Document Title:	
Pinellas Plant – Occupational External Dose	Document Number: ORAUT-TKBS-0029-6 Revision: 00 Effective Date: 09/15/2005 Type of Document: TBD Supersedes: None

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Approval: Signature on File — James W. Neton, Associate Director for Science — Approval Date: 09/15/2005

☒ New ☐ Total Rewrite ☐ Revision ☐ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
01/07/2005	00-A	New Technical Basis Document for Pinellas – Site External Dose. Initiated by Mark D. Notich.
06/20/2005	00-B	Incorporates Task 5 review comments. Initiated by Mark D. Notich.
08/15/2005	00-C	Incorporates OCAS review comments. Initiated by Mark D. Notich.
08/22/2005	00-D	Incorporates additional OCAS review comments. Initiated by Mark D. Notich.
09/07/2005	00-E	Incorporates further OCAS review comments and adds Paul Demopoulos to list of subject experts. Initiated by Mark D. Notich.
09/15/2005	00	First approved issue. Training required: As determined by the Task Manager. Initiated by Mark D. Notich.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
DOELAP	U.S. Department of Energy's Laboratory Accreditation Program
EEOICPA	*Energy Employees Occupational Illness Compensation Program Act* of 2000
GEND	General Electric Aerospace, Neutron Devices
HSR	General Electric Health and Safety Record system
MDL	Minimum Detection Level
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH Office of Compensation Analysis and Support (OCAS) Claims Tracking System
NTA	nuclear emulsion type A film neutron dosimeter
OCAS	NIOSH Office of Compensation Analysis and Support
QA	Quality Assurance
RBE	relative biological effectiveness
RGD	radiation generating device
RTG	radioisotopic thermoelectric generator
TBD	technical basis document
TLD	thermoluminescent dosimeter
U.S.C.	United States Code
XRE	X-ray emission units
XRD	X-ray diffraction units

6.1 INTRODUCTION

Technical Basis Documents (TBDs) and Site Profile Documents are general working documents that provide guidance concerning the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist the National Institute for Occupational Safety and Health (NIOSH) in the completion of the individual work required for each dose reconstruction.

EEOICPA defines a DOE facility as “any building, structure, or premise, including the grounds upon which such building, structure, or premise is located…in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations…pertaining to the Naval Nuclear Propulsion Program).” 42 U.S.C. § 7384*l*(12). Accordingly, except for exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

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

As noted above, the statute includes a definition of a DOE facility that excludes “buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program.” 42 U.S.C. § 7384(12). While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer (i.e., 42 U.S.C. § 7384n(b), entitled “Exposure in the Performance of Duty”) does not contain such an exclusion. Therefore, the statute requires NIOSH to include all radiation exposures in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction.

This Site Profile provides specific information concerning documentation of historical practices at the Pinellas Plant.

General Electric Aerospace, Neutron Devices (GEND) operated the Pinellas Plant for the U.S. Department of Energy (DOE) from its initial startup in January 1957 until 1992, when Lockheed Martin Specialty Components, Inc. took over until nuclear operations ended in 1994; some clean-up operations occurred until the plant closure in 1997. The Plant was built to manufacture neutron generators, a principal component in nuclear weapons. The neutron generators consisted of a miniaturized linear ion accelerator assembled with pulsed electric power supplies. The ion accelerator, or neutron tube, required ultra-clean, 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 operations. It later manufactured other products including neutron detectors, radioisotopic thermoelectric generators (RTGs), high-vacuum switch tubes, specialty capacitors, and specialty batteries (DOE 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 (DOE 1996).

6.1.1 Sources of Radiation

The manufacture of Pinellas Plant products required the use of radioisotopes. These included tritium, depleted uranium, ^{85}Kr, ^{238}Pu, and ^{239}Pu. In addition, the Plant used various analytical devices and calibration sources as part of the production process or for radiation detection device maintenance and calibration.

The Pinellas Plant stored tritium gas in beds of depleted uranium metal. The uranium and tritium joined to form uranium tritide, which permits the storage of large quantities of ultra-pure tritium in a small volume. A search of Plant records indicated that, from the start of operations in 1957 until November 1993, the total amount of tritium received was 234.1 g (8.3 oz), or 8.14×10^{16} Bq (2.2 million Ci). The total amount of tritium shipped as product, waste, or material returned to DOE was 164.6 g (5.8 oz), or 5.92×10^{16} Bq (1.6 million Ci). The amount calculated to have decayed away was 58.4 g (2 oz), or 2.22×10^{16} Bq (0.6 million Ci), and the amount released into wastewater or air was 11.1 g (0.4 oz), or 3.7×10^{15} Bq (0.1 million Ci) (GEND 1993). The majority of the atmospheric releases of tritium were through the four exhaust stacks on Buildings 100, 200, and 800. Tritium is primarily a source of internal exposure through inhalation and ingestion, but not of external exposure because it is a low-energy beta emitter that is readily absorbed in the dead layer of the skin.

Depleted uranium metal in sealed containers stored tritium at normal pressure and temperature. Heating can decompose the tritium bonds in uranium tritide to release ultra-pure tritium while the remaining depleted uranium metal is ready for fast and reversible uptake of tritium at lower temperatures. The depleted uranium metal was fully contained in the tritium storage vessel. The storage vessels should not have been a source of external beta exposure.

Krypton-85, a beta and gamma emitter, was used in two leak detection units as part of the Pinellas Quality Control Program. The leak detection units 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 is a whole-body emitter with the possibility of a skin dose from beta radiation.

Small sealed sources of plutonium produced by Los Alamos National Laboratories were shipped to the Pinellas Plant for use in the RTGs. Each sealed source contained approximately 80% ^{238}Pu and 20% ^{239}Pu. The plutonium sources were enclosed in a triple metal encapsulation. These units were never opened. The capsules were inserted as heat sources for the RTGs (DOE 1983, pp. 2-11). The first recorded receipt of plutonium was on January 18, 1957, when the Plant received a 7-g (4.44×10^{12}-Bq or 120-Ci) ^{238}Pu source to calibrate Health Physics monitoring equipment. Seven plutonium heat sources, totaling 54.4 g (3.515×10^{12} Bq or 950 Ci) of ^{238}Pu, arrived at Pinellas from Sandia National Laboratories on November 4, 1975. About 50 RTG generators were produced every month (Burkhart 1987a, p4). The last on-site plutonium, with the exception of calibration check sources, was removed from the Plant in February 1991 (GEND 1993).

Sources of ionizing radiation at the Pinellas Plant included other low-activity radioactive sources, such as those used to check or calibrate radiation detectors (i.e., calibration sources) and analytical devices employing radioactive byproduct material or X-rays produced by a radiation generating device

(RGD). The calibration sources were maintained in the Health Physics Laboratory in Area 113 of Building 100. While the exact inventory of radioactive sources varied over time, most were sealed microcurie check sources of radioactive isotopes such as ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{60}Co, ^{14}C, and ^{90}Sr.

These low-activity radioactive sources could have included alpha, beta, photon, and neutron emitters. For example, small quantities of ^{14}C-labeled solvents were used in a laboratory testing operation. The largest ^{14}C source was a 2.59×10^{7}-Bq (700-μCi) source used for liquid scintillation counting calibration. Radiation doses from ^{14}C result from internal deposition (DOE 1983). The analytical devices could have used radioactive byproduct material such as ^{85}Kr, ^{109}Cd, or ^{241}Am that requires U.S. Nuclear Regulatory Commission certification. Analytical devices with an RGD would have appropriate radiation shielding to comply with performance regulations of the U.S. Food and Drug Administration as specified in 21 C.F.R. §§ 1020.30, 1020.31, and 1020.40 (FDA 2004) along with Occupational Safety and Health Administration occupational exposure regulation 29 C.F.R. § 1910.1096 (DOL 2003). (Note: The current regulations might have changed in surface radiation levels since 1957.) However, there were recorded incidents at Pinellas involving these types of devices. A listing of unusual events and incidents is included in Table 2-4 of the facilities and processes section.

Table 6-1 lists the X-ray generating equipment and its locations on the Pinellas Plant site. All analytical devices used at the Plant were of the types and source strengths typically used by mainstream industrial or process-related users.

Table 6-1. X-ray producing equipment.

Location	Quantity	Type	ID Number
107	2	X-ray emission (XRE) units	CCN87103, CCN99591
114	2	Industrial X-ray units	MN87904, MN87851
114	1	Faxitron X-Ray Corporation	MN87243
114	1	TFI X-ray television	None found
127	1	Inspector unit	None found
138	1	Electron beam welder	MN62183
161B	2	X-ray diffraction (XRD) units	MN86640, MN86641
161B	1	Micro XRD unit	MN86747
161B	1	Electron microprobe	MN86607
161B	1	Energy dispersive analyzer	MN86475A
162	2	Scanning Electron Microscope (SEM)	MN94109, MN94225
162	1	Transmission Electron Microscope	MN94168
163	1	X-ray thickness gauge	MN550042
164	1	Cabinet X-ray unit	CCN91407
175	1	XRD unit	CN87952
176	1	XRE unit	None found
192B	1	Sedigraph	MN94285
193N	1	SEM	MN91992
194E	1	Picker (cabinet X-ray unit)	MN87042
300	2	Electron beam welder	MN61660, MN76803
300	1	Phillips (cabinet X-ray unit)	MN87810
300	2	Faxitron X-Ray Corporation	MN088001, MN099915
400	2	Electron beam welder	MN61346, None found
400	1	Cabinet X-ray unit	MN63294
Warehouse	1	X-Ray television	None found

Source: GEND 1987, GEND 1986

An ion accelerator facility that was used to test various components generated photons (up to 200 KeV) and neutron (likely 2.5 or 14 MeV) radiation (located in building 800). Commercial neutron generators producing neutron energies of 2.5 or 14 MeV neutrons were also used to calibrate or perform QA checks of various components mostly located in building 100.

6.1.2 Occupational Dosimetry Program Overview

The Pinellas Plant started an external dosimetry program in 1957 to monitor individual employees working in neutron generator production areas. Table 6-2 lists the total number of Pinellas employees and the number of employees monitored for radiation exposure for years with available data. 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 dosimetry (377 of an average yearly labor force of 1,372). During the 1980s, while the data are not completely available, from 370 to approximately 400 of 1,650 to 1,975 workers (approximately 20%) were monitored for radiation dose. No documentation was found to show that all employees were monitored at some time during Pinellas operations. For the majority of Pinellas operations, external dosimetry was exchanged and analyzed monthly. Beginning in January 1990, external dosimetry was exchanged and analyzed quarterly (Burkhart 1988, GEND 1990a).

Table 6-2. Personnel radiation dosimetry from AEC annual reports.[a]

Year	Number of PAO-AEC (or DOE) and GEND employees	Number of monitored employees	Number of employees in a given dose range	
			< 1 rem	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	1,397	281	281	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	NA[b]	NA	NA	NA
1975	NA	NA	NA	NA
1976	NA	317	317	0
1977	NA	300	300	0
1978	NA	297	297	0
1979	NA	334	334	0
1980	NA	376	376	0
1981	NA	389	389	0
1982	NA	408	408	0

a. Source: Data from Form AEC-190.
b. NA – not available.

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 from dosimeters was recorded at the time of measurement, reviewed by Pinellas health physicists, and routinely made available to workers. *External Dose Reconstruction Implementation Guidelines* (NIOSH 2002) 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.

A basis of comparison for dose reconstruction is the Personal Dose Equivalent, Hp(d), where d identifies the depth (in millimeters) and represents the point of reference for dose in tissue. For weakly penetrating radiation of significance to skin dose, d = 0.07 mm and is noted as Hp(0.07). For penetrating radiation of significance to whole-body dose, d = 10 mm and is noted as Hp(10).

6.2 DOSE RECONSTRUCTION PARAMETERS

6.2.1 Historical Administrative Practices

Between 1957 and 1974, GEND-Health Physics conducted radiation dosimetry management and analysis through in-plant processing of X-ray and neutron-sensitive photographic films (Burkhart 1987b). In 1974, GEND contracted with R. S. Landauer Jr. & Co. (Landauer) to be the principal supplier and processor of the dosimetry that GEND used. This arrangement continued until Pinellas Plant operations ended.

The available information indicates that, from the start of nuclear operations in 1957, the Pinellas Plant used film badge dosimetry available from or similar to the type sold by Nuclear-Chicago for the designated radiation control areas (GEND 2004a). Beginning in 1974, the Plant began using dosimetry provided exclusively by Landauer. The original Landauer dosimetry was based on film badge technology (Ward 1974). 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). By the 1980s, GEND was using Landauer Model E1, G1, G5, and U3 badge dosimetry.

From October 1979 to October 1987, the Plant used albedo dosimeters from Mound Laboratories for evaluating exposures to $^{238}PuO_2$ 2-MeV average neutrons and gammas during handling of RTG units at 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 U.S. Department of Energy's 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 dosimetry program at the Pinellas Plant.

There is no consistent documentation on how GEND processed dosimetry for the first 18 years of operation. Individual accounts indicate that the Pinellas Plant could have processed dosimetry during this time. Beginning in 1974, Landauer processed the dosimetry and provided exposure reports to GEND for review after badge processing (Figure 6-1 is a replication of portion of a report (Landauer 1987). Information in the Landauer reports included personnel data (identification number, name, and social security number), 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 Pinellas). The exposure information was entered in each person's exposure history by hand or in a Pinellas-based computer system and the General Electric Health and Safety Record (HSR) system on ionizing radiation (Richards 1986). Attachment A contains examples of the handwritten and computer records for 1960 to 1988. The forms used in 1960 were also used before 1960 and the forms used in 1988 were used until Pinellas ceased operations.

Table 6-3. Pinellas Plant historical dosimetry events.

Date	Event	Reference
April 1957	New employee orientation in radiation safety offered.	GEND 1990a

October 1957	Measured neutron dose rates at all test positions.	GEND 1990a
November 1957	Measured neutron doses of neutron generators at 10 mrem/pulse at 1 in.	GEND 1990a
December 1957	Sandia National Laboratories-Albuquerque asked to provide film badges.	GEND 1990a
January 1960	Full-time Health Physics representative assigned to Area 108.	GEND 1990a
November 1963	Began use of wrist badges in place of ring badges for limited number of employees.	GEND 1990a
February 1965	Memorandum comparing performance of two types of neutron badges and two types of gamma badges.	Szedziewski 1965
Late 1969	Film badge fading study.	GEND 1969
January 1973	Memorandum on dose rate for stress test facility.	Holliday 1973
Third Quarter 1974	Began using Landauer for source of film badges.	GEND 1990a
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.	
October 1986	Memorandum on estimated doses to GEND personnel handling unmarked neutron generator units.	Burkhart 1986
October 1987	End use of Mound neutron dosimeters.	
October 1988	Memorandum on radiation dose rates from RTG heat sources.	GEND 1988
April 1990	Changed from Landauer film badges to TLD dosimetry.	
1971 – 1993	Various determinations for doses from testing of sealed neutron generators.	GEND 1996
September 1994	Nuclear product development and testing end. Other Radiation related work did continue.	

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 (GENDa 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. Analysis of the available claimant records found no documentation that this reporting requirement was ever exceeded during the time Landauer provided dosimetry services to the Plant (1974 to 1994).

GENERAL ELECTRIC COMPANY
NEUTRON DEVICES DEPT
ENVIRONMENTAL HLTH
7887 BRYAN DAIRY RD
LARGO FL 33543

ACCOUNT NO. 70463

Participant ID number	Name	Social security number	Note (see reverse side)	Dosimeter type	Use	Radiation quality	Exposure to badge (millirems) for period(s) indicated below		Cumulative totals (millirems) Calendar quarter		Cumulative totals (millirems) Year to date		Cumulative totals (millirems) Permanent		Adjustments	Sex	Birth date			Number badge reports		Inception date	
							Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow			MO	DA	YR	To date	Qtr	MO	YR
[PIR]	AREA MONITOR 183			E	1		M	M	M	M	M	M	M	M						11	1	11	
[PIR]	[PIR]	[PIR]		U	3			M		M		M		M						24	2	11	84
[PIR]	CONTROL			G	1		M	M	M	M	M	M	260	260						295	5	6	74
[PIR]	TLD CONTROL							M		M		M		M						101	3	2	79
[PIR]	LOAN			U	3			M		M		M		220						96	3	2	79
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	M	M						7	5	9	86
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	100	100		M				256	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	250	250		M				256	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	110	110		F				256	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	10	10						23	3	11	84
[PIR]	[PIR]	[PIR]		G	5			M		M		M		M						23	3	2	85
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	240	240		M				256	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	30	30	250	250		M				255	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	40	40	90	90		M				256	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	90	90		M				256	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	200	100		M				256	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	170	170		M				257	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	M	M	180	180		M				258	5	6	74
[PIR]	[PIR]	[PIR]		G	1		M	M	M	M	40	40	140	140		M				254	5	6	74

PIR = privacy information removed.

Figure 6-1. Regenerated example of a Landauer dosimetry report from the 1970s.

6.2.1.1 Performance Testing

Neutron Studies

Eastman Kodak nuclear emulsion type A (NTA) film was used for neutron measurements and should be similar to the Landauer NTA dosimetry used at Pinellas after 1974 for the Type J badge (GEND 1969, Koperski 2004). As stated in the Hanford, INEEL, and Nevada Test Site Occupational External Dose TBDs, NTA was basically the only common dosimeter method available to measure neutron dose in AEC facilities prior to 1978. Results reported at the first AEC Neutron Dosimetry Workshop in 1969 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 et al. 1969). The neutron spectra at Pinellas were known to be dominated by 14-MeV deuterium-tritium fusion neutrons due to the unique design of the neutron generators. Lower energy fusion neutrons from deuterium-deuterium reactions of 2.5 MeV were also likely to occur. In addition, the method(s) used to calibrate the NTA film (Landauer or other dosimetry supplier) is not known. Typically, the dominant neutron exposure from nuclear weapon components at GEND was readily and reliably measured with NTA film dosimeters. For neutrons from RTG production, Pinellas initially continued with NTA film but changed to polycarbonate dosimeters in 1978; Mound albedo dosimeters were used in the 1980s.

Specific Pinellas Plant Studies

The NTA film badge neutron dosimeters used from 1957 through 1977 underwent track fading during use, causing a loss of information (Holliday 1978). At least for a period, the neutron dosimeters were made of Kodak Type A film (GEND 1969). GEND established a factor of 3 to correct for track fading beginning in January 1970, based on a track fading study (GEND 1969). 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/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 (GEND 1969). The Landauer polycarbonate badge that replaced these badges in 1978 did not undergo track fading, so no correction factor was applied after 1978 (Holliday 1978). The Landauer I8 Neutrak TLD was limited with sensitivity to RTG neutrons, calculated to be 67% of the true dose by GEND health physics personnel.

6.2.1.2 Reports

An as-low-as-reasonably-achievable (ALARA) Program report discussing occupational exposures was submitted to the manager of the Environmental Health and Safety Program. Attachment A contains examples of the reports kept by the Environmental Health and Safety Program and its radiation protection program from 1960 to 1988 for one claimant.

6.2.2 <u>Dosimetry Technology</u>

This analysis was unable to locate specific designs of the film dosimeters used for approximately the first 20 years (1957 to 1974) at the Pinellas Plant, and there is limited documentation that indicates there was an early relationship with Nuclear-Chicago (GEND 2004a). However, the dosimetry type and sources are well documented in the Landauer exposure reports from 1974 until the Plant ceased operations. Table 6-4 summarizes the monitoring technique and describes expected and known Plant dosimeters. Table 6-5 summarizes the Minimum Detection Level (MDL) of these dosimeters along with the maximum potential missed dose (NIOSH 2002). The MDL, which is widely used in other documents prepared for the NIOSH Dose Reconstruction Project, can vary depending on dosimeter type, processing equipment, calibration techniques, and procedures. Because of these variations, a review of typical MDLs for photon dosimeters was conducted and is documented in ORAU 2004a. The typical maximum missed dose per exchange cycle for photon dose for film dosimeters is 40 mrem for DOE facilities in general.

6.2.3 Dosimetry Calibration Practices

GEND 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) *Personal Dosimetry Performance – Criteria for Performance* (ANSI 1993). Each test used approximately six to nine badges.

For the G1 film emulsion package, badges were exposed to the Shepherd model 81-12 ^{137}Cs beam irradiator in Building 800 (a gamma check for 662-KeV photons). For beta calibration, the badges 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 badges to keep them free from uranium contamination.

Calibration of the E1 polycarbonate badges 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.

The R1 film badge, TLD albedo badge, and CR-39 badge were placed on a water phantom and exposed to a Shepherd model 149 ^{241}Am/Be calibrator. 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.

Further details of the dosimetry are listed in Table 6-5. This includes the dosimeter types along with some dosimeter configuration and energy response characteristics. Table 6-5 lists the associated MDLs and the maximum potential missed photon or beta dose. Even though the dosimeter designations or types changed, the MDLs did not vary much over the operational history of the Pinellas Plant.

However, even though there is GEND 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 from the personnel packets, the densities on the personnel film were normalized to Landauer controls only and a non-minimal 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 (Koperski 2004).

Table 6-4. Dosimetry used at Pinellas Plant for external whole-body, wrist and extremity exposures.

Period	Monitoring technique	Dosimeter description
		Beta/photon Dosimeters
1957 – June 1974 *whole body*	Photographic film badge. Some hand calculations prior to 1960.	Nuclear-Chicago or similar film badges. Nuclear-Chicago film badge contained single film packet. Three filters (front and back) were incorporated into film badge for energy dependence: cadmium, aluminum, and lead (ORAU 2003b).
July 1974 – About 1983* *whole body*	Landauer Type K (neutron, beta-gamma), J (beta and gamma).	Type J and K dosimetry were film badges but the K dosimeter had NTA film for high-energy neutron radiation. Gamma and X-ray: 30 keV to 20 MeV; beta: over 1.5 MeV.
About 1974* – April 1990 *whole body*	Landauer G1.	Film emulsion packaged placed in standard Gardray holder/badge for monitoring beta, X-ray, and gamma exposure. Insensitive to neutron radiation. Required in areas where krypton-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.
May 1990 – 1997 *whole body*	Landauer Z1 dosimeter.	Comprised of 3 TLD-700 chips for monitoring beta, X-ray and gamma exposure. Insensitive to neutron radiation. Replaced Landauer G1.
July 1974 – About 1983* *wrist*	Landauer Type M (wrist beta-gamma) badges.	Type M dosimetry was a film badge. Gamma and X-ray: 30 keV to 20 MeV; beta: over 1.5 MeV.
About 1983* – 1990 *wrist*	G5 wrist film badge.	Responded to beta, X-ray, and gamma exposure to provide data on extremity dose. Extremity dosimetry was worn in locations where plutonium oxide was handled. Gamma and X-ray: 30 keV to 20 MeV; beta: over 1.5 MeV.
1991 – 1997 *wrist*	K5 TLD wrist badge.	Comprised of 3 TLD-100 chips.
1957-1974	Film badge-*finger.*	Nuclear-Chicago or similar film badges. Nuclear-Chicago film badge contained single film packet. Three filters (front and back) were incorporated into film badge for energy dependence: cadmium, aluminum, and lead (ORAU 2003b).
About 1983* – 1997 *finger ring*	U3 TLD (LiF).	Responded to beta, X-ray, and gamma exposure to provide data on extremity dose. Extremity dosimetry was worn in locations where plutonium oxide was handled. Gamma and X-ray: 30 keV to 20 MeV; beta: over 1.5 MeV.
		Neutrons
1957 – 1978 *whole body*	NTA film badge.	Kodak Nuclear Track Emulsion NTA films: Fast neutrons undergoing elastic collision with content of emulsion or cellulose acetate base material produce recoil protons, which are recorded as photographic tracks in emulsion. Track density is linear function of dose. Developed image exhibits tracks caused by neutrons, which can be viewed using appropriate imaging method (i.e., oil immersion) and 1000X power microscope or projection capability.
July 1974 – About 1978* *whole body*	Landauer Type J badge.	Landauer NTA film badge for neutrons 1 to 10 MeV.
About 1978* – 1997 *whole body*	Landauer Neutrak E1 dosimeter.	Polycarbonate (lexan) neutron recoil track registration device used to monitor fast neutron interactions. Neutrak 144 has 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. E1 could be combined with G1 (and later with Z1). Accelerator operators were required to wear E1/G1 combination. Workers were required to wear E1/G1 dosimeters when working around neutron generators. E1/G1 dosimeter or G1 dosimeter was required when working with calibration sources.
October 1979 – October 1987 *whole body*	Mound albedo dosimeter.	Evaluated exposures to $^{238}PuO_2$ 2-MeV average neutrons and gammas during handling of RTG units at Building 400.
October 1987 – 1994 *whole body*	Landauer I8, I1 or RI Neutrak Extended Range dosimeter.	Combined TLD albedo neutron monitor with 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 above-described elements. Qualitative relationship was derived to determine ratios of neutrons of various energies. This badge was combined with G1 to make dosimeter, known as R1 that monitored beta, X-ray, gamma, and neutrons. R1 film badge arrangement, which was used in locations where $^{238}PuO_2$ was handled, replaced Mound albedo dosimeter. I8 did not meet all DOELAP requirements during performance testing. After G1 was replaced by Z1 (Z1 was called F1 beginning in 1995), combined unit was known as I1. After production of RTGs was halted in October 1991, I1 was only used as area monitor for americium-beryllium (AmBe) source. I8 is still offered by Landauer.

Sources: Burkhart 1987b, 1988; GEND 1990a,b; Greene 1985; Holliday 1978; Landauer 2004; Ingle 1991; Weaver 1991, 1995, 1996; Passmore 2004; Koperski 2004.

* This analysis found no documentation that shows the start of G1, U3, G5, I8, and E1 dosimeter use and the end of Type K, J, and M badges use.

Table 6-5. Minimum Detectable Level (MDL) and Maximum Potential Missed Photon or Beta Dose.

Dosimeter	**Period of Use**	**MDL (rem)**[a]	**Max Annual Missed Dose (rem) (MDL/2)**
Nuclear Chicago or Pinellas film badge–*whole body*	1957-1974	0.04 photons 0.04 beta	0.24 beta -photons (monthly)
Landauer G1- *whole body*	About 1974[b] – April 1990	0.02 photons 0.04 beta	0.06 photons (monthly) 0.02 photons (quarterly) 0.24 beta (monthly) 0.08 beta (quarterly)
Landauer Type K *whole body*	July 1974-About 1983[b]	0.02 photons 0.04 beta	0.12 photons (monthly) 0.24 beta (monthly)
Landauer Type J *whole body*	July 1974-About 1983[b]	0.02 photons 0.04 beta	0.12 photons (monthly) 0.24 beta (monthly)
Landauer Z1 dosimeter - *whole body*	May 1990- 1997	0.01 photons 0.04 beta	0.06 photons (monthly) 0.24 beta (monthly)
Film-badge-*wrist*	1957- June 1974	0.04 photons 0.04 beta	0.24 beta-photons (monthly)
Landauer Type M - *wrist*	July 1974-About 1983[b]	0.02 photons 0.04 beta	0.12 photons (monthly) 0.24 beta (monthly)
G5 wrist film badge – *wrist*	About 1983[b] – 1990	0.02 photons 0.04 beta	0.12 photons (monthly) 0.04 photons (quarterly) 0.24 beta (monthly) 0.08 beta (quarterly)
K5 TLD *wrist*	1991-1997	0.01 photons 0.04 beta	0.06 photons (monthly) 0.24 beta (monthly)
Film badge-*finger*	1957-1974	0.04 photons 0.04 beta	0.24 beta-photons (monthly)
U3 TLD (LiF) - *finger ring*	About 1983[b] – 1997	0.03 photons 0.04 beta	0.18 photons (monthly) 0.08 photons (quarterly) 0.24 beta (monthly) 0.08 beta (quarterly)

[a.] Estimated MDLs for commonly used photon dosimetry (ORAU 2004a).
[b.] Dates are approximate. No information could be found regarding when the G1 replaced the Type K and J, when the G5 replaced the Type M, or when use of the U3 began.

6.2.4 Workplace Radiation Fields

Potential sources for workplace radiation fields at Pinellas can be placed in two categories, radionuclides and machine-generated X-rays, neutrons, and electrons. Radionuclides were used directly in the manufacturing processes, manufacturing support, and various calibration sources. Machine-generated X-rays from the equipment listed in Table 6-1 supported the Quality Assurance program and process monitoring, and provided specific manufacturing support (i.e., E-beam welding and operation of an accelerator).

Table 6-6 lists radionuclides that would contribute to workplace radiation fields. The radionuclides applied in the manufacturing processes at the Pinellas Plant were kept in containers, in sealed sources, or in the process piping.

Because most of the primary radiation from these sources (alphas and betas) would not penetrate the containers, sealed source encapsulation, or the process piping, and the workers would not be in close contact with the sources, the expected radiation fields would be very small. In the cases of tritium and ^{85}Kr, which were gases in the Pinellas processes, vent hoods or direct connections to ventilation exhaust systems quickly removed the gases from worker spaces. The largest calibration source was a 120-Ci ^{137}Cs source used in a Model 81-12 Beam Calibrator manufactured by J. L. Shepard and Associates (GEND 1977). Three neutron sources were used at various times, two of which contained ^{239}Pu (1.7 Ci and 0.43 Ci) and an AmBe source with 10 Ci of ^{241}Am. All three were removed from the Pinellas site by the end of 1991 (1979, 1990, and late 1991, respectively). All other calibration sources were in the mCi and µCi ranges and were sealed, and would not contribute to occupational doses (other than to workers who used the mCi sources) (GEND 2004b).

Table 6-6. Radionuclides contributing to workplace radiation fields.

			Energies and abundances of major radiations[a]			
Nuclide	**Source**	**Half-life**	**Alpha (MeV)**	**Beta (keV)**	**Gamma (MeV)**	**Neutron (MeV)**
H-3	Loaded in neutron generators	12.33 yr	---	18.6	X-rays were also produced probably of medium energy – 30 –250 kev.	14 MeV and 2.5 MeV neutrons from testing of D-T neutron generators 2.5 MeV neutrons from D-D and D-T neutron generators.
Kr-85	Leak check source	10.72 yr	---	687.1 (99.6%)	0.514 (0.4%)	---
Cs-137	Calibration source	30.07 yr	---	1175.6 – (5.4%) 511.6 (94.6%)	0.6617 (decay of Ba-137m)	---
Am-241	Part of AmBe sealed neutron source	432.2 yr	5.49 (85%) 5.44 (12.8%) 5.39 (1.4%) 5.54 (0.3%)	---	59 (35.9%) 13.9 (42.7%)	AmBe produces thermal neutrons by α-n reaction.
Depleted uranium metal powder for H-3 storage						
U-238	99.75% weight	4.51E9 yr	4.15 (21%) 4.20 (79%)	---	---	Weak spontaneous fission (2 MeV).
U-235	0.25% weight	7.1E8 yr	4.21 (6%) 4.37 (17%) 4.40 (55%) 4.60 (5%)	---	0.144 (11%) 0.163 (5%) 0.186 (57%) 0.205 (5%)	Weak spontaneous fission (2 MeV).
U-234	0.0005% weight	2.47e5 yr	4.72 (28%) 4.77 (72%)	---	0.053 (0.12%)	---
Plutonium isotopes used in RTG enclosed in triple metal-encapsulated sealed sources						
Pu-238	80%	87.74 yr	5.50 (72%) 5.46 (12%)	---	---	Weak spontaneous fission (2 MeV Avg) α, ^{18}O reaction.
Pu-239	20%	24,110 yr	5.16 (88%) 5.11 (11%)	---	---	Spontaneous fission (2 MeV) α, ^{18}O reaction.

a. Energy information from Hacker 2001.

The only open-area radiation fields to be encountered by workers would be from the testing of neutron generators and the use of machinery-generated X-rays. This was caused by locating a neutron generator test stand or X-ray generating equipment in a room.

For neutron generator tests, there was no shielding around the test area with the exception of the room walls. X-ray generating equipment was designed to be in a shielded enclosure that, by certification, was below 0.5 mR/hr at 5 cm from the surface of the device. Most devices would have a lower radiation field. Shielding around the test area was added later at an unspecified time. There was also X-ray production from the tritium tube testing. This is implied by a description of exposures in a GE memo (Greene 1984) and in a memo from Sandia lab describing X-ray generation from neutron tube testing. By calculation, it is assumed that X-ray dose was linear to the beam current of electrons and ions. The dose equivalent of X-rays produced was close to that of the neutron dose equivalent without any shielding of the tube present (Brainard 1991).

To support the production of the RTGs, Pinellas health physicists measured RTG radiation fields to yield 10 mrem/hr gamma and 3 mrem/hr neutron at 10 cm (approximately 4 in.) from the surface of the device (PDN 240001101).

Another indicator of the expected radiation fields experienced by Pinellas workers comes from a review of the dosimetry records in the NIOSH Office of Compensation Analysis and Support (OCAS) Claims Tracking System (NOCTS) database of the 285 claimants for external exposures. Of the 285 claimants, 60 have Pinellas employment with whole-body external doses from all forms of radiation greater than 1 mrem, with a total of 18.140 person-rem. Of this total dose, 3.085 rem (17%) are from intake of tritium, 7.152 rem (39.4%) are from neutron exposure, 6.587 rem (36.3%) are from beta/gamma exposure, and 1.317 rem (7.3%) are for extremity doses from beta/gamma exposure. Of the 60 claimants with external exposures, 34 have lifetime doses greater than 100 mrem, and nine have Pinellas lifetime doses from all sources greater than 500 mrem. Most of these doses were accumulated in a sporadic manner by receiving a dose over a fraction of a year and/or not having any recordable doses for several months or for years in some cases. Because a limited number of monitored employees received extremity dosimetry, only 5 of the 60 claimants with external doses have recorded lifetime extremity doses (20, 28, 56, 483, and 730 mrem).

The claimants' exposure histories are supported by the annual radiation exposure summary reports compiled by the AEC from 1960 to 1973, which describe two cases in which a Pinellas worker received more than 1 rem for the year.

6.2.4.1 Beta-Gamma Exposures

The NIOSH Interactive RadioEpidemiological Program (NIOSH 2002) discusses three photon energy bands – below 30 keV, 30 to 250 keV, and above 250 keV. The principal source of photons to the greater number of Pinellas workers would have been the various X-ray machines due to the limited access by a small number of workers to direct contact with radionuclides that emit photons (^{85}Kr in the two Radiflo leak detectors, the one ^{137}Cs sealed source in a shielded calibration machine, depleted uranium in the tritium storage cylinder, and $^{238}PuO_2$ RTG heat sources).

The X-ray machines would generate photon energies below 250 keV. Because the machines were shielded, those used probably have a range of energy settings; and because measurements of the photon energies on the outside of the shielding are not available, this analysis grouped this source of photons in the 30- to 250-keV energy interval, which should be claimant-favorable. Table 6-7 lists beta and photon energies and percentages for processes at the Pinellas Plant.

Table 6-7. Beta and photon radiation energies and percentages for Pinellas Plant processes.

Facility or location	Process type	Radiation type	Energy interval	Percentage
Buildings 100, 200, 300, 400, Medical	Neutron generator production, quality assurance, and RTG production.	Photon	30 - 250 keV	100
Building 100, Area 109	Product analysis (Radiflo and X-ray).	Beta Photon	> 250 keV 30 – 250 keV > 250 keV	100 86 14
Building 800	Calibration and accelerator.	Photon	30 - 250 keV	100

External exposure due to beta particles is unlikely. The predominant source of beta at the Pinellas Plant was tritium, but this radionuclide emits a low-energy beta of less than 30 keV. Such a low-energy beta would not penetrate the dead layer of the skin. The only sources of beta particles with sufficient energy to penetrate the skin are ^{85}Kr and ^{137}Cs (Note, there was the use of depleted uranium (DU) beds for tritium processing but the DU was contained in small metal cylinders that would have attenuated the beta component from the worker). Several incidents occurred in which workers were exposed to ^{85}Kr, so beta should be considered in the area where the two Radiflo units were located.

The ^{137}Cs was in a sealed source in a shielded cabinet in the concrete Building 800, so the probability of worker beta exposures was remote.

Beta exposures were possible for X-ray diffraction and electron beam devices if containment of the beams were compromised. It is more likely that exposures would have been from X-rays or bremsstrahlung production and not from any free electron beam. The exposures, if diffuse, would have been monitored by film badge or TLD monitored personnel. Most unusual occurrences were documented and any likely penetrating or non-penetrating exposures would have been addressed in personnel medical records.

6.2.4.2 Neutron Exposures

There were two distinct neutron sources at the Pinellas Plant: 2.5 and 14-MeV neutrons from the testing of neutron generators and 2-MeV average neutrons from the plutonium sealed sources in the RTGs. The locations of the operations producing neutrons include a small number of areas. However, personnel wore neutron dosimetry in other locations; Table 6-8 lists the locations where workers wore neutron dosimetry and the expected neutron source energy.

Table 6-8. Selection of neutron radiation energies for Pinellas Plant processes.

Facility or location	Process type	Neutron energy
107	Tube assembly	2-14 MeV
128	Tube test	2-14 MeV
131	Final test	2-14 MeV
132M	Fan room	2-14 MeV
182	Tube assembly	2-14 MeV
183	General development	2-14 MeV
184	Tube testing	2-14 MeV
191	CPE hood room	2-14 MeV
194	Engineering environmental testing	2-14 MeV
	Radioanalytical Laboratory	2-14 MeV
Building 200	Product QA testing	2-14 MeV
Building 300		2-14 MeV
Building 400	RTG assembly and testing	0-12 MeV
Building 800	Calibration and accelerator	2-14 MeV
Medical		2-14 MeV

The RTG PuO_2 heat source spectrum is illustrated in figure 6-2. The spectrum was probably obtained from the mound plant and was used to analyze the effectiveness of various Landauer’s Neutrak TLND dosimeters by the Pinellas health physics department (Burkhart, 1987a). It was determined that the Landauer dosimeter responded to only about 67 % of the dose equivalent for the RTG PuO_2 heat source spectrum.

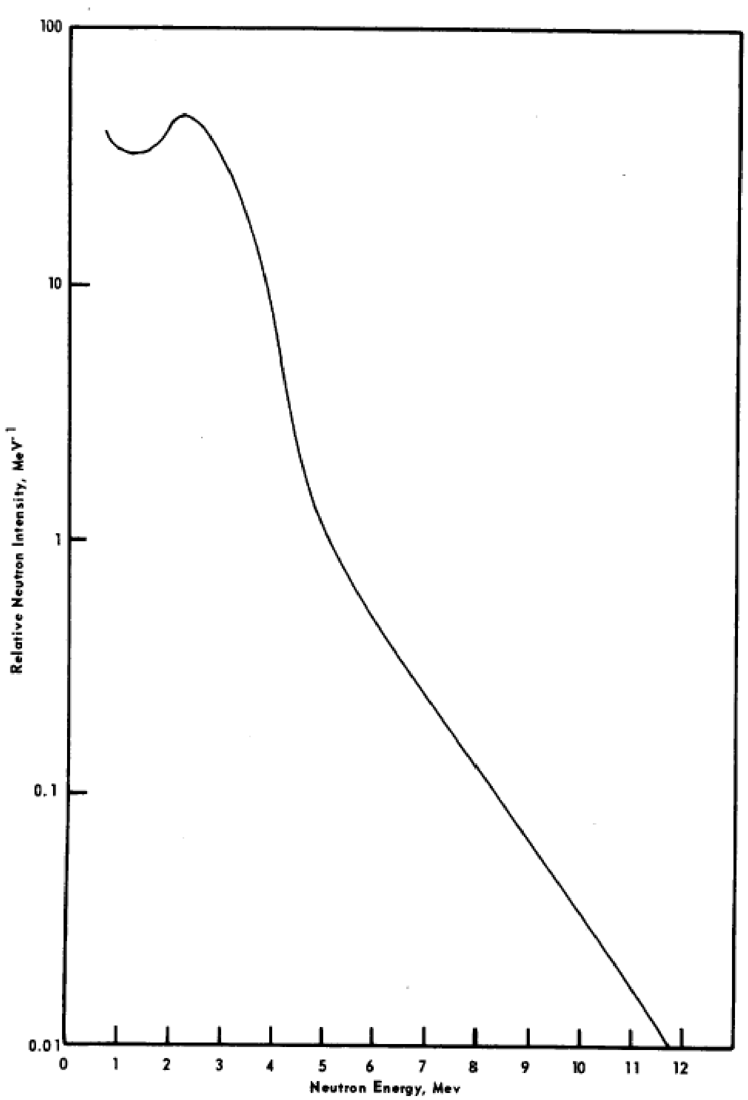

Figure 6-2.[a] RTG Plutonium Source Neutron Energy Spectrum – PuO_2 Microspheres.
a. (Burkhart, 1987a)

6.3 ADJUSTMENTS TO RECORDED DOSE

Adjustments to Pinellas Plant recorded doses are necessary to arrive at a claimant-favorable dose, considering the uncertainty associated primarily with the complex workplace radiation fields and exposure geometries. A key item for dose reconstructors to understand about the GEND radiation protection program is that for an individual lifetime dose (denoted as the "NDD" lifetime dose in GEND files), the internal exposure from tritium was combined with the external exposure from neutrons, gammas, and X-rays. To reconstruct a claimant's lifetime dose properly, the dose reconstructor should separate the tritium dose from the rest of the external dose. As discussed in Section 6.2.4, 60 claimants have recorded lifetime doses equal to or greater than 1 mrem. Table 6-9 lists the results of a review of their records that indicated external exposure determined the segregation between doses from tritium, neutrons, photons, and extremity.

Table 6-9. Internal and external doses among Pinellas claimants (mrem).

Total Pinellas lifetime dose	Tritium dose	Neutron dose	Photon dose	Extremity dose, if available
3,770	87	218	3,465	
1,111	1,111	0	0	
1,054	705	271	78	
914	15	632	267	28
802	33	60	709	
791	2	601	178	483
599	236	283	80	
519	379	140	0	
506	1	244	256	
494	174	214	106	
480	0	110	370	730
461	15	347.5	98.5	
357	0	357	0	
350	4	346	0	
320	8	216	87	
317	31	247	39	
133	0	133	0	
264	2	123	139	56
262	0	262	0	
248	0	218	30	
241	0	231	10	
227	1	201	25	
220	0	220	0	
219	16	100	103	
209	0	82	127	
191	19	140	32	
189	11	161	17	
183	0	183	0	
172	14	126	32	
140	140	0	0	
127	0	74	53	
120	0	120	0	
100	0	100	0	
83	3	0	80	
74	0	14	60	20
65	0	0	65	
61	1	60	0	
52	8	44	0	
37	23	14	0	
47	N/A	N/A	N/A	
46	0	46	0	
40	0	40	0	
35	0	35	0	
35	0	35	0	
30	0	0	30	
30	0	0	30	
27	0	27	0	
22	2	20	0	
21	5	0	16	
20	0	20	0	
17	0	17	0	
14	0	14	0	
11	9	0	2	
9	9	0	0	
8	8	0	0	
8	8	0	0	
5	0	5	0	
4	4	0	0	
2	0	0	2	
1	1	0	0	

N/A – not applicable. Highest case number used in this table was case #16921.

The recorded Pinellas doses show that there is not a consistent relationship between recorded neutron and photon doses. 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 relative 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 a 3:1 neutron to photon ratio was measured based upon neutron and photon exposure rates from the processing of the RTG PuO_2 heat sources. The exposure rates measured at this time were 0.18 mR/hr gamma and 0.37 mR/hr neutron at 24 inches. Actual dose equivalent received form removal and processing of 15 units for one worker (apparently the typical workload was 50 generators / month for perhaps three personnel) amounted to 7.1 mrem gamma and 20.9 mrem neutron dose equivalents or approximately a 3:1 neutron to photon ratio (GEND 1983). Since the RTG radioisotopic ratios and activity remained unchanged and the work-stations and processes consistent, this ratio can also be considered a constant for RTG work conducted from 1975 through 1990.

6.3.1 Photon Dose Adjustments

No adjustments to photon doses (including X-rays) are known to have been made for Pinellas dosimetry. No adjustments to photon doses are necessary for dose reconstruction with the exception of those specified as part of defining the missed dose.

6.3.2 Neutron Dose 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 – 14 MeV (ICRP 1990). This value is higher than other values that could have been used (such as those in NCRP 1971).

The plutonium in the RTGs emits neutrons with an energy range of thermal to 12 MeV (Figure 6-2) and a 2 MeV average. The available GEND documentation does not describe any separate processing of the dosimetry applied for RTG manufacture that is different from the other neutron dosimetry. Therefore, this analysis assumed that the RBE of 10.0 was applied for the RTG neutron source, which would be consistent with ICRP (1990).

The ICRP 60 weighting factor is 10 for the neutron energy band from 2 to 14 MeV for neutron generators, which is equal to the value that Pinellas used historically. The highest ICRP 60 weighting factor is 20 for the neutron energy band from 0 to 2 MeV, which comprises about 25% of the neutrons. Table 6-10 represents the neutron energy bins and associated dose fractions to be used for the RTG PuO_2 heat source workers. The most reasonable correction factor for converting the ICRP 38 to the ICRP 60 neutron radiological weighting factor would be 1.47.

A correction for the under-response of NTA film to lower energy neutrons of < 500 keV including albedo neutrons is based on 67% track fading per month for NTA film, 33% poor low energy response correction factor for TLD (RTG workers only) and a track fading correction for TLDs. The corrections are summarized in Table 6-10.

Table 6-10. Selection of neutron radiation energies and associated dose fractions for the RTG building 400 Pinellas Plant processes.

Facility or Location	Process type	Neutron energy	Default Dose Fraction	ICRP 60 correction factor
Building 400	RTG assembly and testing	0-2 MeV	0.25	0.48
Building 400	RTG assembly and testing	2-12 MeV	0.75	0.99

6.3.3 Beta Dose Adjustments

Beta doses were monitored but not routinely recorded. The primary source of beta or non-penetrating dose was from the use of two RadiFlow leak testers located in area 109 from about 1963 though 1994.

Since beta monitoring for ^{85}Kr started prior to the DOELAP standard release, which used a calibration factor from ^{90}Sr/^{90}Y source that tended to underestimate the dose from ^{85}Kr exposures. To compensate for the lower energy of ^{85}Kr relative to that of ^{90}Sr/^{90}Y a correction factor may have been used for the Pinellas site based upon the more similar ^{204}Tl energy spectrum. To compensate for the energy differences a multiplication factor of about 3.5 (GEND 1985b, PDN 240001210) times the reported non-penetrating dose should be used for dosimetry prior to about 1986. From 1986 onwards, when DOELAP and NAVLAP standards included ^{204}Tl calibration criteria for ^{85}Kr exposures it is not necessary to utilize this correction factor. It is not clear from the Pinellas Plant records whether the ^{204}Tl energy calibration or equivalent was requested by Pinellas of Landauer or other vendors prior to 1986.

6.4 MISSED DOSE

There is missed dose for Pinellas Plant workers. The following sections discuss photon and neutron missed dose.

6.4.1 Photon and Beta Missed Dose

Missed photon and beta dose to Pinellas Plant workers could occur for the following reasons: (1) there is no recorded dose for workers who did not work in certain operations, and (2) a worker dose during a monitoring period was recorded as zero because the dosimeter response was less than the MDL. Many workers were not monitored for external dose because such doses would not exceed 10% of the radiation protection guides. This practice resulted in large numbers of workers not being monitored for external radiation exposure from 1957 through 1994. Note, the vast majority of these workers may not have worked with or near any radioactive materials or areas since most of the Pinellas Plant products did not include the use of radioactive materials or radiation generating devices.

Missed dose is primarily estimated on dosimeter results n (the number of zero or < MDL values) multiplied by MDL/2. The MDL is particularly important during the early years of operation, when MDLs were probably higher and the dosimeter exchange rate was monthly rather than quarterly. One option to estimate a claimant-favorable maximum potential dose is to multiply the MDL by the number of zero dose results. This will provide an estimate of the maximum missed dose to the worker. The following sections consider missed photon dose for dosimeter results less than the MDL according to facility or location, dosimeter type, year, and energy range.

The analysis assumed that unmonitored (i.e., nonradiation) workers did not receive a significant dose compared to monitored workers; therefore, assigning a photon dose distribution for each year based on the dose received by monitored workers would ensure a claimant-favorable estimate of any unmonitored worker 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.

6.4.1.1 Missed Dose by Facility or Location

Table 6-11 lists potential missed dose by facility or location. Records that identified facilities or locations in which specific types of dosimetry were used are not available. Rather, the types of dosimeters were assigned to facilities and locations based on the operations that were conducted.

Table 6-11. Photon and beta dosimetry missed dose by facility or location.

Facility or location[a]	Period of use	Dosimeter	MDL (rem)[b]	Exchange frequency	Max. annual missed dose (rem)[c]
Building 100, Areas 107, 108, 109, 132M, 155, 157/158, 182, 191 Buildings 200	1957-1974	film – whole body	0.04	Monthly (n=12)	0.24 beta -photons
Building 100, Areas 107, 108, 109, 132M, 155, 157/158, 182, 191 Buildings 200, 400, 1000	July 1974 – About 1983[d]	Landauer Type K (beta-gamma)-whole body	0.01 photons 0.04 beta	Monthly (n=12)	0.06 photons 0.24 beta
Building 100, Areas 107, 108, 109, 132M, 155, 157/158, 182, 191 Buildings 200, 400, 1000	July 1974 – About 1983[d]	Landauer Type J – whole body	0.01 photons 0.04 mrem beta	Monthly (n=12)	0.06 photons 0.24 beta
Building 100, Areas 107, 109, 114, 131, 132, 139, 148, 161, 175, 176, 181, 183, 184, 191, 194, 196; Buildings 200; 300; 400; 800; Medical	About 1974[d] – April 1990	Landauer G1	0.01 photons 0.04 beta	Monthly until Jan. 1990 (n=12) Quarterly afterward (n=4)	0.06 photons (monthly) 0.02 photons (quarterly) 0.24 beta (monthly) 0.08 beta (quarterly)
Building 100, Areas 107, 109, 114, 131, 132, 139, 148, 161, 175, 176, 181, 183, 184, 191, 194, 196; Buildings 200; 300; 400; 800; Medical	April 1990 – 1997	Landauer Z1 dosimeter	0.01 photons 0.04 beta	Quarterly (n=4)	0.02 photons 0.08 beta
Building 100, Areas 107, 131, 161, 175, 181	1957-1974	Film badge - wrist	0.04	Monthly (n=12)	0.24 beta -photons
Building 100, Areas 107, 131, 161, 175, 181; 400	July 1974 – About 1983[d]	Landauer Type M (wrist)	0.01 photons 0.04 beta	Monthly (n=12)	0.06 photons 0.24 beta
Building 100, Areas 107, 131, 161, 175, 181; Building 400	About 1983[d] – 1990	G5 wrist film badge	0.01 photons 0.04 beta	Monthly (n=12)	0.06 photons (monthly) 0.02 photons (quarterly) 0.24 beta (monthly) 0.08 beta (quarterly)
Building 100, Areas 107, 131, 161, 175, 181; Building 400	1991 – 1997	K5 TLD wrist badge	0.01 photons 0.04 beta	Quarterly (n=4)	0.02 photons 0.08 beta
Building 100, Areas 131, 139	1957-1974	Film badge - finger	0.04	Monthly (n=12)	0.24 beta -photons
Building 100, Areas 131, 139; Building 400	About 1983[d] – 1997	U3 TLD (LiF) finger ring	0.03 photons 0.04 beta	Monthly until Jan. 1990 (n=12) Quarterly afterwards (n=4)	0.18 photons (monthly) 0.06 photons (quarterly) 0.24 beta (monthly) 0.08 beta (quarterly)

a. As determined from site operational information.
b. Estimated MDLs for commonly used photon dosimetry (ORAU 2004a).
c. Maximum annual missed dose calculated using the MDL divided by 2 (NIOSH 2002).
d. Dates are approximate. No information could be found to determine when the G1 replaced the Type K and J, the G5 replaced the Type M, and use of the U3 began.

This analysis assumed that workers wore finger and wrist dosimetry in Building 400 for the production of RTGs due to the handling of plutonium (Weaver 1987).

Unmonitored dose should be assigned to account for external dose that may have received that was not measured. Summarized dosimetry data available for the period 1983–1993 indicates that the highest annual external dose for an individual at the Pinellas Plant was 0.550 rem. Typical annual dosimetry results for personnel monitored between 1957 and 1979 indicated few individuals received doses greater than 0.500 rem. Even though doses at the Pinellas Plant were expected to be lower than the maximum individual dose, the maximum doses may be assigned based on an assumption of 0.550 rem to each full or partial year. However, typically over 95% of monitored workers received annual doses below 0.100 rem. The only exceptions found to this were for the years 1958 and 1960 when only 80% and 84% of the monitored population were below 0.100 rem. The data indicates that an annual dose of 0.100 rem is representative of the upper 95th percentile dose for the Pinellas Plant. The unmonitored photon doses would be adjusted by DCF and other applicable factors.

6.4.1.2 Missed Dose by Dosimeter Type and Year

Table 6-11 summarizes the missed photon dose by dosimeter type and year. The MDLs for the specific beta/photon dosimeters used until the 1970s are not known; however, the dosimeters would be comparable to those used at other AEC/DOE sites. A claimant-favorable assumption of 40 mrem is appropriate for these dosimeters (NIOSH 2004a).

6.4.1.3 Missed Dose by Energy Range

An estimate of the missed dose by energy range is possible based on the predominant radiation sources or radionuclides used at the various Plant facilities, primarily lower (<100 keV) energy photons from plutonium. The recorded dose from the dosimeter response does not typically provide information to estimate discrete energy ranges. It is possible to examine the energy response characteristics of the respective multi-element dosimeters, but such an analysis does not recognize the substantial uncertainties present in the workplace associated with shielding, radiation scattering, and mixed radiation fields.

6.4.2 <u>Neutron Missed Dose</u>

The possibility of missed neutron dose at the Pinellas Plant could have occurred due to the following:

- Track fading in NTA film.
- An MDL of 50 mrem for NTA film (ORAU 2003a).
- Under-response of NTA film to lower energy neutrons, particularly those less than 500 keV, including albedo neutrons.
- MDLs as noted in Table 6-13 for TLDs.
- Under-response of TLDs to lower energy neutrons (< 2 MeV) as calculated by GEND Health Physics for RTG neutron spectrum.
- Signal fading in TLD neutron dosimeters

Table 6-12 summarizes the neutron missed dose by facility or location segregated by the mode of the missed dose (i.e., track fading, MDL, and poor energy response).

Table 6-12. Neutron dosimetry missed dose by facility or location.

Facility or location[a]	Period of use	Dosimeter	Missed dose per badge exchange (rem)	Exchange frequency	Max. annual missed dose (rem)
Building 100, Areas 128, 131, 148, 176, 181, 182, 183, 184, 191, 194, 196; Buildings 200; 800	1957 – 1978[b]	NTA track film	0.0335 (track fading)[c]{1957-1969}	Monthly (n=12)	0.402
			0.05 (MDL)[d]	Monthly (n=12)	0.60
			0.03 (poor energy response)[e] {For RTG 1975-1990 only}	Monthly (n=12)	0.36
Building 100, Areas 128, 131, 148, 176, 181, 183, 184, 191, 194, 196; Buildings 200; 800	July 1974 – About 1983[b]	Landauer Type K	0.0335 (track fading)[c]	Monthly (n=12)	0.402
			0.04 (MDL)[f]	Monthly (n=12)	0.24
			0.03 (poor energy response)[e] {For RTG 1975-1990 only}	Monthly (n=12)	0.36
Building 100, Areas 128, 131, 148, 176, 181, 183, 184, 191, 194, 196; Buildings 200; 800	About 1978[b] – 1997	Landauer Neutrak E1 dosimeter	0.02 (MDL)[f]	Monthly until Jan. 1990 (n=12) Quarterly afterwards (n=4)	0.24 0.08
			0.0066 (poor energy response)[f] {For RTG 1975-1990 only}	Monthly (n=12)	0.079
Building 100, Area 182; Building 400	October 1979 – October 1987	Mound albedo dosimeter	0.01 (MDL)[d]	Monthly (n=12)	0.12
			0.011 (signal fading)[h]	Monthly (n=12)	0.132
			0.0033 (poor energy response)[f] {For RTG 1975-1990 only}	Monthly (n=12)	0.040
Building 100, Area 182; Building 400	October 1987 – 1997	Landauer I8 Neutrak Extended Range dosimeter	0.02 (MDL)[f]	Monthly until Jan. 1990 (n=12) Quarterly afterwards (n=4)	0.24 0.08
			0.0066 (energy dose response)[f] {For RTG 1975-1990 only}	Monthly until Jan. 1990 (n=12) Quarterly afterwards (n=4)	0.079 0.020

a. As determined from site operational information.
b. Dates are approximate. No documentation could be found to verify the dates for when the E1 replaced the Type J and when the Type J replaced the NTA track film.
c. 67% track fading per month as determined in a fade study (GEND 1969). This is multiplied by the MDL of 0.05 rem to obtain the amount of missed dose due to track fading per badge exchange.
d. (ORAU 2004b, Table 6-17).
e. Film NTA poor energy response calculated from the Savannah River Site correction factor of 1.14 neutrons in the energy range of 0.1 to 2 MeV. This correction would be only applied to RTG exposures (ORAU 2003a).
f. 67% dose response of Neutrak ER or I8 dosimeter to RTG neutrons as determined by GEND health physics group. 1.33 is multiplied by the MDL to obtain the missed dose due to poor low-energy response leading to a poor dose response. This correction would be only applied to RTG exposures (240001308 – 1987).
g. Landauer dosimetry specifications from Passmore (2004).
h. Mound dosimetry correction for signal fading (ORAU 2004b).

6.4.2.1 Missed Dose by Dosimeter Type and Year

Table 6-12 summarizes the MDL to be used for each dosimetry technology and the corresponding missed dose segregated by the mode of the missed dose (i.e., track fading, MDL, and poor energy response). Little information could be found regarding the MDL for each dosimetry technology throughout most of the history of the Pinellas Plant. Therefore, an MDL is proposed for cases in which a limit is not known so missed dose can be calculated. The purpose of the proposed MDL values is to be claimant-favorable.

6.5 UNCERTAINTY

For measuring film badge doses, the MDLs quoted in the literature ranged from about 10 to 40 mrem for beta/photon radiation; it is possible to read a photon dose of 100 mrem to within 15 mrem if the exposure involved photons with energies between several hundred keV and several MeV (Morgan

1961). The estimated standard error in recorded film badge doses from photons of any energy is ±30%.

For NTA films, the estimated standard error for the assigned photon dose is within 30%. When measuring neutrons with NTA films, the estimated standard error for the assigned neutron dose is within 50 mrem. The sensitivity of the polycarbonate neutron dosimeter (Type E1) was 30 ± 15 mrem, as measured in 1978, with a minimum detection limit of 20 mrem (Holliday 1978).

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GLOSSARY

absorbed dose, D

Amount of energy imparted by radiation to unit mass of absorbing material (100 ergs per gram), including tissue. The unit used prior to the use of the International System of metric units (SI) is the rad; the SI unit is the gray.

accreditation

In relation to this document, recognition that a dosimeter system has passed the performance criteria of the DOE Laboratory Accreditation Program (DOELAP) standard (DOE 1986) in specified irradiation categories.

accuracy

If a series of measurements has small systematic errors, they are said to have high accuracy. The accuracy is represented by the bias.

albedo dosimeter

A TLD device that measures the thermal, intermediate, and fast neutrons that are scattered and moderated by the body from an incident fast neutron flux.

Atomic Energy Commission

Original agency established for nuclear weapons and power production; a successor to the Manhattan Engineering District (MED) and a predecessor to DOE.

backscatter

Deflection of radiation by scattering processes through angles greater than 90 degrees, with respect to the original direction of motion.

beta particle

A charged particle of very small mass emitted spontaneously from the nuclei of certain radioactive elements. Most (if not all) of the direct fission products emit (negative) beta particles. Physically, the beta particle is identical with an electron moving at high velocity.

claimant-favorable

Refers to the process of estimation based on technical considerations of the parameters significant to dose such that there is no underestimation of the estimated dose.

curie

A special unit of activity. One curie exactly equals 3.7×10^{10} nuclear transitions per second.

densitometer

Instrument that has a photocell to determine the degree of darkening of developed photographic film.

dose equivalent (H)

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

DOELAP

The DOE Laboratory Accreditation Program accredits DOE site dosimetry programs based on performance testing and onsite reviews performed on a 2-year cycle.

dose equivalent index

For many years the dose equivalent used to calibrate neutron sources that were used in turn to calibrate neutron dosimeters; a concept of summing the maximum dose equivalent delivered in the International Commission on Radiation Units and Measurements sphere at any depth for the respective neutron energies even though the maximum dose occurred at different depths.

dosimeter

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

dosimetry system

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

error

Term used to express the difference between the estimated and "true" value. Error can also be used to refer to the estimated uncertainty.

exchange period (frequency)

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

exposure

As used in the technical sense, exposure refers to a measure expressed in roentgens of the ionization produced by gamma (or X-) rays in air.

extremity

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

fast neutron

Neutron of energy between 10 keV and 10 MeV.

film

Generally means a "film packet" that contains one or more pieces of film in a light-tight wrapping. The film when developed has an image caused by radiation that can be measured using an optical densitometer.

film dosimeter

A small packet of film in a holder that attaches to a worker.

filter

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

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

gray (Gy)
The SI unit of absorbed dose (1 Gy = 100 rad).

intermediate energy neutron
Neutron of energy between 0.5 ev (assumed to be 0.4 ev because of cadmium cutoff in neutron response) and 10 keV.

ionizing radiation
Electromagnetic radiation (consisting of photons) or particulate radiation (consisting of electrons, neutrons, protons, etc.) capable of producing charged particles through interactions with matter.

isotopes
Forms of the same element having identical chemical properties but differing in their atomic masses. Isotopes of a given element all have the same number or protons in the nucleus but different numbers of neutrons. Some isotopes of an element can be radioactive.

kilo-electron volt (keV)
An amount of energy equal to 1,000 electron-volts.

luminescence
The emission of light from a material as a result of some excitation.

Minimum Detection Level (MDL)
Often confused because the statistical parameters necessary to its calculation are not explicitly defined. Nonetheless, often assumed to be the level at which a dose is detected at the two-sigma level (i.e., 95% of the time). The MDL should not be confused with the minimum recorded dose.

minimum recorded dose
Based on a policy decision, the minimum dose level that is routinely recorded. A closely related concept is the dose recording interval.

million-electron volt (MeV)
An amount of energy equal to 1,000,000 electron-volts.

neutron
A basic particle that is electrically neutral weighing nearly the same as the hydrogen atom.

neutron, fast
Neutrons with energy equal or greater than 10 keV.

neutron, intermediate
Neutrons with energy between 0.4 eV and 10 keV.

neutron, thermal

Strictly, neutrons in thermal equilibrium with surroundings. In general, neutrons with energy less than the cadmium cutoff at about 0.4 eV.

Personal Dose Equivalent, $H_p(d)$

Radiation quantity recommended for use as the operational quantity to be recorded for radiological protection purposes by the International Commission on Radiological Units and Measurements. Represented by $H_p(d)$, where d identifies the depth (in millimeters) and represents the point of reference for dose in tissue. For weakly penetrating radiation of significance to skin dose, d = 0.07 mm and is noted as $H_p(0.07)$. For penetrating radiation of significance to whole-body dose, d = 10 mm and is noted as $H_p(10)$.

photon

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

quality factor, Q

A modifying factor used to derive dose equivalent from absorbed dose.

rad

A unit of absorbed dose equal to the absorption of 100 ergs per gram of absorbing material, such as body tissue.

radiation

One or more of beta, neutron, and photon radiation.

radiation monitoring

Routine measurements and the estimation of the dose equivalent for determining and controlling the dose received by workers.

radioactivity

The spontaneous emission of radiation, generally alpha or beta particles, gamma rays, and neutrons from unstable nuclei

radioisotopic thermoelectric generator

A radioisotope thermoelectric generator (RTG) is a very simple electrical generator that obtains its power from passive radioactive decay. Such a generator uses the fact that radioactive materials (such as ^{238}Pu/^{239}Pu) generate heat as they decay. The heat used is converted into electricity by an array of thermocouples.

random errors

When a given measurement is repeated, the resulting values, in general, do not agree exactly. The causes of the disagreement between individual values must also be causes of their differing from the "true" value. Errors resulting from these causes are *random* errors.

rem

A unit of dose equivalent, which is equal to the product of the number of rads absorbed and the quality factor.

roentgen
A unit of exposure to gamma (or X-ray) radiation. It is defined precisely as the quantity of gamma (or X-) rays that will produce a total charge of 2.58×10^{-4} coulomb in 1 kg of dry air. An exposure of 1 R is approximately equivalent to an absorbed dose of 1 rad in soft tissue.

scattering
The diversion of radiation from its original path as a result of interactions with atoms between the source of the radiation and a point at some distance away. Scattered radiations are typically changed in direction and of lower energy than the original radiation.

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

Sievert (Sv)
The SI unit for dose equivalent. (1 Sv = 100 rem.)

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

systematic errors
When a given measurement is repeated and the resulting values all differ from the "true" value by the same amount, the errors are systematic.

thermal neutron
Strictly, neutrons in thermal equilibrium with surroundings. In general, neutrons of energy less than the cadmium cutoff of about 0.4 ev.

tissue equivalent
Used to imply that the radiation response characteristics of the material being irradiated are equivalent to tissue. Achieving a tissue-equivalent response is typically an important consideration in the design and fabrication of radiation measuring instruments and dosimeters.

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

thermoluminescent dosimeter (TLD)
A holder containing solid chips of material that when heated will release the stored energy as light. The measurement of this light provides a measurement of absorbed dose. The solid chips are sometimes called crystals.

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

X-ray
Ionizing electromagnetic radiation of extranuclear origin.

ATTACHMENT A
EXAMPLES OF PINELLAS PLANT EXPOSURE RECORDS

D

Period 5-60 to [redacted] Name [redacted]

Soc. Sec. No. [redacted] No. [redacted] MUL-334-R-1

Date	uc/l	mrem(B)	mr(F)	mrem(F)	Total	Date	uc/l	mrem(B)	mr(F)	mrem(F)	Total
6-7	0.00	<20			<20						
7-5	0.07	<20			<20						
		<			<						
8-11	0.64	<20			<20						
		<			<						
9-6	0.00	<20			<20						
		<			<						
10-28	0.06	<20			<20						
		<			<						
11-17	0.00	<20			<20						
		<			<						
12-6	0.22	<20			<20						
		<			<	0.00					

B

EXPOSURE RECORD

Period 1-61 to Name [redacted]

Soc. Sec. No. [redacted] No. [redacted] MUL-334-R-1

Date	uc/l	mrem(B)	mr(F)	mrem(F)	Total	Date	uc/l	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						
			<	<	<						

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

RADIATION EXPOSURE SUMMARY

SOCIAL SECURITY NUMBER - [redacted]
BADGE - [redacted]

STRICTLY
PRIVATE
INFO.

[redacted]

ACCUMULATED
RADIATION EXPOSURE

CURRENT YEAR 1968
ACCUMULATED DOSE
IN REMS -000,000

TOTAL DOSE ACCUMULATED
AT NEUTRON DEVICES
DEPT IN REMS -000,053

A REM, ROENTGEN EQUIVALENT MAN, IS USED AS A MEASURE OF RADIATION DOSE OF ANY IONIZING RADIATION ESTIMATED TO PRODUCE A BIOLOGICAL EFFECT EQUIVALENT TO THAT PRODUCED BY ONE ROENTGEN OF X-RAYS. THE MAXIMUM PER-MISSIBLE RADIATION DOSE THAT MAY BE ACCUMULATED BEYOND 18 YEARS OF AGE IS LIMITED TO AN AVERAGE OF 5 REMS PER YEAR /MPD EQLS,/N-18/ 5 WHERE N IS CURRENT AGE IN YEARS/ AND NOT MORE THAN 12 REMS IN ANY ONE YEAR
IF ANY QUESTIONS---CONTACT HEALTH PHYSICS.

FC-600(10-70)

PERSONNEL MONITORING RECORD

BADGE [redacted]

NAME [redacted]

S.S.No. [redacted]

SECTION 652

ACCUMULATED WHOLE BODY (REM)

	1971	1972	1973	1974
	.000			
YEAR		.020	—	0.000
NDD		.073 .062	.073 .062	0.073
LIFE		.073	.073	0.073

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
1/73	0	0			1-74	0	0		
2/73	0	0			2/74	0	0		
3/73	0	0			3/74	0	0		
4/73	0	0			4/74	0	0		
5/73	0	0			5/74	0	0		
6/73	0	0			6/74	0	0		
7/73	0	0			7/74	0	0		
8/73	0	0			8/74	0	0		
9/73	0	0			9/74	0	0		
10/73	0	0			10/74	0	0		
11/73	0	0			11/74	0	0		
12/73	0	0			12/74	0	0		

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 .042	.073 .0
LIFE	.053	.053	.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		

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

041 E1 G-1

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

262	NDD TOTAL	262
262	LIFETIME TOTAL	262

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

NDD 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

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

041 E1

Year 1982	WHOLE BODY N	WHOLE BODY G	WHOLE BODY T	Total YTD	EXTREMITY G	EXTREMITY N	Total YTD
JAN	m	m		m			
FEB	m	m		m			
MAR	m	m		m			
APR	m	m		m			
MAY	m	m		m			
JUN	m	m		m			
JUL	m	m		m			
AUG	m	m		m			
SEP	m	m		m			
OCT	m	m		m			
NOV	m	m		m			
DEC	m	m		m			
TOTAL	m	m		m			

No Tritium exposure prior to 1975

273	NDD TOTAL	~~273~~	262
273	LIFETIME TOTAL	~~273~~	262

Year 1983	WHOLE BODY N	WHOLE BODY G	WHOLE BODY T	Total YTD	EXTREMITY G	EXTREMITY N	Total YTD
JAN	m	m		m			
FEB	m	m		m			
MAR	m	m		m			
APR	m	m		m			
MAY	m	m		m			
JUN	m	m		m			
JUL	m	m		m			
AUG	m	m		m			
SEP	m	m		m			
OCT	m	m		m			
NOV	m	m		m			
DEC	m	m		m			
TOTAL	m	m		m			

NDD 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

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