter result above the dosimeter's LOD was reported and only two neutron dosimeter results at two different locations were reported as being above the dosimeter's LOD.

Based on the area dosimeter data that were evaluated, the worst-case annual photon dose is 20 mrem plus 11 dosimeters worth of missed dose, and the worst-case annual neutron dose is 40 mrem plus 11 dosimeters worth of missed dose. Because area dosimeter results correspond to a 8,760-hour year versus a 2,500-hour work-year, the worst-case annual doses needed to be adjusted by a maximized occupancy factor of 0.2854 (2,500/8,760). For the photon and neutron dosimeters used during this period, no other dose adjustments were needed as indicated in Section 6.3. For 1984–1986, the LOD/2 values for the applicable photon and neutron dosimeters were 5 mrem and 10 mrem per dosimeter exchange, respectively. Based on those values, the maximum likely external dose to an unmonitored worker would be <64 mrem/yr (21 mrem/yr from photons and 43 mrem/yr from neutrons). Because it is unlikely that a Pinellas Plant worker would have spent 100% of their time within 65 in. of a radiation source without being monitored, this is likely a significant overestimate of an unmonitored worker's potential external dose.

The potential doses to workers in the RTG areas of Building 400 are potentially much higher than 64 mrem/yr. However, because all types of plutonium are considered to be special nuclear material, access to the RTG areas was more strictly limited. Because Pinellas Plant personnel having work assignments in radiation areas were required to wear dosimeters per General Operating Procedures (Greene 1985b; GE 1982), and because access to the RTG areas would have been controlled for security purposes, it is much less likely that personnel would have been able to receive significant

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unmonitored doses in the RTG areas. Therefore, the potential doses for unmonitored workers in the RTG areas were also likely less than 64 mrem/yr.

B.4 INAPPLICABILITY OF ORAUT-OTIB-0020

Because an unmonitored worker's potential to receive external dose at the Pinellas Plant was significantly less than the dosimetry program's ability to detect doses that low, the unmonitored dose approach described in ORAUT-OTIB-0020, *Use of Coworker Dosimetry Data for External Dose Assessment* (ORAUT 2011d), which uses only coworker data, can result in an unreasonable overestimate of an unmonitored Pinellas Plant worker's external doses. This determination is supported by an analysis of the available area dosimeter results, which have a longer effective monitoring period per dosimeter exchange, and the fact that on average >79% of the annual whole-body doses reported for Plant workers were ≤20 mrem.

The ORAUT-OTIB-0020 approach requires the LOD/2 approach for accounting for the coworker's potential missed doses, which is favorable to claimants (ORAUT 2011d). Based on the maximum likelihood doses above, the ORAUT-OTIB-0020 approach results in an unreasonably excessive unmonitored dose estimate for unmonitored Pinellas Plant workers. Because of this and because the 95th-percentile dose is already greater than the maximum likelihood dose, the potential missed doses were not factored into the unmonitored dose assignment for the Pinellas Plant. Another alternative would be to use the maximum likelihood dose of 64 mrem/yr as the unmonitored dose assignment. However, a decision was made to use the higher unmonitored dose assignment of 100 mrem/yr to ensure that the worker's external doses are not underestimated.

B.5 ASSIGNING UNMONITORED DOSES AS PHOTON VERSUS NEUTRON

Because the unmonitored external dose assignment includes both photon and neutron dose components and because the proportions of those dose components are unknown and highly variable, an evaluation was performed to determine which of the applicable radiation types and energy groups to assign the unmonitored doses as.

The only photon energy distribution that is used for the external doses for Pinellas Plant workers is 100% 30-250 keV photons, which is also the most favorable-to-claimant photon energy distribution. Therefore, only 30-250 keV photons were evaluated for the potential unmonitored dose assignment.

Based on the information in the main body of this document, there are only two neutron energy distributions for the various areas at the Pinellas Plant. For the neutron generators areas at the Plant, the neutron energy distribution was 100% 2-20 MeV neutrons. For the RTG areas in Building 400, the neutron energy distribution was 50% 0.1-2 MeV and 50% 2-20 MeV neutrons. Given that it was unlikely that a worker would have been able to spend any significant time in the presence of the PuO_2 sources in the RTG areas without having to wear a dosimeter, the predominant neutron energies that unmonitored workers at the Plant were likely exposed to were 2-20 MeV neutrons. Therefore, only 2-20 MeV neutrons were evaluated for the potential unmonitored dose assignment.

The unmonitored dose assignment of 100 mrem/yr was assigned as photon dose and then neutron dose to compare the POC results using each of the IREP cancer models. Because ORAUT-OTIB-0005, *Internal Dosimetry Organ, External Dosimetry Organ, and IREP Model Selection by ICD-9 Code* (ORAUT 2012b), indicates that there could be multiple external organ dose selections for a given IREP cancer model, this evaluation was performed using only the external organ dose selection that resulted in the highest dose (i.e., the selection with the highest organ dose conversion factor) for a

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given IREP cancer model selection. Each IREP cancer model was evaluated using the following hypothetical scenario assumptions:

1. The hypothetical worker was a male, with the exception of cancer models that are only applicable to females.

2. The worker was 18 years old at the time of the first exposure. Therefore, a year of birth of 1939 and a first year of employment date of 1957 were selected.

3. The worker was assumed to be employed and unmonitored for 5 years (i.e., during all of 1957 through 1961).

4. Only an unmonitored dose of 100 mrem was assigned for each year of employment.

5. The date of diagnosis was set at 12 years after the last year of employment (i.e., 1973).

Because the unmonitored dose assignment represents a population dose, no uncertainty correction factors were applied to the unmonitored dose assignment. As indicated in the main body of this document, no dosimeter correction factors need to be applied to the photon doses. Even though the main body of this document indicates that dosimeter corrections factors would be applied to the reported neutron doses for most years, no dosimeter correction factors were applied when the unmonitored doses were evaluated as neutron doses. The basis for this is that the unmonitored dose assignment is essentially an arbitrary value that has been determined to be more favorable to claimants than the maximum likelihood dose for the Pinellas Plant, and the evaluation of the maximum likelihood dose for the Plant utilized neutron dosimeter data that did not require any adjustments, as indicated in Section 6.3. In addition, the ICRP Publication 60 correction factor for 2-20 MeV neutron doses is 1.00 for the Plant, so this correction factor had no impact on the neutron doses being evaluated (ICRP 1991).

The results of this evaluation are summarized in Table B-2 below. With the only exceptions being the acute myeloid leukemia, chronic myeloid leukemia, and leukemia (less chronic lymphocytic leukemia) IREP cancer models, the assignment of the unmonitored doses as 100% 30-250 keV photons provides a more favorable-to-claimant POC. At the time of this document’s preparation, it was determined that out of 393 Pinellas Plant claims, which excludes pulled claims, there are only 5 leukemia claims that are affected by the photon-versus-neutron unmonitored dose issue. However, because the unmonitored workers at any site only need to be assigned 50th-percentile coworker doses and because the unmonitored external dose assignment is greater than the maximum likelihood dose, assigning an unmonitored external dose of 100 mrem/yr as only photon dose is still considered to be favorable to claimants for the leukemia cases based on the results of this evaluation.

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Table B-2. Evaluation of POCs associated with assigning unmonitored doses as either photon or neutron dose.

Applicable cancer models	Worst-case external dose organ selection	Photon dose POC (%)	Neutron dose POC (%)
Acute lymphocytic leukemia	Red bone marrow	17.89	11.01
Acute myeloid leukemia	Red bone marrow	10.59	11.83
All digestive	Stomach	4.34	2.56
All male genitalia	Testes	3.57	2.21
Bladder	Bladder	4.68	3.52
Bone	Bone surfaces	4.98	3.38
Breast	Breast (female)	7.58	4.04
Chronic myeloid leukemia	Red bone marrow	12.63	12.71
Colon	Colon	5.33	3.96
Connective tissue	Thyroid	5.36	3.45
Esophagus	Esophagus	4.95	3.99
Eye	Eye	4.72	3.08
Female genitalia (less ovary)	Bladder	0.04	0.03
Gallbladder	Bladder	11.66	6.65
Leukemia (less CLL)	Red bone marrow	15.69	18.34
Liver	Liver	17.14	10.61
Lung	Thyroid	5.72	3.03
Lymphoma and multiple myeloma	Thyroid	3.43	1.77
Malignant melanoma	Skin	10.09	7.63
Nervous system	Thyroid	2.41	1.45
Non-melanoma - basal cell carcinoma	Skin	10.20	7.82
Non-melanoma - squamous cell carcinoma	Skin	0.33	0.15
Oral cavity and pharynx	Thyroid	2.59	1.54
Other and ill-defined sites	Thyroid	5.19	3.13
Other endocrine	Thyroid	6.30	4.00
Other respiratory	Thyroid	2.26	1.05
Ovary	Bladder	5.42	3.84
Pancreas	Stomach	2.47	1.60
Rectum	Colon	1.70	1.17
Stomach	Stomach	7.95	4.81
Thyroid	Thyroid	16.08	7.10
Urinary organs (less bladder)	Testes	6.24	4.24