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Document Title: **Area IV of the Santa Susana Field Laboratory, the Canoga Avenue Facility, the Downey Facility, and the De Soto Avenue Facility (sometimes referred to as Energy Technology Engineering Center [ETEC] or Atomics International) – Occupational External Dose**	Document Number: ORAUT-TKBS-0038-6 Revision: 02 Effective Date: 04/26/2010 Type of Document: TBD Supersedes: Revision 01

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/22/2006	00	New technical basis document for the Energy Technology Engineering Center – Occupational External Dose. First approved issue. Initiated by Melton H. Chew.
11/16/2006	01	Approved Revision 01 to change the site name to Atomics International throughout the document in keeping with DOE site naming conventions. Updated required language in Section 6.1. Constitutes a total rewrite of document. Incorporates internal formal review comments and corrects typographical errors. Adds a paragraph to section 6.1.2 and clarification to missed dose and magnitude of background dose, Sections 6.2 and 6.8 respectively, as requested by DOL. This revision results in no change to the assigned dose, and no PER is required. Training required: As determined by the Task Manager. Initiated by Melton H. Chew.
04/26/2010	02	Revised to incorporate SEC information in Section 6.1.2 and corrected an error in Table 6-8 pertaining to NTA film and footnote b. Incorporated formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Melton H. Chew.

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ACRONYMS AND ABBREVIATIONS

AI	Atomics International
D	deuterium
DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
hr	hour
keV	kiloelectron-volt, 1,000 electron-volts
MDL	minimum detectable level
MeV	megaelectron-volt, 1 million electron volts
mR	milliroentgen
mrad	millirad
mrem	millirem
MWt	megawatt (thermal)
NIOSH	National Institute for Occupational Safety and Health
NTA	nuclear track emulsion, type A
NVLAP	National Voluntary Laboratory Accreditation Program
OW	open window
PIC	pocket ionization chamber
POC	probability of causation
QF	quality factor
SNAP	Systems for Nuclear Auxiliary Power
SRE	Sodium Reactor Experiment
T	tritium
TBD	technical basis document
U.S.C.	United States Code
WB	whole body
wk	week
§	section or sections

6.1 INTRODUCTION

Technical basis documents (TBDs) and site profile documents are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historic background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). These documents may be used to assist NIOSH staff in the completion of the individual work required for each dose reconstruction.

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

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation[1]] guidelines established under subsection (c) …" [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation, 42 C.F.R. Pt. 82) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work (NIOSH 2007a).

The statute also includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition excludes Naval Nuclear Propulsion Facilities from being covered under the Act, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally-derived radiation exposures at covered facilities in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external occupational radiation exposures are considered valid for inclusion in a dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived (NIOSH 2007a):

- Background radiation, including radiation from naturally occurring radon present in conventional structures
- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

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

6.1.1 Purpose

The purpose of this TBD is to describe external dosimetry systems and practices at Area IV of the Santa Susana Field Laboratory, Canoga Avenue Facility, Downey Facility, and De Soto Avenue Facility (sometimes referred to as Energy Technology Engineering Center [ETEC] or Atomics International). This document discusses historical and current practices at the facilities that, unless otherwise noted, used the same dosimeters and external dosimetry programs (Rutherford and Barnes 2006) in relation to the evaluation of external exposure data for monitored and unmonitored workers.

6.1.2 Special Exposure Cohort Petition Information

Although NIOSH found that it is not possible to completely reconstruct radiation doses for the SEC classes below, NIOSH intends to use any internal and external monitoring data that may become available for an individual claim (and that can be interpreted using existing NIOSH dose reconstruction processes or procedures). Therefore, dose reconstructions for individuals employed at the Area IV, Canoga Avenue, De Soto Avenue, or Downey facilities during the SEC periods stated below, but who do not qualify for inclusion in the SEC, may be performed using these data as appropriate.

Class Added to the SEC

Area IV of SSFL (1955-1958)

- All employees of the Department of Energy (DOE), its predecessor agencies, and DOE contractors and subcontractors who worked in any area of Area IV of the Santa Susana Field Laboratory for a number of work days aggregating at least 250 work days from January 1, 1955 through December 31, 1958, or in combination with work days within the parameters established for one or more other classes of employees in the SEC (Sebelius 2009).

NIOSH determined in 2009 (NIOSH 2009) that it cannot estimate internal exposures with sufficient accuracy during the period from 1955 through 1958. This includes the time from the beginning of Area IV radiological activities in 1955, to late 1958 (selected as December 31, 1958 for SEC evaluation purposes). NIOSH intended the end of the SEC period to correspond with the date after which a routine bioassay program existed at SSFL and after which sufficient internal monitoring was thought to have been identified. Later in 2009 after further data review, NIOSH determined that sufficient data are not available for adequate dose reconstruction until January 1, 1965; NIOSH subsequently initiated a second SEC class for Area IV for the years 1959-1964, as described below.

Classes Recommended by NIOSH for addition to the SEC

Area IV of SSFL (1959-1964)

- All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked in any area of Area IV of the Santa Susana Field Laboratory from January 1, 1959 through December 31, 1964, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort (NIOSH 2010a).

Through the course of ongoing dose reconstruction, continued data capture efforts, and investigations associated with SEC-00093, NIOSH determined in 2010 (NIOSH 2010a) that it cannot estimate with sufficient accuracy the potential internal exposures to various radionuclides to which the proposed class may have been subjected during the time period from January 1, 1959 through December 31, 1964. NIOSH found that it is likely feasible to reconstruct external dose, including occupational medical dose, for Area IV of the Santa Susana Field Laboratory workers with sufficient accuracy.

Canoga Avenue Facility

- All employees of the Department of Energy, its predecessor agencies, and its contractors and subcontractors who worked at the Canoga Avenue Facility, Los Angeles, California, from January 1, 1955 through December 31, 1960 for a number of working days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees in the SEC (NIOSH 2010b).

NIOSH determined in 2010 (NIOSH 2010b) that it cannot estimate internal exposures with sufficient accuracy during the period from 1955 through 1960. This includes the entire covered period for the Canoga Avenue Facility. NIOSH found that it is likely feasible to reconstruct external dose, including occupational medical dose, for Canoga Avenue workers with sufficient accuracy.

Downey Facility

- All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the Downey Facility in Los Angeles County, California, from January 1, 1948 through December 31, 1955, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort (NIOSH 2010c).

NIOSH determined in 2010 (NIOSH 2010c) that it cannot estimate internal exposures with sufficient accuracy during the period from 1948 through 1955. This includes the entire covered period for the Downey Facility so only partial dose reconstructions will be performed for individuals who do not qualify for inclusion in the SEC.

De Soto Avenue Facility

- All employees of the Department of Energy, its predecessor agencies, and their contractors and subcontractors who worked at the De Soto Avenue Facility in Los Angeles County, California, from January 1, 1959 through December 31, 1964, for a number of work days aggregating at least 250 work days, occurring either solely under this employment or in combination with work days within the parameters established for one or more other classes of employees included in the Special Exposure Cohort (NIOSH 2010d).

NIOSH determined in 2010 (NIOSH 2010d) that it cannot estimate internal exposures with sufficient accuracy during the period from 1959 through 1964. The De Soto Avenue Facility has a covered period of DOE 1959-1995 and DOE Remediation 1998. Therefore, dose reconstructions will be performed for 1965 through 1995 and partial dose reconstructions will be performed for individuals who do not qualify for inclusion in the SEC for 1959 through 1964.

6.1.3 Scope

This TBD contains supporting documentation to assist in the evaluation of occupational external doses from processes that occurred at SSFL. An objective of this document is to provide supporting technical data to evaluate, with assumptions favorable to claimants, occupational external doses that can reasonably be associated with worker radiation exposures. This document addresses the evaluation of unmonitored and monitored worker exposure, missed dose, and the bias and uncertainty associated with the monitoring of external dose.

The SSFL facilities, which include four locations, have been identified in various ways over time. This TBD uses SSFL to refer to all locations unless more specific location information is warranted. In that context, SSFL includes Area IV of the Santa Susana Field Laboratory (which has also been known as the Nuclear Development Field Laboratory, the Liquid Metal Engineering Center, and the Energy Technology Engineering Center), portions of the Downey facility, the Canoga facility, and the De Soto facility.

North American Aviation (NAA) entered into a contract with AEC to conduct nuclear research operations at Area IV and the Downey, Canoga and De Soto sites. At that time, Atomics International, an internal division of NAA, was the company's designated nuclear research and development division. In addition to the employees of the AI division, other employees of NAA who worked at any of the above sites during the AEC contract period are potentially eligible for EEOICPA benefits.

SSFL had its own dosimeter in the beginning that was very similar to the multielement film dosimeters used at the Y-12 plant (ORAUT 2009b) and the Hanford Site (ORAUT 2010) based on the design developed by Pardue, Goldstein, and Wollan (1944) as well as pocket ionization chambers (PICs or *pencil dosimeters*). Both penetrating and nonpenetrating doses were recorded. SSFL started using commercial vendors in the early 1960s and continued that practice throughout the rest of its operating life.

6.2 MISSED DOSE

Missed doses at SSFL facilities generally resulted from dosimeter minimum detectable levels (MDLs) and exchange periods. In reviewing an individual dose record from December 31, 1956, to December 30, 1957, entries were both weekly and biweekly with the former starting in May 1957 (Author unknown 1956). This would suggest that exchange periods varied with time, job, and individual. SSFL (1960) states, "Normally film badges are to be worn for monthly periods except where the possibility of exceeding 100 mrem/wk of exposure is expected. Then the badges are to be analyzed more frequently." Therefore, missed doses before 1963, if not derived by review of individual records, would be based on weekly exchanges and would be applicable to both *Hp(0.07)* and *Hp(10)*. Starting in 1963, most dosimeters were processed by their vendor (Landauer or its predecessor) (Garcia and Carpenter 1963a). On occasion, workers wore special dosimeters to monitor nonroutine work such as "hot jobs or cell entries" and always without their regular dosimeter. These special dosimeters were always worn in pairs; the results were averaged, and that average result was sent to the vendor for inclusion in the total dose for that period's regular dosimeter result. It has not been determined if the special dosimeter procedure was in effect before 1963. Extremity finger ring film dosimeters were worn on both hands, and individual results were recorded for each hand. It has not been determined when this practice started, but it was in place in the December 31, 1956, dose record (Author unknown 1956) and included what appears to be the same exchange periods.

In cases of lost or destroyed dosimeters, results were derived from past results of similar work, coworker results, or the product of instrument measurements and time spent in the radiation zone. These practices are typical of sites with similar circumstances.

Neutron doses were measured with neutron track analysis, type A (NTA) film beginning with the start of reactor operations and the use of Van de Graaff accelerators. Both fast and thermal neutrons were measured and recorded as whole-body (WB) dose in rem. The NTA film is not effective at energies

<0.5 MeV or at exposures of <50 mrem (ORAUT 2009b). However, cadmium and lead filters over the beta-gamma film were included in the film holder. The difference in densities behind these filters provides a means of detecting thermal neutrons via a neutron-gamma reaction in the cadmium filter. The thermal neutron dose, if any, was included with the dose detected by the NTA film. It has not been determined what quality factors (QFs) were used. However, because a Po-Be neutron source was used for calibration, a reasonable assumption would be QF = 10 (Garcia 1970).

Missed doses for unmonitored employees could be as much as 500 mrem or 10% of whatever standard was in effect at the time of employment as allowed by AEC and its successors (AEC Manual Chapter 0524 and DOE Order 5480.11). However, the site policy was that everyone who entered a controlled area was issued a dosimeter (AI 1960a). To allow for the possibility that this policy was not followed or that records may not be available, an external dose coworker study has been published (ORAU 2009a). The unmonitored workers may have been exposed to annual doses, above background, ranging from 10 to 40 mrem (ORAUT 2007) if they worked in Area IV.

Table 6-1 lists the periods of use, types of dosimeters, exchange periods, MDLs, and estimated annual missed doses.

Table 6-1. Estimated annual missed photon, beta, and neutron dose (rem).

Period[a]	**Dosimeter**[b]	**Exchange period**	**MDL**[c]	**Estimated annual missed dose**[d]
1954–1962	Pocket dosimeter (PIC)	Daily	0.005	0.625
		Weekly	0.04	1.04
	Site-specific two-element film	Biweekly	0.04	0.52
		Monthly	0.04	0.24
1963–1979	Landauer multielement film	Monthly	0.04[e]	0.24
		Quarterly	0.04	0.08
1980[f]–present	Landauer multielement film	Quarterly	0.01[g]	0.02
1954–1989	NTA film	Bi-weekly	<0.05	0.650
		Monthly	<0.05	0.300

a. Estimated use periods for first entry. Landauer or its predecessor was the vendor in 1963 and maybe earlier (Garcia and Carpenter 1963a).
b. Neither the actual number of dosimeter elements of the first entry dosimeter nor the period of use of PICs has been determined.
c. Estimated MDLs for each dosimeter in the workplace even though many doses were reported at less than the MDL.
d. Estimated annual missed dose calculated using MDL/2 from NIOSH (2002).
e. Based on NAS (1989).
f. Neutron dosimeters continued monthly exchanges (Tuttle 1979).
g. Yoder (2005).

6.3 RADIATION ENERGIES AND PERCENTAGES AT SELECTED FACILITIES

As described in ORAUT (2006a), there were many different types of facilities and processes at SSFL and other facilities during their periods of operation; these include reactors, critical test facilities, fuel preparation and postirradiation examination facilities, accelerator and calibration facilities, and support facilities. Most reactors were low power (a few kilowatts), with the maximum being 20 MWt, and all had relatively short operating histories. The major accelerator was a Van de Graaff (Deuterium-Tritium) machine producing neutrons with a maximum energy of 14 MeV. The fuel examination and manufacturing facilities, reactors, and critical facilities handled fissionable fuels with various enrichments, mostly compounds of uranium including carbides. They also handled relatively small quantities of plutonium and thorium with the exception of Buildings 4023, 4029, 4030, and 4363. SSFL did not perform chemical separations of irradiated fuel and, therefore, there were minimal gross fission product problems. The Canoga facility performed some nuclear fuel reprocessing experiments, but the metallic uranium had not been highly irradiated according to one of the workers (Miles 2009). SSFL did declad some fuels in the hot cells, which resulted in considerable quantities of those fission products with high fission yields (e.g., ^{90}Sr and ^{137}Cs). There was some ^{152}Eu and ^{154}Eu along with some ^{3}H. Tables 6-2 and 6-3 list the facilities and related data.

Table 6-2. Beta and photon energies and percentages at reactors and critical facilities.

Process/ building	Description[a]	Operations Begin	Operations End	Radiation type	Energy (keV)	Percentage
All	Reactors	1956	1980	Beta	>15	100
				Photons	30–250	25
					>250	75
4143	SRE reactor	1957	1964	Beta	>15	100
				Photons	30–250	25
					>250	75
4010	SNAP Experimental Reactor and SNAP 8 Development ReactorS8ER	1959	1965	Beta	>15	100
				Photons	30–250	25
					>250	75
4024	SNAP 2 Development ReactorS2DR	1961	1962	Beta	>15	100
	SNAP 10 Flight Simulation ReactorS10FS3	1965	1966	Photons	30–250	25
	SNAP test facilities	1971	1971		>250	75
4028	Shield Test Reactor and Shield Test and Irradiation ReactorSTIR	1961	1972	Beta	>15	100
				Photons	30–250	25
					>250	75
4059	SNAP 8 Development ReactorS8DR	1968	1969	Beta	>15	100
				Photons	30–250	25
					>250	75
4009	Organic Moderated ReactorOMR, and Sodium Graphite ReactorSGR	1958	1967	Beta	>15	100
				Photons	30–250	25
					>250	75
4100	Advanced Epithermal Thorium ReactorAETR	1960	1974	Beta	>15	100
				Photons (thorium)	30–250	25
					>250	75

a. SNAP = Systems for Nuclear Auxiliary Power; SRE = Sodium Reactor Experiment.

6.4 NEUTRON RADIATIONS AND PERCENTAGES

Table 6-4 lists facilities with neutron radiations. They are reactors, accelerators, and fuel storage facilities. The table includes the plutonium fuel storage facilities, Buildings 4005 and 4064, which were used for Pu storage from 1967 to 1987 and from 1958 to 1993, respectively. However, these facilities are assumed to be a negligible contributor to neutron doses due to the limited quantities of fuel present at any one time. NTA film was implemented in 1956 to measure personnel exposures to the “degraded fission spectrum” that was expected from facilities such as the SRE. A study performed at the time showed that SSFL had a good understanding of the shortcomings of NTA film (AI 1956). Initially, NTA film was incorporated in the film dosimeters if there was a potential of exposure >100 mrem/month whole bode dose in those facilities where neutron exposures were possible (AI 1960b, AEC 1963). How that was determined has not been found. However, it appears that NTA film was added for specific locations where neutrons were a concern (AI 1960b). In the dose record, there are entries in the “n” column. The dose recorded was the sum of fast neutron exposure and thermal neutron exposure, if any.

A neutron survey report of the SRE Hot Cell containing a 14-MeV neutron generator (Clow 1966) lists dose rates of 75 mrem/hr fast and 11.8 mrem/hr thermal with “the assumption that all fast neutrons are 14 MeV." Clow also states, "As further surveys are taken and the spectrum completely analyzed, the dose rates may be reduced." These surveys were done on the roof of the facility and were higher than those taken at "a window" (62.2 mrem/hr fast and 7.1 mrem/hr thermal) or "at the console" (7.1 mrem/hr fast and 2.2 mrem/hr thermal). The Van de Graaff accelerator with its D-T reaction generates 14-MeV neutrons that are quite monoenergetic in the 0° and 180° directions (Etherington 1958), which might support the assumption that all fast neutrons can be treated as 14 MeV.

Table 6-3. Beta and photon energies and percentages at support facilities.

Building	Description	Operations Begin	Operations End	Radiation	Energy (keV)	Percentages
*SRE-4003, 4163, 4041, 4654, 4689, 4653, 4606, 4773	Support facilities	1954	1964	Beta	>15	100
				Photons	30–250	25
					>250	75
*4020	Hot Laboratory	1957	1988	Beta	>15	100
				Photons	30–250	25
					>250	75
*4064	Fuel Storage	1958	1993	Beta	>15	100
				Photons	30–250	25
					>250	75
4011	Radiation Instrument Calibration Laboratory	1984	1996	Beta	>15	100
				Photons	30–250	25
					>250	75
*4021/4022	Radiation Materials Handling Facility	1959	Present	Beta	>15	100
				Photons	30–250	25
					>250	75
4100	Calibration Laboratory	1985	Present	Beta	>15	100
				Photons	30–250	25
					>250	75
4363	Mechanical Component	1956	1963	Beta	>15	100
				Photons	30–250	50
					>250	50
4029	Radioactive Measurement Laboratory	1959	1974	Beta	>15	100
				Photons	30–250	25
					>250	75
4030	Van de Graaff accelerator	1960	1964	Beta	>15	100
				Photons	30–250	25
					>250	75
4023	Liquid Metal Component Testing	1962	1986	Beta	>15	100
				Photons	30–250	50
					>250	50
*4005	Union Carbide Fuel Pilot Plant	1964	1967	Beta	>15	100
				Photons	30–250	25
					>250	75
*4055	Nuclear Materials Development Facility	1967	1979	Beta	>15	100
				Photons	30–250	25
					>250	75

*For operations involving Th-232, 1964 and 1979.

Table 6-4. Facilities, neutron energies, percentages, and correction factors.

Facility	Source	Neutron energy (MeV)	Default dose % and correction factors
Reactors	Reactors	0.1–2.0, W_R=20	100% Correction factor = 1.91
Pu fuel storage Buildings. 4005 & 4064	Spontaneous fission and alpha- neutron reactions		
4030 Van de Graaff accelerator	D-T reaction	2–14 max, W_R=20	100% Correction factor = 1.32

The distribution of energies and International Commission on Radiological Protection Publication 60 conversion correction factors (ICRP 1991 and ORAUT 2006b) are also listed in Table 6-4. The correction factor for the 2- to 14-MeV energy group was calculated from data in the Y-12 TBD (ORAUT 2009b).

6.5 RECORDED DOSE PRACTICES

Recorded dose quantities at SSFL are given in Table 6-5 and include those provided by the site, Landauer (the site vendor), and special dosimeters (Hart 1979). The special dosimeters were processed by site personnel using site calibrations, and only the results were sent to the vendor for inclusion in the individual's total dose for that period. This could have resulted in different quantities, on occasion, from those listed in Table 6-5.

Table 6-5. Recorded dose practices.[a]

Period	Dosimeter measured quantities	Compliance dose quantities[b]
1954–1962 + NTA film	Beta = OW, mrem[c] Photon (P), mR Fast Neutron (FN), mrem	Skin = OW + P WB = P + FN
1963–1984 Landauer + NTA film	Beta (B) or nonpenetrating, mR Photon (P), mR Fast Neutron (FN), mrem	Skin = (B) + P WB = B + P + FN WB = 0.15 (B-X-ray) + P + FN[d]
1985–present	Nonpenetrating (Npen) Penetrating (Pen) Fast Neutron (FN)	Skin = Npen + WB[e] WB = Pen + neutrons[e]

a. OW = open window.
b. Before 1985, the Landauer assessment or calibration quantity was the roentgen at the surface of the body. In 1985, Landauer switched to International Commission on Radiation Units and Measurements tissue doses to incorporate American National Standards Institute Standard N 13.11 (HPS 1983) and DOE Laboratory Accreditation Performance Program (DOELAP)(DOE 1986) performance testing dose quantities (Yoder 2005).
c. Garcia and Carpenter (1963 b) discusses the use of eye and gonadal shields that, if used, reduced beta values by a factor of 2.
d. Garcia and Carpenter (1963 b).
e. Garcia (1970).

Garcia and Carpenter (1963a) provided a formula for correcting beta doses measured by the special dosimeters that is different from that in Garcia (1970). The differences are not great and are limited to beta dose corrections. The differences could be the result of a change from DuPont to Kodak film, which could have occurred in the period between the two procedures. Landauer changed to Kodak film in 1968 with the introduction of its Gardray film badge (Yoder 2005).

6.6 INTERPRETATION OF REPORTED DOSES

Table 6-6 summarizes the guidance on the interpretation of reported doses. Personnel doses from Landauer before 1985 were reported in milliroentgen as either penetrating (photon) or nonpenetrating (beta) exposure if beta activity was present. The reported total values included any special dosimeter results sent by SSFL for that exchange period. Dose reconstructors should obtain organ doses, as needed, from *External Dose Reconstruction Implementation Guideline* (NIOSH 2002).

In general, reported doses have been corrected for background using site-furnished controls. The controls were dosimeters at locations on the site used for storing personnel dosimeters. All personnel dosimeters were stored in storage racks when workers left the site at the end of their shifts. No workers took their dosimeters home at night; all were kept at the site and, as far as could be determined, this practice was in place since startup.

The exception to background correction could occur if individual dosimeters were not exchanged in time to be included with the regular exchange because controls were sent only with each exchange batch. While this could lead to an incorrect result, that result would be favorable to claimants because it would include background and, therefore, err on the high side (Rowles 1988).

Table 6-6. Interpretation of reported dose.

Period	Reported quantity	Description	Interpretation of zeros[a]	Interpretation of blanks (no data)	Rollup of individual and annual data[b]	Monitored/ unmonitored
1954–1962	Skin = rad WB = mR Neutrons = rem	mrad, mR, and mrem used interchangeably	MDL/2 times number of zeros	If no dosimeter for that period, treat as unmonitored.	If special dosimeters were used, include results.	All personnel expected to be exposed to >100 mrem in an exchange period were required to be monitored.
1963–present	Skin = mrem WB = mrem Neutrons = mrem	mrem used for all	MDL/2 times number of zeros	If no dosimeter for that period, treat as unmonitored.	If special dosimeters were used, include results.	Workers entering controlled areas were required to wear a dosimeter.

a. The missed dose is calculated by assigning a value of MDL/2 to all recorded doses <MDL/2 which includes zero values. See guidance in IG-001 (NIOSH 2007b).
b. If special dosimeters were used, the results were forwarded to the vendor for inclusion in the totals for that period. It has not been determined if this was always accomplished.

6.7 EXTERNAL COWORKER STUDY

A external coworker study has been published to provide information to allow dose reconstructors to assign doses that are based on site coworker data to workers who were employed at Area IV and associated sites and for whom there is no or limited monitoring data (ORAUT 2009a).

6.8 ADJUSTMENTS TO RECORDED DOSE

Because most but not all penetrating photons are above 30 keV, it is suggested that an adjustment is necessary to account for the contribution to *Hp(10)* from low-energy photons from uranium and thorium. It is estimated that a correction equal to 10% of the <250-keV values should be made. Corrections are made for each energy group. Table 6-2 should be consulted for the applicable facility specific energy fractions. This adjustment also increases the nonpenetrating *Hp(0.07)* dose, regardless of which dosimeter was used, because that dose was always the sum of the OW and WB doses. Table 6-7 lists these corrections. The fading correction for NTA film is about 9%/week (Meyer 1994), and the angular dependence correction factor is 1-3 (Kathren 1965).

Table 6-7. Adjustments to recorded dose.

Period	Dosimeter	Facility	Adjustments to reported dose	
			Photon Energy	Multiply by
1954–1963	Site-specific	All facilities	30-250 keV	1.1
			> 250 keV	1.0

1963–1985	Landauer	All facilities	30-250 keV	1.1
			> 250 keV	1.0
1985–present	Landauer	All facilities	30-250 keV	1.1
			> 250 keV	1.0

6.9 BIAS AND UNCERTAINTY

Bias and uncertainty values were not found in any site data. The uncertainty factors in Table 6-8 are proposed based on judgment of uncertainty of dosimeter performance in the site specific fields.

Table 6-8. Uncertainty.[a]

Dosimeter	Uncertainty Factor[a]
Two-element Film Dosimeter (1954-63)	1.4
Multi-element Film (1964-present	1.3
NTA Film (1954-present) (2-14 MeV)	1.3
NTA Film (1954-present) (0.1-2 MeV	1.5

a. Estimated variability of measured dose based on dosimeter technology as used in site radiation fields for long term workers.

6.10 ATTRIBUTIONS AND ANNOTATIONS

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

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GLOSSARY

accreditation
Recognition that a dosimeter system has passed the performance criteria of the DOE Laboratory Accreditation Program (DOELAP), (DOE 1986), in specified irradiation categories or the National Voluntary Laboratory Accreditation Program (NVLAP).

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

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.

favorable to claimants
Using a process of estimation based on technical considerations such that the estimated dose is not underestimated.

deep dose equivalent [*Hp(10)*]
The dose equivalent at the respective depth to 10 millimeters in tissue.

dose equivalent (*H*)
The product of the absorbed dose (*D*), the quality factor (*Q*), and any other modifying factors. The special unit is the rem. When *D* is expressed in gray, *H* is in seiverts (1 sievert = 100 rem.)

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.

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

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

exposure
A measure expressed in roentgens of the ionization produced by gamma (or X) rays in air.

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 within 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.

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.

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

nonpenetrating dose [*Hp(0.07)*]
Designation (i.e., NP or NPen) on film dosimeter reports that implies a radiation dose, typically to the skin of the whole body, from beta and lower energy photon radiation.

open window (OW)
Designation on a dosimeter that implies the use of little or no shielding. It commonly is used to label the film response corresponding to the open window area.

penetrating dose [*Hp(10)*]
Designation (i.e. P, Pen, or Neutrons and Gamma) on a dosimeter of the dose recorded at depth of 10 millimeters.

personal dose equivalent [*Hp(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. The personal dose equivalent is represented by *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 millimeter and is noted as *Hp(0.07)*. For penetrating radiation of significance to whole-body dose, d = 10 millimeters and is noted as *Hp(10)*.

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

PM
A procedure detailing specific actions or directions and usually limited to one service or activity.

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

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

rem
A unit of dose equivalent in human tissue equal to the product of the number of rads and the quality factor and any other modifying factors. The word derives from roentgen equivalent in man.

rep
Historically, used extensively for the specification of permissible doses of ionizing radiations other than X-rays or gamma rays. Several definitions have appeared in the literature but the most widely adopted is a unit of absorbed dose with a magnitude equal to 93 ergs per gram. The word derives from roentgen equivalent physical.

roentgen
A unit of exposure to gamma or X-rays. 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 kilogram of dry air. An exposure of 1 roentgen is approximately equivalent to an absorbed dose of 1 rad in soft tissue.

sievert
The International System unit for dose equivalent (1 sievert = 100 rem).

skin dose
Absorbed dose at a tissue depth of 0.07 millimeters (7 milligrams per square centimeter).

tissue equivalent
Term used to imply that the radiation response of the material being irradiated is equivalent to tissue.

whole-body dose
Commonly defined as the absorbed dose at a tissue depth of 10 millimeters (1,000 milligrams per square centimeter); also used to refer to the "dose of record."

X-ray
Ionizing electromagnetic radiation of extra-nuclear origin.