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☐ New ☒ Total Rewrite ☐ Revision ☐ Page Change

FOR DOCUMENTS MARKED AS A TOTAL REWRITE, REVISION, OR PAGE CHANGE, REPLACE THE PRIOR REVISION AND DISCARD / DESTROY ALL COPIES OF THE PRIOR REVISION.

PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
10/10/2003	00	First approved issue. Initiated by Edward D. Scalsky.
01/09/2004	01	Approved Issue of Revision 01. Initiated by Edward D. Scalsky.
10/05/2006	01 PC-1	Approved page change revision to add updated required language on page 8 in Section 6.1. Adds Purpose Section (6.1.1) and Scope Section (6.1.2) to page 9. Makes reference to ORAUT-OTIB-0017 on page 10 in Section 6.2 for guidance to be used. Adds two references to pages 56 and 58 in Reference Section. No changes occurred as a result formal internal review. Incorporates NIOSH formal review comments. 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 Edward D. Scalsky. Signature on File 09/02/2006 Edward D. Scalsky, Document Owner Signature on File 09/05/2006 John M. Byrne, Task 3 Manager Signature on File 09/29/2006 Edward F. Maher, Task 5 Manager Signature on File 10/03/2006 Kate Kimpan, Project Director Brant A. Ulsh Signature on File for 10/05/2006 James W. Neton, Associate Director for Science
11/21/2006	02	Approved Revision 02 to incorporate SC& A comments and responses to claimant concerns. Constitutes a total rewrite of document. Incorporates internal and NIOSH formal review comments. 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 Edward D. Scalsky.
06/05/2007	03	Approved revision initiated to include Attributions and Annotations. No further changes occurred as a result for formal internal review. Incorporates formal NIOSH review comments. 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 Edward D. Scalsky
01/07/2010	04	Revision initiated to incorporate neutron and photon measurement data collection and analysis of Hanford once-through cooling production reactors, 200 Area Plutonium Facilities, 300 Area and Miscellaneous Research Facilities with potential neutron exposure, and coworker analyses previously contained in ORAUT-OTIB-0030. Incorporated formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Fred Duncan.

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ACRONYMS AND ABBREVIATIONS

AP	anterior-posterior (X-ray)
AEC	U.S. Atomic Energy Commission
CEDR	Comprehensive Epidemiologic Data Resource
cm	centimeter
CP	Cutie Pie (measurements)
CTW	Construction Trade Worker
d	day
DCF	dose-rate conversion factors
DOE	U.S. Department of Energy
DOELAP	DOE Laboratory Accreditation Program
DUN	Douglas United Nuclear, Inc.
EEOICPA	Energy Employees Occupational Illness Compensation Program Act
EURATOM	European Atomic Energy Community
eV	electron-volt
FFTF	Fast Flux Test Facility
FR	*Federal Register*
ft	foot
gal	gallon
GE	General Electric Corporation
GM	geometric mean
GSD	geometric standard deviation
H&S	Health and Safety
HAPO	Hanford Atomic Products Operations
HEW	Hanford Engineer Works
HMPD	Hanford Multipurpose TLD
$H_p(d)$	Personal Dose Equivalent at depth d in tissue
HQ	Headquarters
hr	hour
IARC	International Agency for Research on Cancer
ICRP	International Committee for Radiological Protection
in.	inch
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt
LOD	Limit of Detection
m	meter
MED	Manhattan Engineer District
MeV	megaelectron-volt
MDL	minimum detection level
Mg	milligram
Min	minute
mm	millimeter

mR	milliroentgen
mrem	millirem
mSv	millisievert
MW	megawatt
MWD	megawatt-day
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NOCTS	NIOSH-OCAS Claims Tracking System
NP	neutron-to-photon
NRC	U.S. Nuclear Regulatory Commission
NTA	Eastman-Kodak Nuclear Track, Type A emulsion
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
ORNL	Oak Ridge National Laboratory
OW	(Hanford) designation of open window (i.e., no filter) nonpenetrating dose
PFP	Plutonium Finishing Plant
PFPP	Plutonium Fuels Pilot Plant
PIC	pocket ionization chamber (i.e., “pencil” dosimeter)
PNNL	Pacific Northwest National Laboratory
POC	probability of causation
PRTR	Plutonium Recycle Test Reactor Facility
PUREX	Plutonium-Uranium Extraction Plant
R	Roentgen
RBE	Relative Biological Effectiveness
RCT	Radiation Control Technologist
RECUPLEX	Recovery of Uranium and Plutonium by Extraction
REDOX	Reduction Oxidation Plant
REIRS	Radiation Exposure Information Record System
rem	radiation equivalent man
RG	Rubber Glove
RL	DOE Richland Operations Office
RM	Remote Mechanical
RMA	Remote Mechanical A (line) series of gloveboxes
RMC	remotely operated series of gloveboxes
S	(Hanford) designation of penetrating dose behind 1 mm thick silver filter
SEC	Special Exposure Cohort
SRS	Savannah River Site
TBD	technical basis document
TED	track-etch dosimetry
TEPC	Tissue Equivalent Proportional Counter
TIB	technical information bulletin
TLD	thermoluminescent dosimeter
UNI	United Nuclear Industries
U.S.C.	United States Code

W	watt
WB	whole-body
yr	year
§	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 can 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 on 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

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

- Radiation from X-rays received in the diagnosis of injuries or illnesses or for therapeutic reasons

6.1.1 Purpose

Hanford was established in 1942 as a major government-owned nuclear weapons production site fabricating reactor fuel, eventually operating nine nuclear material production reactors and building five major chemical separation plants, and producing plutonium for nuclear weapons. Later operations included nonmilitary applications of nuclear energy. The purpose of this TBD is to describe the external dosimetry systems and practices at Hanford. This document discusses historical and current practices in relation to the evaluation of external radiation exposure of monitored and unmonitored workers.

6.1.2 Special Exposure Cohort Petition Information for Hanford

Special Exposure Cohort (SEC) petitions for Hanford are:

Class Added to the SEC

- Employees of DOE, its predecessor agencies, or DOE contractors or subcontractors who were monitored or should have been monitored for internal radiological exposures while working at the Hanford Engineer Works in the 300 Area fuel fabrication and research facilities from October 1, 1943 through August 31, 1946; the 200 Area plutonium separation facilities from November 1, 1944 through August 31, 1946; or the 100 B, D, and F reactor areas from September 1, 1944 through August 31, 1946; for a number of workdays aggregating at least 250 workdays or in combination with workdays within the parameters established for one or more other classes of employees in the SEC (72 FR 55214).

- Employees of DOE, its predecessor agencies, and DOE contractors or subcontractors who worked from September 1, 1946 through December 31, 1961 in the 300 area, or January 1, 1949 through December 31, 1968 in the 200 areas (East and West) at the Hanford Nuclear Reservation in Richland, Washington, for a number of workdays aggregating at least 250 workdays occurring either solely under this employment or in combination with workdays within the parameters established for one or more other classes of employees in the SEC (73 FR 37459).

Class Recommended by NIOSH for addition to the SEC

- All workers of DOE, its predecessor agencies, and their contractors and subcontractors who worked at the Hanford Site in Richland, Washington, from October 1, 1943 to June 30, 1972, for a number of workdays aggregating at least 250 workdays, occurring either solely under this employment or in combination with workdays within the parameters established for one or more other classes of employees included in the SEC (NIOSH 2009).

Dose reconstruction guidance in this document for periods prior to July 1, 1972 is presented to provide a technical basis for partial dose reconstructions for non presumptive cancers not covered within the SEC class through June 30, 1972.

6.1.3 Scope

An objective of this document is to provide a technical basis to evaluate external radiation exposure to workers that can reasonably be associated with Hanford operations under EEOICPA legislation. Consistent with NIOSH guidelines, this document identifies options to adjust historical recorded occupational external dose to account for current scientific methods and protection factors. The methods and concepts of measuring occupational external doses to workers have evolved since the beginning of Hanford operations. In particular, this document presents the methods to prepare worker dose information for input to the NIOSH Interactive RadioEpidemiological Program (IREP).

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 6.11. Attachments A to G are provided for special topics with substantial supporting data such as determination of coworker dose, shallow dose assignment and neutron dose bounding analyses.

6.2 MED/AEC/DOE EXTERNAL RADIATION DOSIMETRY

External radiation dosimetry refers to the measurement of radiation external to (i.e., outside) the body such as occurs with medical X-rays, cosmic rays, or radiation from natural occurring radioactivity in the earth. Primary types of radiation typically significant to exposure to workers are beta, photon (i.e., X-ray and gamma) and neutron radiation, respectively, each with characteristic properties of origin and interaction with matter. Facilities containing X-ray equipment, particle accelerators, nuclear reactors, natural or manmade radionuclides, etc., have potential for external radiation exposure of workers. External Radiation Dosimetry can be contrasted with Internal Radiation Dosimetry, which is concerned with quantification of radiation exposure from radionuclides internal (i.e., inside) to the body.

6.2.1 History of Radiation Safety Guidance

During the early 1950s, the NCRP introduced the concept of permissible dose to replace the tolerance dose concept. The NCRP recommended that the maximum permissible dose to the gonads and blood-forming organs be 0.3 rem (3 mSv) per week in 1954 which corresponds to an annual WB dose limit of 15 rem (150 mSv). In the later 1950s, the potential significance of cumulative radiation exposure to genetic and cancer risks became a concern leading to implementation of the WB dose limit of 5 × (N-18) rem, where N is measured in years. In the later 1980s, changes in the WB dose limit were associated with an NCRP recommendation to limit WB dose to a maximum of 10 rem averaged over 5 years (i.e., average of 2 rem/yr). The historical trend in WB, dose limits, and in comparison with the median and 95th percentile Hanford recorded WB annual doses is presented in Figure 6-1. Hanford administratively controlled the photon dose to 3 R per year beginning in 1954 extending to about 1972. The recommended annual dose limits by applicable scientific and regulatory agencies are shown in Figure 6-1. Appendix D provides a more detailed history of Hanford radiation dose control limits.

6.3 HANFORD OPERATIONS

Hanford operations involved several processes of the nuclear weapons development cycle (DOE 1996, 1997, Marceau et al. 2002) and played a significant role in the U.S. nuclear weapons program. In the 1940s these processes included construction and operation of new industrial scale facilities for nuclear fuel fabrication; nuclear reactor operations; radiochemical separations; refining, finishing and storing plutonium; and handling the associated radioactive waste. Peak production of plutonium was achieved during the latter 1950s to the mid-1960s. Hanford personnel were involved in research and development of reactor systems, nuclear fuel, nuclear weapons and peaceful applications of nuclear technology such as nuclear power plants and radioisotopes for medical diagnosis and therapy. Hanford operations conducted extensive studies of facility design and processes to evaluate potential hazards to personnel as noted in the historical events timeline in Attachment D. As described in Wilson (1987) Central Site-wide and respective 100, 200 and 300 Operational Area safety committees were established and a series of Special Hazard Bulletins were issued by these committees to alert staff to potential hazards and required procedures.

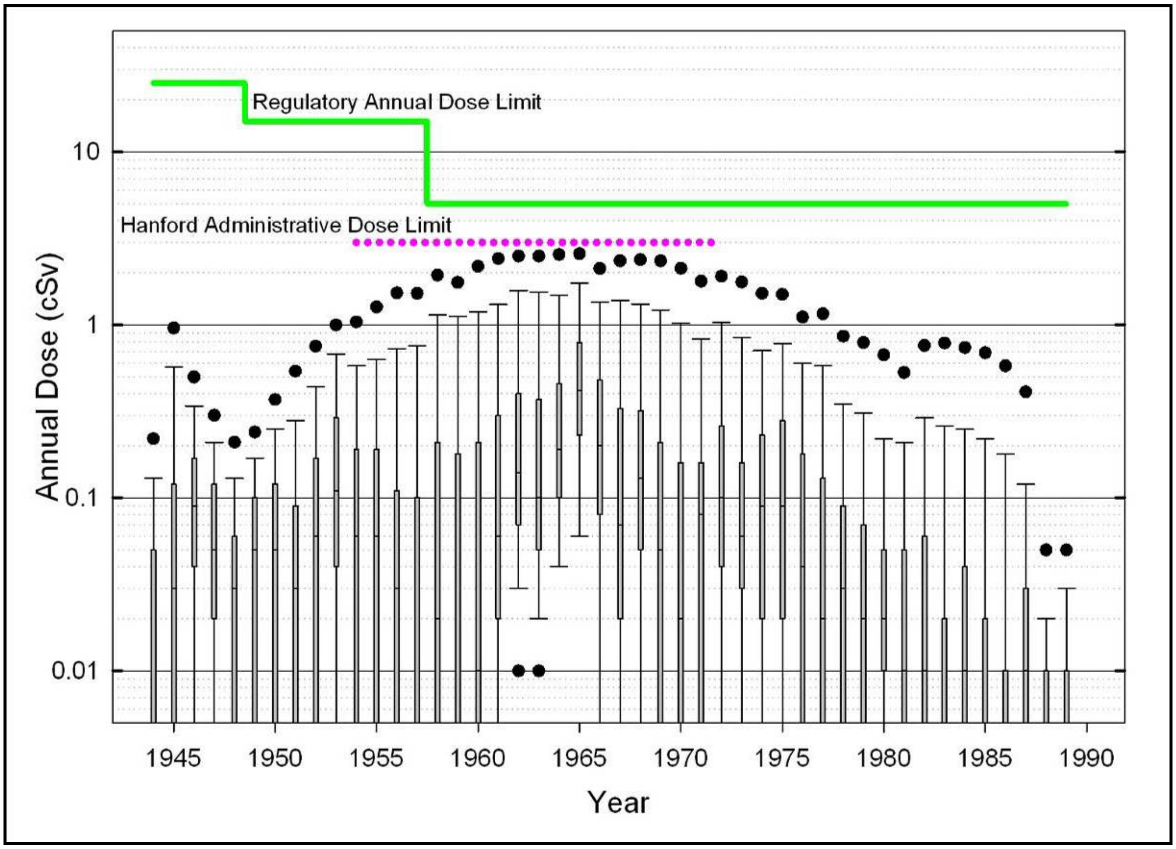

Figure 6-1. Box plot of historical measured Hanford worker whole-body annual doses showing median, whiskers at 25th and 75th percentiles, respectively, and bullets at 95th percentile compared to official and Hanford administrative dose limits.

Records of radiation doses to individual workers from personnel dosimeters worn by the worker and coworkers are available for Hanford operations beginning in 1944 (Buschbom and Gilbert 1993) and reviews of the Hanford personnel dose data for 10- and 15-year periods from Hanford startup in Parker (1954) and Keene (1960), respectively. Doses from these dosimeters were recorded at the time of measurement and routinely reviewed by Hanford operations and radiation safety staff for compliance with radiation control limits. Hanford used an administrative annual external gamma whole body dose limit of 3R per year from about 1950 to about 1972, as shown in Figure 6-1, because of known uncertainties in the measured neutron dose and anticipated future changes in radiation dose limits. The NIOSH External Dosimetry Implementation Guide (NIOSH 2007b) has identified these records to represent the highest quality records for retrospective dose assessments. The information in this section pertains to analyzing these records and has been updated to address parameters regarding skin, testicular, or breast radiation dose that could result from acute beta (electron) radiation exposure under short-term accidental or incident nonroutine workplace exposure profiles. Nonpenetrating radiation during routine operations is also addressed in this section [1].

Radiation dosimetry practices were initially based on experience gained during several decades of radium and X-ray medical diagnostic and therapy applications. These methods were generally well advanced at the start of the Manhattan Engineer District (MED) program to develop nuclear weapons beginning in about 1940. The primary new challenges encountered by MED, and later AEC, operations to measure worker dose to external radiation involved [2] (1) comparatively large quantities of high-level radioactivity, (2) mixed radiation fields involving beta, photon (gamma and X-ray), and (3) neutron radiation with low, intermediate, and high energies.

6.3.1 Radiation Safety Practices

Information regarding routine Hanford radiation safety practices historically is presented in a technical report prepared by Wilson (1987), and for the earliest years in a report by Parker (1946). Table 6-1 lists several of the Radiation Protection Procedures manuals issued prior to splitting the Hanford Site operation among several contractors, each typically with its own guidance manuals, in 1965. The last document in Table 6-1 provides a comparatively detailed summary of Hanford radiation protection limits and practices for almost all years. Attachment D contains a much more detailed summary of Hanford radiation protection WB, skin, and extremity dose limits historically and, in Table D-2, a historical timeline of numerous radiation associated reports and events that tend to illustrate the magnitude of Hanford Radiation Safety practices.

Table 6-1. Hanford pre-1965[a] radiation protection procedures manuals.

Document no.	Description	SRDB ID
HEW-7-703, Parts I and II	*Hanford Engineer Works Operating Standards Manual*-100, 200, and 300 Areas that outline operational limits and criteria.	DuPont 1943–1946
HW-7-4282	*Medical Department, Health Instrument Section, Manual of Standard Procedures–Personnel Meters* issued May 1, 1946, pertaining to administration of the Hanford pencil meter and beta/photon film dosimeter programs.	HEW 1946
HW-46104	*Manual of Standard Procedures for 100, 200 and 300 Area Survey Work*, dated December 1, 1949. This is a comparatively large manual containing radiation exposure limits, contamination limits, Special Work Permits, protective clothing, Special Hazards Bulletins, descriptions of the monitoring equipment and general monitoring information regarding radiation types, selections of instruments, etc.	GE 1949
Manual of Standard Procedures	*Health Instrument Operational Division, Manual of Standard Procedures, Personnel Meters*, issued August 18, 1950. This manual describes procedures used with the radiation instruments and dosimeters.	GE 1950
HW-25457	*Radiological Sciences Department Manual of Radiation Protection Standards*, issued December 15, 1954.	GE 1954
HW-45674	Hanford Irradiation Processing Department issued *Radiation Control Standards and Procedures* manual dated December 14, 1956.	GE 1956
HW-25457, Rev 2	*Manual of Radiation Protection Standards, Hanford Atomic Products Operation, General Electric Company*, issued March 1, 1960.	GE 1960
Procedures Manual	*Hanford External Dosimetry Operations, Operating Procedures*, issued March 25, 1963.	GE 1963
HW-78500	*N-Reactor Radiation Protection and Procedures*, issued January 1, 1964. This document describes Hanford Operations and N Reactor division operational radiation controls.	Vanderbeek 1964
File: 1967-10	DOE-RL Health and Safety Division prepared historical summary of Hanford Radiation Protection Standards and Practices.	Hicks and Yesberger 1967

a. Beginning in 1965, routine Hanford operations were divided among several contractor organizations each typically with a company-specific procedures manual as described in the last entry in this table.

6.3.1.1 Radiological Record Practices

Hanford workers entering operating areas were monitored for exposure to ionizing radiation using assigned pocket ionization chambers (PICs) (January 1944) and personnel dosimeters (March 1944), and records maintained of the measured doses (Wilson 1987). Hanford practice to assign the whole body (WB), skin, and extremity doses maintained in the radiological records from the dosimeter measured unshielded [i.e., open window (OW)] and shielded (i.e., noted by S for 1 mm thick silver shield in the Hanford two-element film dosimeter) is summarized in Table 6-2. Trends in the number of monitored workers and the collective dose for these workers are shown in Figure 6-2. This figure illustrates the number of monitored workers and the number with positive recorded WB dose from photon and neutron radiation, respectively. The trend in measured WB (i.e., photon, neutron, and tritium) dose in this figure does not reveal abrupt changes that might be indicative of significant changes in personnel dosimetry practices or the assignment of dosimeters (Buschbom and Gilbert 1993). However, Figure 6-2 does illustrate an abrupt change in the number of workers with a recorded neutron dose greater than zero. The situation concerning technical limitations to measure neutron radiation dose is discussed later in this TBD. Basically, workers entering a radiological controlled 100, 200, or 300 Area were monitored, the results recorded and the majority of workers had some positive measured dose. Wilson (1987) provides a description of the historical Hanford radiation safety organization, practices, and technology.

Table 6-2. Historical Hanford recorded dose practices [71].

Year	Dosimeter measured quantities	Compliance dose quantities
Two-element beta/photon film dosimeter[a]		
1944–47	OW = open window, mrep	Skin = OW + S
	S = “shielded filter” dosimeter response, mR	WB = S
1948–50	Beta = open window, mrep	Skin = beta + WB
	Gamma = “shielded filter” dosimeter response, mR	WB = gamma
Two-element beta/photon film dosimeter + NTA neutron dosimeter		
1950–57	Beta = open window, mrep	Skin = beta + WB
	Gamma = “shielded filter” dosimeter response, mR	WB = gamma + neutron
Multielement beta/photon dosimeter + NTA neutron dosimeter		
1957–58	Beta	Skin = beta + gamma + 65% X-ray + neutron
	Gamma	
	X-ray	WB = gamma + 0.35% X-ray + neutron
	Neutron	
1959–71	Beta (-B-)	Derma (skin) = beta + WB + 65% X-ray
	Gamma (-G-)	
	X-ray (-X-)	WB (penetrating) = gamma + neutron + 35% X-ray)
	Fast neutron (F-N)	
	Slow neutron (S-N)	
Thermoluminescent dosimeter		
1972–94	Nonpenetrating (NPEN)	Skin = NPEN + WB
	Penetrating (PEN)	
	Slow neutron (SN)	WB = PEN + SN + FN
	Fast neutron (FN)	
1995–2003	Shallow (Sh)	Skin = Sh + Dp + Nt
	Deep (Dp)	WB = Dp + Nt
	Neutron (Nt)	

From 1948-56, when dosimeter quantities for each period were noted as beta or gamma, the cumulative dosimeter dose quantities continued to be labeled as OW and S.

6.3.2 Incidents

External radiation dose from worker involvement in incidents is included in the dose of record for Hanford workers. There have been significant incidents during the history of Hanford. A few primary incidents are described below:

P-11: The purpose of the 120 Building so called P-11 facility was to test critical safe geometries to assist with design of the fuel reprocessing systems and systems at the 234-5 Plutonium Finishing Plant. The P-11 processes were purposely operated near the edge of criticality to determine

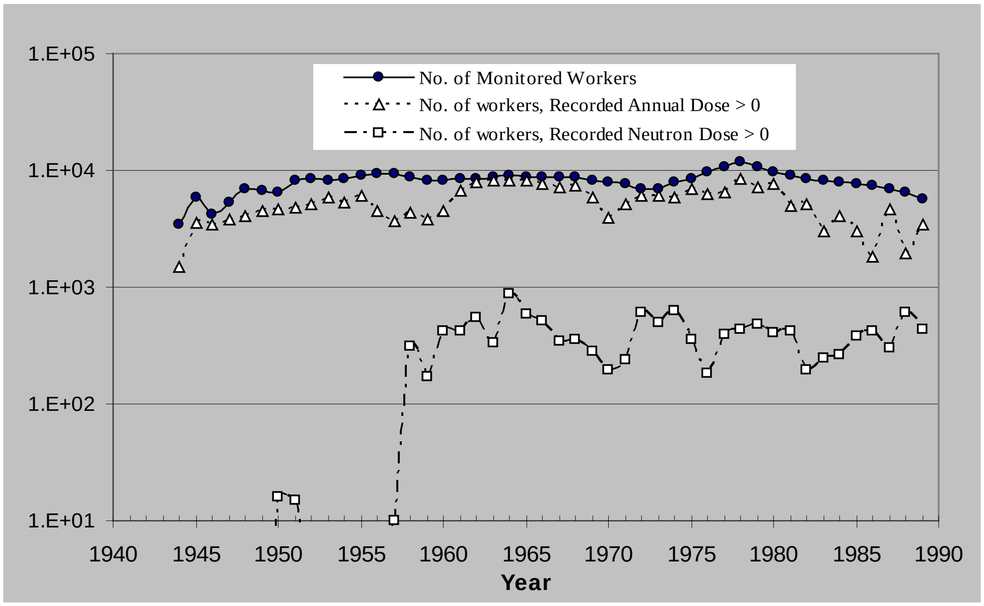

Figure 6-2. Trend in the number of Hanford monitored workers, the number of workers with recorded photon or neutron doses >0, and the total collective dose, 1944–1989 [3].

operational bounds. These bounds were exceeded resulting in a fire during 1950 in the atmospheric exhaust filter systems (Leonard 1952).

RECUPLEX: A criticality accident occurred on April 7, 1962, in a plutonium waste chemical recovery facility called RECUPLEX associated with the 234-5 building. Twenty-four workers were involved, including two patrolmen stationed at the entry gatehouse. Photon doses to workers were measured with personnel dosimeters. Neutron doses were determined from WB counts and blood activation measurements along with measurements of ^{32}P in hair and radioactivity in objects that were on the workers as well as threshold detectors and recording instruments in the building. The highest exposed worker received 23-30 rad from fast neutrons and 63 R to the central part of the body. This person also received about 42-54 rad from the fast neutron radiation to his eyes (Gamertsfelder et al. 1962).

PRTR: A fuel element and pressure tube failure occurred while testing, one of the purposes for the PRTR, a defective nuclear fuel element on January 29, 1965 resulting in extensive contamination of the 309 Building which housed this test reactor (McConnon 1968). The reactor was restarted in 1968 after a significant effort to decontaminate the facility and to redesign some of its capabilities.

^{241}Am Explosion: In 1976, a chemical explosion occurred at Hanford resulting in a nuclear chemical operator being extensively contaminated and receiving an intake of ^{241}Am by skin absorption and inhalation (see Section 5 of the Hanford Site Profile, ORAUT 2007a).

N Reactor: On December 16, 1977, an irradiated fuel discharge occurred exposing four workmen on an elevator resulting in personnel radiation exposures in excess of radiation safety limits. The incident was identified as a Class B occurrence (according to DOE radiation protection guidance. An investigation committee was formed to oversee the process of determination of cause for the accident and the process of dose reconstruction (UNI 1978).

The foregoing are major incidents but the term “incidents” had a much broader meaning historically at Hanford as illustrated in *Radiological Sciences Department Annual Report, 1954* (Mickelson and Staff 1955) which contains the following summary statistics. Apparently any unusual event or deviation from procedure could result in an investigation per the various incidents described in Attachment D, Table D-2.

	Reported radiation incidents			
Year	Informal	Class I	Class II	Total
1944	5	0	3	8
1945	88	35	6	129
1946	85	39	4	128
1947	99	27	2	128
1948	126	38	2	166
1949	121	36	0	157
1950	124	20	5	149
1951	77	25	13	115
1952	130	71	12	213
1953	239	69	26	334
1954	287	76	20	383

6.4 DOSE RECONSTRUCTION PARAMETERS

Examinations of the beta, photon (X-ray, gamma ray), and neutron radiation type, energy, and geometry of exposure in the workplace and the characteristics of the Hanford dosimeter response are crucial to the assessment of error of the original recorded dose in relation to the shallow $H_p(0.07)$ and deep $H_p(10)$ dose equivalent. The bias and uncertainty for current Hanford dosimetry systems are well documented (Rathbone 2002), which is required by the DOE Laboratory Accreditation Program (DOELAP) implemented in 1985 (DOE 1986). The performance of historical dosimetry systems can often be evaluated using current DOELAP and previous (Unruh et al. 1967) testing protocols. Dosimeter response characteristics for radiation types and energies in the workplace are crucial to the overall analysis of error in recorded dose [4].

Overall, accuracy and precision of the original recorded individual worker doses and their comparability to be considered in using NIOSH (2007b) guidelines depend on (Fix et al. 1997a):

- **Administrative practices** adopted by facilities to calculate and record personnel dose based on technical, administrative, and statutory compliance considerations.

- **Dosimetry technology**, which includes the physical capabilities of the dosimetry system, such as the response to different types and energies of radiation, in particular in mixed radiation fields.

- **Calibration and Dosimeter Response Characteristics** of the monitoring systems and similarity of the methods of calibration to sources of exposure in the workplace.

- **Workplace radiation fields** that might include mixed types of radiation, variations in exposure geometries, and environmental conditions.

An evaluation of the original recorded doses based on these parameters is expected to provide the best estimate of $H_p(10)$ and, as necessary, $H_p(0.07)$ for individual workers with the least relative overall uncertainty.

6.4.1 Hanford Historical Administrative Practices

Historically, Hanford had an extensive radiation safety monitoring program to measure exposure in the workplace using portable radiation instruments (Howell et al. 1989), contamination surveys, zone controls, and personnel dosimeters (Parker 1954; Wilson 1987). This was done directly or under the guidance of a specially trained group of radiation specialists (i.e., radiation protection technologists). The results from the personnel dosimeters were used to measure and record dose from external radiation exposure to Hanford workers throughout the history of Hanford operations (Wilson 1987). These dosimeters, as noted in the Health Instrument section of routine reports (Miller 1946; Parker 1948a; also see Table D-2), include one or more of the following:

- Personnel WB beta/photon dosimeters
- PIC dosimeters
- Personnel extremity dosimeters
- Personnel WB neutron dosimeters

Figure 6-3 is an illustration of the dose of record for a single long-term Hanford worker using these dosimeters. Hanford began operations in 1944 using in-house dosimeter and processing technical support. Hanford based its beta/photon film dosimetry methods on the dosimeter design developed at the Metallurgical Laboratory by Pardue, Goldstein, and Wollan (1944). This design was implemented at several of the MED sites. Hanford implemented its individual worker neutron dosimetry methods beginning in 1944 using PICs with a ^{10}B-enriched lining and portable instruments. In 1950, the Eastman-Kodak Nuclear Track, Type A (NTA) emulsion dosimeter capability was implemented [5].

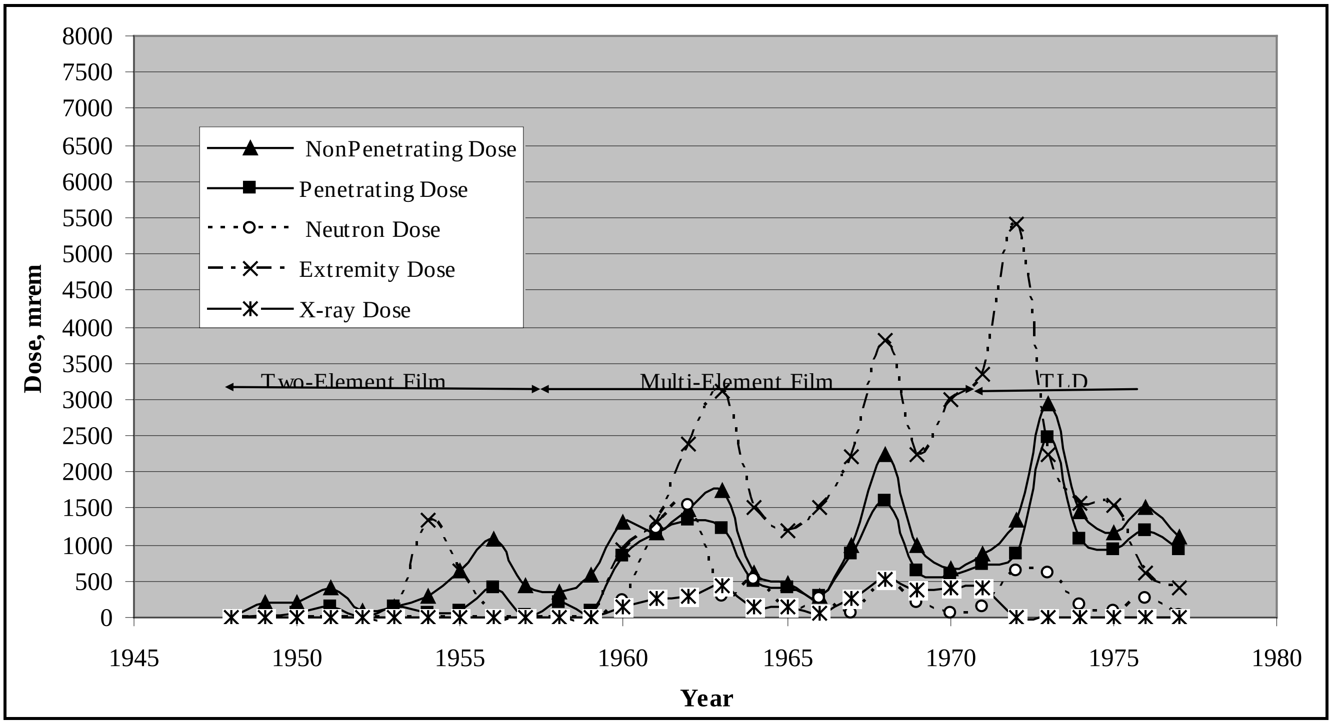

Figure 6-3. Annual dose components for a single Hanford worker, 1948–1976 [7].

Parameters concerning Hanford administrative practices significant to dose reconstruction include [6]:

- Policies to assign dosimeters to workers (Parker 1955).
- Policies to exchange dosimeters.
- Policies to record the measured dose and not using a notional dose (i.e., some identified value for lower dosed workers often based on a small fraction of the regulatory limit).
- Policies to estimate dose for missing or damaged dosimeters.

- Policies to replace destroyed or missing records.
- Policies to evaluate and record dose for incidents.
- Policies to obtain and record occupational dose to workers for other employer exposure.

Hanford policies appear to have been in place for all of these parameters (Parker 1948a; see Table D-2). Routine Hanford practices appear to have required assigning dosimeters to all workers who entered a controlled radiation area (Hart 1967). Dosimeters were exchanged on a routine schedule. All dosimeters were processed and the measured results were recorded and used to estimate dose. There appears to be no use of recorded notional doses, although there are issues of “missed” recorded dose for low-dosed dosimeters (see section on “missed dose”) as well as recorded doses for individual dosimeters at levels less than the statistical Lower Limit of Detection (LOD).

Administrative practices are generally described in Wilson (1987) and contained in the procedures documents listed in Table 6-1. Important Hanford practices include preparation of Special Work Permits (SWPs) (See Table D-2), which were prepared by the tens of thousands in the early years of Hanford operations, to address worker protective measures in the conduct of the task considering radiation types, energies, geometry, contamination, etc., and the use of Special Hazards Bulletins prepared for several general topics such as contaminated instruments, handling injured workers in contaminated areas, radiation zone ingress and egress, etc., used in Site-wide employee training. This was an activity administered through area and central safety committees. A description of the content of the historical recorded dose values for each year by Fix, Carbaugh, and MacLellan (2001) and detailed information for each worker is in the NIOSH claim documentation. The claim documentation provides specific information to be evaluated regarding the recorded dose of record. There does not appear to be any significant administrative practice that would jeopardize the integrity of the recorded dose of record. Gilbert (1990) found agreement between the original paper records and computerized dose records. In addition, thousands of Hanford processed dosimeter films were examined in the 1960s at the University of Pittsburgh as part of the AEC Worker Health and Mortality Study (Mancuso, Sanders, and Brodsky 1966). The evaluation by University of Pittsburgh researchers was that the Hanford recorded dose showed that “good quality control was exercised over the film badge calibration and processing procedures at Hanford over the years (i.e., 1944-61).”

6.4.2 Hanford Personnel Dosimetry Technology

Early Hanford external dosimetry methods were essentially the same as practices adopted at the MED Metallurgical Laboratory (of the University of Chicago) and Clinton Engineering Works (now Oak Ridge National Laboratory [ORNL]) laboratories. Parker (1945) described results of intercomparisons of dosimeter processing and exposure calculations between these three laboratories prior to declaring the Hanford system capable of routine dosimeter processing. Comparisons of dose interpretation among these MED/AEC sites and other sites were done through the years (Wilson 1960a; Wilson et al. 1990). These sites followed a similar evolution in dosimetry technology using PICs in addition to a two-element film dosimeter in the 1940s and early 1950s, multielement film dosimeters in the later 1950s, followed by multielement thermoluminescent dosimeters (TLDs) in the 1960s and 1970s. The adequacy of the dosimetry methods to measure radiation dose accurately is determined from the radiation type, energy, exposure geometry, etc., as described in later sections. The dosimeter exchange frequency was gradually lengthened, generally corresponding to the period of the regulatory dose controls (GE 1954). Major operational events at Hanford associated with radiation have been described in several historical documents (Wilson 1987; Wilson et al. 1990; Fix et al. 1997; see Attachment D.) A brief summary of the dosimetry systems and period of use is presented in Table 6-3.

Table 6-3. Hanford historical dosimetry systems. (See Attachment D, Table D-2 for more detail.)

Date	Description	Exchange
Beta/photon radiation personnel dosimeters		
1/1/1944	PICs assigned to measure dose for each worker prior to film dosimeter availability. Thereafter, PICs used in addition to film dosimeters.(HEW 1946; Wilson 1987).	Daily[a]
10/1944	Two-element (i.e., OW and 1-mm silver filter) film dosimeter issued to personnel (HEW 1946).	Weekly
1/1948	Two-element film dosimeter exchange changed.	Biweekly
1/1950	Extremity film dosimeter implemented.	
4/1957	Multielement film dosimeter implemented.	Biweekly
5/1957	Multielement film dosimeter exchange period changed.	Monthly
1962	Multielement film dosimeter with nuclear accident capabilities implemented.	Monthly
1963	Implemented dosimeter exchange for nonradiological workers.	Quarterly
1/1971	Basic (one-chip) TLD implemented.	Annual[b]
Neutron radiation personnel dosimeters		
1940s	Enriched B-10 lined pocket ionization chambers assigned.	Daily[a]
1950	NTA film was issued to personnel to measure neutron dose.	Weekly
7/1957	Neutron dosimeter (NTA + beta/photon film) implemented	Weekly
7/1958	Exchange period changed.	Biweekly
Beta/photon/neutron personnel dosimeters[c]		
1/1972	Five-chip Hanford Multipurpose TLD (HMPD) implemented.	Monthly
7/1978	Four-chip HMPD implemented.	Monthly
1/1984	Five-chip HMPD reinstated.	Monthly
1/1/1995	Commercial Harshaw TLD system implemented. Routine dosimeter exchange is quarterly and monthly [8].	Monthly

a. Exchange as often as necessary but not to typically exceed 1 day.
b. Basic TLD exchange for nonradiological workers varied but many were exchanged annually.
c. Exchange period varied depending on exposure potential but monthly was routine for radiological workers.

6.4.2.1 Beta/Photon Radiation Personnel Dosimeters

The following paragraphs describe the Hanford beta/photon dosimeters and period of routine use to provide the recorded dose of record.

Pocket Ionization Chamber, 1944. During January 1944, before the Hanford film dosimetry system was operational, PICs were used for a few months to provide the dose of record (Wilson 1987). PICs were issued to employees in duplicate (i.e., two to each worker) and exposures were recorded daily. PICs consist of an electrically charged chamber that indicates radiation exposure as the charge decreases. The decrease in charge occurs from radiation exposure (i.e., ionization) but can also occur from any cause that reduces charge such as humidity, physical impact, etc. Therefore, PICs typically overestimate the exposure from routine handling and environmental effects (Watson 1957). Because of “false-positive” dose from routine handling and environmental effects, the lower of the two readings for each day was used to calculate the dose for comparison with the daily dose limits at that time. Following use as the earliest dosimeters, PICs have been used throughout the history of Hanford operations to provide administrative control of worker dose until the dosimeter being worn was processed and the dose calculated. It has been routine practice since at least the early 1950s to compare the doses measured with PICs and dosimeters and, for significant differences, to document the reason(s) for the discrepancy [9].

Two-Element Film Dosimeter, October 1944 to March 1957. Hanford implemented a two-element beta/photon dosimeter in 1944 based on the design developed by Pardue, Goldstein, and Wollan (1944) at the Metallurgical Laboratories. This basic dosimeter design was used at the Clinton Laboratory (now ORNL) and later by many other MED/AEC/DOE laboratories. The Hanford design consisted of an open window and a 1-mm silver shield. Records of dosimeter film processing identify the regions of the dosimeter film as “OW” for open window and “S” for shielded. A calibration factor for each batch of film was used to convert measured optical density to dose. The optical density and the interpreted dose are included in the original Hanford dosimetry forms. In 1952, the practice was begun to include 20% of the OW dose to the S dose to calculate the penetrating dose in plutonium facilities (Fix, Wilson, and Baumgartner 1997b). However, this practice has not been verified with the actual dosimeter processing results and recorded doses.

Another feature of the Hanford beta/photon film dosimeter was the use of DuPont 502-type film with a sensitive (lower radiation dose response) and an insensitive (typically accident-level dose response) film packet. Normally, only the sensitive film was useful for personnel dose assessment. However, Hanford individual worker personnel dose forms included space to record the insensitive film response. Prior to 1957, the processing data were recorded manually. Worker personnel dose forms were updated each year to enable staff to record dosimeter results directly for each dosimeter exchange period and each operating area. These forms were organized to enable manual entry of dosimeter results and to record the total annual and cumulative dose for each worker [10].

In 1958 (approximately), annual dose data were transferred to the newly implemented Hanford radiological computer database. During entry of the older records, a dose recorded prior to 1958 as a multiple of 5 mrem (0, 5, 10, 15, etc.) was rounded up to the first multiple of 10 mrem (15 mrem became 20, etc.). This provided consistency with the new (computer-based) practice of recording dose only to the first multiple of 10 mrem (10, 20, 30, etc.). This practice is still in use [11].

Multielement Film Dosimeters, April 1957 through December 1971. Hanford used multielement film dosimeters to measure beta, X-ray, and gamma radiation dose components in one of two designs during the periods of 1958 through 1961 and 1962 to 1971, respectively. These “beta/photon” film dosimeters consisted of four shielded regions of film and provided a substantially improved capability to measure the shallow, $H_p(0.07)$, and deep, $H_p(10)$, dose equivalent. Processing results (i.e., optical density) were recorded for the film response behind each filter and an algorithm was used to calculate the dose components. Thirty-five percent of the X-ray dose was assigned to the WB dose of record based on depth dose measurements in water at Hanford for 16-keV k-fluorescent X-ray (Wilson et al. 1990). Water closely simulates the radiation response of tissue. The WB dose also included the assigned neutron dose, as described in this chapter, and beginning in March 1964, the assigned tritium dose based on methods described in Chapter 5 along with other nuclide intake into the body. The tritium dose was recorded separately after 1987. The skin dose of record was calculated as the sum of the WB (i.e., penetrating, 35% of X-ray, neutron, and tritium) and nonpenetrating doses.

Thermoluminescent Dosimeter, January 1972 through December 1994. Hanford has used TLDs in a few configurations. A “Basic” TLD (Kathren 1970) with limited capability for beta and photon (X- and gamma ray) radiation was used from January 1, 1971, through about 1988. This dosimeter, which had one chip, was assigned to personnel with little or no potential to receive dose (Wilson 1987). Hanford Multipurpose TLDs (HMPDs) were used from January 1, 1972, through December 31, 1994, to measure beta, photon, and neutron radiation. HMPDs originally had a five-chip design, which was changed to a four-chip design in July 1977 (Glenn 1977) to enable use of a commercial reader system and then returned to a five-chip design in January 1983 (Fleischman 1982) until the system was replaced on January 1, 1995, with a commercial system. The same filtration was used in the HMPD through all the years of use. These dosimeters were assigned to personnel likely to work in radiation fields. The HMPD was first accredited for performance testing in 1989 by the DOELAP in beta, photon and neutron radiation categories. The system has been reaccredited during later (typically 2-year) accreditation cycles [12].

Commercial TLD System, January 1995–Present. Hanford implemented a commercial Harshaw TLD system on January 1, 1995. This system includes a four-chip beta/photon dosimeter and a separate neutron dosimeter. Technical characteristics are described in the Hanford External Dosimetry Technical Basis Manual (Rathbone 2002).

6.4.2.2 Neutron Radiation Personnel Dosimeters

Hanford has used three general types of neutron dosimeters, which differ substantially in their response to neutron radiation (Brackenbush et al. 1980).

- **Pocket Ionization Chamber.** Prior to 1950, Hanford relied on PICs with enriched ^{10}B liners to detect slow neutron exposure (Wilson 1987).
- **Neutron Track Emulsion.** Hanford used NTA film to measure neutron radiation from January 1, 1950, through December 31, 1971. The film was inserted into the two-element beta/photon dosimeter along with the beta/gamma film until 1958 when a plastic multielement neutron dosimeter with thermal neutron capabilities was implemented.
- **Thermoluminescent Dosimeter.** The HMPD for beta, photon, and neutron radiation was implemented on January 1, 1972. The HMPD was implemented as a 5-chip design with an automated reader system (Kocher et al. 1971). Hanford implemented a commercial Harshaw TLD system on January 1, 1995.

The following paragraphs describe the Hanford personnel neutron dosimeters and their periods of use (Fix, Wilson, and Baumgartner 1997b).

Pocket Ionization Chamber, Prior to 1950. Enriched ^{10}B liners were used in PICs to detect slow neutron exposure (Wilson 1987). This method is generally acceptable to detect the presence of slow neutrons but not for dose measurement. There is no recorded neutron dose for any Hanford worker prior to 1950 (Buschbom and Gilbert 1993).

NTA Film, January 1950 to December 1971. Hanford NTA film, which was introduced on January 1, 1950, was processed independently from the beta/photon film even though the NTA film was typically exchanged along with the beta/photon film. Prior to 1957, NTA film was housed in the two-element beta/photon dosimeter holder along with the beta/photon film. The first Hanford neutron dosimeter was implemented in 1958. This dosimeter had an NTA film to measure fast neutron radiation in addition to sensitive and insensitive beta/gamma film and selected filters (i.e., cadmium, tantalum) to measure thermal neutron radiation. The Hanford policy to process NTA film varied historically but basically involved the practice to read all NTA film for the 200 West plutonium facilities and, for other Hanford facilities, to process the NTA only if the photon dose was at least 100 mrem. This was based on the observation (Watson 1959) that neutron dose was always accompanied by photon dose. For the other facilities, potential neutron dose was considered to be relatively small compared to the photon dose. A neutron dose is recorded for all Hanford workers assigned an NTA film. If it was not processed, a zero neutron dose is recorded. The earliest recorded neutron dose for Hanford workers occurred in 1950 (Buschbom and Gilbert 1993).

Five-Chip HMPD, January 1972 to June 1977. The five-chip HMPD incorporated a neutron dose capability that involved three of the five chips (i.e., 3, 4, and 5). The combination of these chips provided capabilities to estimate thermal (i.e., slow) and fast neutron components with the capability (chip 5) for an accurate beta/photon response correction (i.e., neutron-sensitive chips also respond to photon and high-energy beta radiation) (Kocher et al. 1971). Effective July 1, 1977, the dose algorithm was changed to use data for only four of the chips (i.e., not chip 5) to utilize the four-chip cards that were being implemented (Wilson et al. 1990).

Four-Chip HMPD, July 1977 to December 1983. The HMPD dosimeter was modified to a four-chip design to accommodate introduction of a commercial reader system in the later 1970s that required the dosimeter cards to pivot around the center where chip 5 was located. Tens of thousands of

HMPD cards were fabricated with chip 5 removed. These modified cards were used in the original five-chip holders.

Five-Chip HMPD, January 1984 to December 1994. Routine dose evaluation with the five-chip HMPD was returned to service effective on January 1, 1984. Several refinements were made to this system (Wilson et al. 1990) to prepare for DOELAP performance testing. The HMPD was first accredited by DOELAP for performance testing in neutron categories in 1989 and reaccredited every subsequent (typically 2-year) accreditation cycle thereafter.

Commercial TLD System, January 1995 to Present. Hanford implemented a commercial Harshaw TLD system beginning on January 1, 1995. The neutron dosimeter system was originally a combination TLD and track-etch dosimetry (TED) system but essentially the TLD capability was used for all routine dose evaluations. Routine use of the TED capability has been discontinued because it did not accurately measure worker dose in the workplace (Scherpelz et al. 2000).

6.4.3 Calibration and Dosimeter Response Characteristics

In 1944, when the Hanford two-element personnel dosimeter was being implemented, an intercomparison test was performed with the Metallurgical and Clinton Laboratories to evaluate the dosimetry systems, which were essentially identical (Parker 1945). This testing led to the judgment that the Hanford system could be used for routine personnel dosimetry. The evaluation also concluded that greater attention to beta and low-energy X-rays was needed at Hanford and that neutron films (i.e., NTA) are useful only for higher neutron exposures than would normally occur at Hanford. These statements were made in 1945 prior to operation of many of the Hanford facilities. Later, it became evident that mixed beta/photon radiation fields and neutron radiation presented a significant technical challenge, which led to ongoing research and development in Hanford dosimetry technology [13].

Potential error in recorded dose is dependent on the dosimetry technology response characteristics to each radiation type, energy, and geometry; the methodology used to calibrate the dosimetry system; and the similarity between the radiation fields used for calibration and in the workplace. Early evaluations of Hanford workplace radiation fields were performed, such as for uranium by McAdams (1949a), plutonium surface dose (Roesch 1957; Keene 1957a), and neutron instruments by McAdams (1949b, 1950). The potential error is much greater for dosimeters with significant variations in response, such as the film dosimeters to low-energy photon radiation and the NTA and HMPD response to neutron radiation [14].

6.4.3.1 Hanford Beta/Photon Dosimeters

Hanford dosimeters were originally calibrated using ^{226}Ra gamma, uranium beta, and 80-keV X-rays (HEW 1946). Routine irradiation in air (i.e., no phantom) of calibration film was done for each batch of film. This included 10 exposure levels from 100 to 30,000 mR to ^{226}Ra gamma radiation, 7 exposure levels from 100 to 5,000 mrads to uranium beta radiation, and 7 exposure levels from 100 to 1,000 mR from 80-keV X-ray radiation (HEW 1946). A set of calibration films was processed with all personnel dosimeters even if there was only one personnel assigned dosimeter processed (HEW 1946). In the early 1950s, Hanford k-fluorescent X-ray capabilities were used to develop more precise dosimeter response characteristics for the lower energy photon fields in plutonium facilities (Wilson 1987; Fix, Gilbert, and Baumgartner 1994; Wilson et al. 1990). Studies by Fix et al. (1981, 1982) describe technical characteristics of Hanford recorded dose compared to the delivered $H_p(0.07)$ and $H_p(10)$ dose equivalent based on work performed for Hanford's participation in the DOELAP dosimeter performance testing that was formally required in the latter 1980s (DOE 1986). At that time, it was concluded that a 10% decrease in the recorded dose would result from on-phantom calibration irradiations. This effect is partially compensated by the 3% increase in recorded dose resulting from the ^{137}Cs dose to exposure conversion factor (Fix et al. 1982, Study 2).

No change in the recorded dose is proposed to account for the approximate 7% overestimate in the recorded dose prior to the implementation of on-phantom calibration or other similar comparatively small changes because of the overall uncertainty of changes made over the years. Table C.2 of Wilson et al. (1990) lists a chronology of changes to the Hanford TLD system. Wilson (1960b) measured a standard deviation of ±25% (one-sigma) based on numerous laboratory low-dose level photon irradiations performed to estimate the dosimetry detection level (i.e., about 30 mrem).

6.4.3.2 Hanford Beta/Photon Dosimeter Response Characteristics

Several studies of Hanford film dosimeter performance, stability of latent image, etc., were performed during the 1950s (Wilson 1957a,b, 1960a,b,c). As described in Wilson et al. (1990), many intercomparison and performance studies were done at Hanford and between Hanford and other MED/AEC/DOE facilities. These studies generally confirmed the acceptability of Hanford assessment of nonpenetrating and penetrating dose as defined at that time. Figure 6-4 shows the laboratory measured anterior-posterior (AP) photon energy response of the Hanford dosimeter systems. As noted in this figure, the film dosimeter OW response shows a significant over-response to lower energy photon radiation. Operationally, the over-response was so significant that some option was necessary to interpret the dosimeter OW response based on the anticipated radiation fields in the work environment. Hanford did use 80-kVp X-rays in 1946 (HEW 1946) to calibrate film used in dosimeters assigned to plutonium facility workers. The ratio of the OW to the filtered film response was routinely used in dose evaluation (Larson and Roesch 1954) to improve dose evaluation in mixed fields. An analysis is described in a letter from A. R. Keene to G. E. Backman in 1957 regarding the history beginning in 1949 of using a fraction (0.2) of the OW response to add to the penetrating dose in plutonium facilities with low-energy photons and no beta radiation (Keene 1957b). The Hanford recorded skin dose is calculated as the sum of the OW and S filtered film response. The recorded Hanford WB dose illustrated in Figure 6-3 was calculated using 20% of the OW film response in addition to the measured S film response using the historical Hanford dosimeter testing data in Appendix A of Wilson et al. (1990). As illustrated in Figure 6-3, the calculated WB dose for the lower energy photons characteristic of Hanford plutonium facilities is conservatively estimated using this practice in comparison with $H_p(10)$. The practice is applicable only to workers in Hanford plutonium facilities.

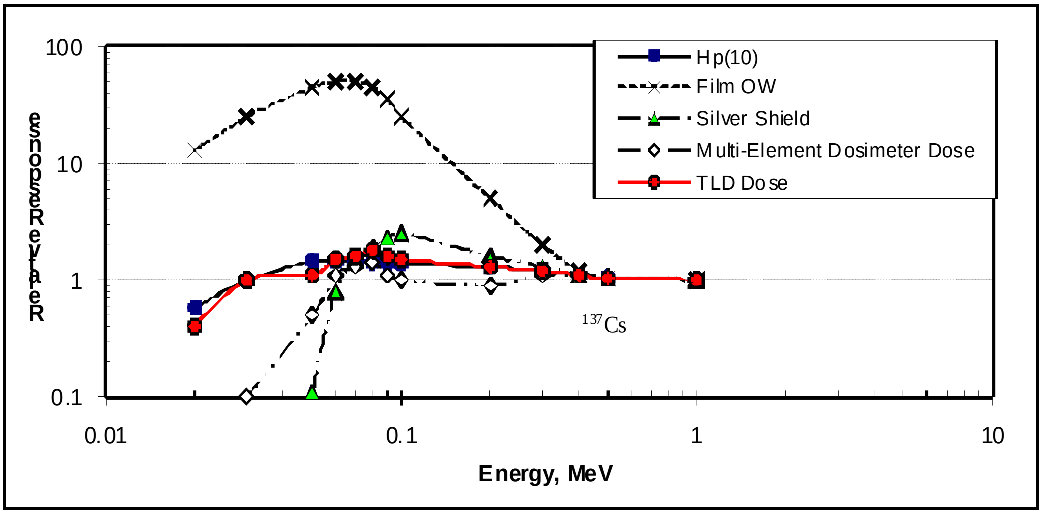

Figure 6-4. Measured Hanford dosimeter photon response characteristics (Wilson et al. 1990).

Several studies of the HMPD were performed (Fix et al. 1981, 1982) in preparing for the DOELAP performance testing that included explicit identification of dose quantities (HPS 1983; DOE 1986) as measured in comparison to what is now referred to as the *Personal Dose Equivalent*, $H_p(d)$, where d refers to a 0.07- or 10-mm depth in tissue. In general, only small changes (±10%) were necessary to improve comparison in laboratory studies with the deep, $H_p(10)$, dose equivalent although additional changes were necessary to improve overall precision (Fix et al. 1982; Wilson et al. 1990).

In recent years, further studies of early dosimeter performance, primarily compared to $H_p(10)$, have been made because of its use in worker health effect studies. The International Agency for Research on Cancer (IARC) conducted a dosimeter intercomparison study to higher energy (i.e., >100-keV) photons of 10 commonly used dosimetry systems used throughout the world (Thierry-Chef et al. 2002). Two of the film dosimeter designs were from Hanford: (1) the two-element dosimeter design (identified as US-2) and (2) the multielement film dosimeter design (identified as US-8). The IARC Study considered that exposure to dosimeters worn by workers could be characterized as AP, rotational and isotropic irradiation geometries, or a combination thereof. Dosimeter response to selected photon energies was measured using two phantoms, which were used to simulate the effect of the worker's body on the measured dosimeter response.

Hanford has conducted performance testing of historical film dosimeter designs using AP (Wilson et al. 1990) and angular (Fix, Gilbert, and Baumgartner 1994) irradiations on a phantom essentially identical to the phantom used in the IARC studies. These studies included lower energy (i.e., <100-keV) photons that are significant in Hanford plutonium facilities. The Hanford study results for energies greater than 100 keV are consistent with the IARC results, showing an overestimate of Hp(10) for the two-element dosimeter. For energies less than 100 keV, the two-element dosimeter will underestimate the photon dose without using some method of adjustment such as a fraction of the dosimeter OW or silver shielded response. This potential under-response is evident in the original University of Chicago two-element dosimeter energy response curve (Pardue, Goldstein, and Wollan 1944).

The performance of the multielement film dosimeter compared to $H_p(0.07)$ and $H_p(10)$ was analyzed using the multielement dosimeter results in Appendix A of Wilson et al. (1990). The results are presented in Table 6-4. This information provides good evidence that the multielement film dosimeter reasonably estimates $H_p(10)$ and $H_p(0.07)$. Application of the practice to include 20% of the OW dose to the penetrating dose applied to Hanford plutonium facilities, if applied to workers in the Hanford reactor and radiochemical facilities with primarily mixed beta and photon fields, would result in a significant overestimate of $H_p(10)$ as noted in Table 6-4 for uranium and $^{90}Sr/^{90}Y$ exposures.

A report by Fix, Gilbert, and Baumgartner (1994) describes laboratory measurements of Hanford film and thermoluminescent dosimeter angular response characteristics used to estimate the bias and uncertainty in recorded Hanford dose using methods developed by the National Research Council (1989) based on considerations of bias and uncertainty in radiological, environmental, and radiation field parameters. The report identifies biases and uncertainties in personnel dosimeter results for photon energies greater than 100 keV. Bias factors were found to primarily depend on the photon radiation energy, the geometry, and the dosimetry system.

6.4.3.3 Hanford Neutron Dosimeters

Historical aspects of Hanford neutron fields, NTA dosimeters, and calibration are described in Roesch (1951, 1954), Swanberg (1959) and Wilson (1960b,c) and a historical evaluation of Hanford NTA and HMPDs described by Fix, Wilson, and Baumgartner (1997b). Brackenbush et al. (1980) describes the energy response characteristics of NTA and thermoluminescent dosimeters, and these are characteristic of Hanford neutron dosimeters. Fundamentally, the NTA dosimeter is capable of an

Table 6-4. Analysis of multielement film dosimeter dose (Wilson et al. 1990).[a]

Source	Exposure (mR)[b]	Delivered dose, mrem[c]		Dosimeter dose			Recorded dose[d]	
		$H_p(0.07)$	$H_p(10)$	Beta	X-ray	Gamma	Skin	WB
16 keV	40	43	15	0	40	0	40	14
	80	86	30	16	78	7	101	34
	160	173	61	106	160	0	266	56
59 keV	30	44	46	0	64	24	88	46
	50	74	77	0	126	37	163	81
	80	118	123	0	216	50	266	126
Cs-137	50	52	52	0	0	50	50	50
	240	247	247	0	0	240	240	240
	750	773	773	0	0	726	726	726
	1,000	1,030	1,030	0	0	993	993	993
Sr-90/Y-90	50	50	0	74	0	0	74	0
	240	240	0	302	4	0	306	1
	750	750	0	1,000	16	0	1,016	6
	1,000	1,000	0	1,340	18	0	1,358	6

a. Wilson et al. 1990, Appendix A, dosimeter data, average value shown in table.
b. Photon dose in mR and beta dose in mrad.
c. Exposure to dose conversion factors from DOELAP Standard (DOE 1986).
d. Skin dose = beta + X-ray + gamma. WB = gamma + 0.35 × beta

accurate dose estimate for higher energy neutron radiation greater than about 1 MeV because the NTA has a lower energy threshold of about 700 keV.

The Hanford TLD (Kocher et al. 1971) has a comparatively high response to thermal neutrons and is generally used to measure neutron radiation scattered from the workers body (i.e., the Albedo effect). The NTA and thermoluminescent neutron dosimeters must be calibrated to neutron spectra similar to that present in the workplace for accurate dose results. There are many Hanford reports on technical aspects of neutron source calibration (Fix, Wilson, and Baumgartner 1997b). Several address the controversy concerning whether a first-collision or multiple-collision neutron dose factor should be used. A significant change based on Hanford studies (Budd 1963) showed no significant statistical difference in response between NTA dosimeters exposed to PuBe and PuF_4 neutron source irradiations in-air and on-phantom. Based on this, the identified action was to change to the multiple-collision Relative Biological Effectiveness (RBE) dose from a single collision RBE dose effective with the 2-week period ending July 12, 1963. The difference in recorded dose between the two calibration references was an increase in recorded neutron dose of about 35%.

6.4.3.4 Hanford Neutron Dosimeter Response Characteristics

Response characteristics of Hanford neutron dosimeters are described generally by Brackenbush et al. (1980), Kocher et al. (1971) and Fix et al. (1997b). Fundamentally, the NTA film response to neutron radiation decreases with decreasing neutron energy with essentially no response less than a “threshold” energy of approximately 400 keV. In actual Hanford workplace radiation fields, the threshold energy is substantially greater because of the NTA film response to photon radiation which makes reading the neutron-induced tracks more difficult and fading of the tracks which is most pronounced for lower energy neutron because the tracks are shorter. The threshold in Hanford plutonium facilities has been reported to be approximately 800 keV (Swanburg 1958). The albedo TLD response is comparatively high at lower energies and gradually declines. The TLD responds to all significant neutron radiation energies in Hanford workplaces albeit proper calibration is essential for accurate dose determination (Kocher et al. 1971; SRDB 15397).

6.4.4 Workplace Radiation Fields

Hanford operations are characterized by significant complex beta, photon, and neutron radiation fields in Hanford reactor, irradiated fuel processing, plutonium handling, and radioactive waste facilities [15]. Generally workplaces can be distinguished between those with significant beta and photon radiation exposures only and those with potential for neutron radiation exposures.

6.4.4.1 Beta/Photon Radiation

Field measurements of beta and primarily photon radiation spectra and dose have been performed on many occasions. Table 6-5 is a summary of several of those measurements that included the photon spectra. It is evident in the results from these measurements that the vast majority of photon dose is associated with higher energy photons with the exception of the plutonium facilities (308, 234-5) where 17-keV X-rays from plutonium and 60-keV photons from ^{241}Am are significant [16].

Another source of workplace measurement data to evaluate beta and photon dose is presented in Nichols et al. (1972), in which data were collected from parallel field testing in 1970 and 1971 of the Hanford multielement film dosimeter and the HMPD that was implemented on January 1, 1972. Measurements were performed using dosimeters placed on water-filled carboys at 49 work locations in the Plutonium-Uranium Extraction Facility (PUREX) Facility, B-Plant, Plutonium Finishing Plant (PFP), 105-KE Building (reactor operating), 100-N (reactor not operating), and the 325-B, 325, and 327 Buildings. Table 6-6 lists the collective nonpenetrating and penetrating dose measured with the Hanford film dosimeter and HMPD and, when available, the open window (nonpenetrating) and closed window (penetrating) ionization chamber “Cutie Pie” (CP) measurements. The latter section of this table includes results of measurements with selected calibration sources. The information in Table 6-6 generally shows variability in the field measurements are similar to those of the calibration sources. A wide range of mixed beta and photon radiation and energies is characteristic of the Hanford facilities. The most significant difference in penetrating dose occurred at the B-Plant. This is likely associated with the relatively high nonpenetrating radiation dose indicative of beta and lower energy photons and the penetrating dose response of the HMPD to higher energy beta radiation as noted in Fix et al. (1982) and Wilson et al. (1990). The HMPD records a penetrating dose for higher energy beta radiation such as ^{90}Sr/^{90}Y, when there should be none, because there is only 380-mg/cm^2 density thickness in the aluminum filter over the HMPD chip used to calculate the deep dose. The nonpenetrating response of the film dosimeter was routinely calibrated with a uranium slab source, whereas a ^{90}Sr/^{90}Y source was routinely used to calibrate the HMPD nonpenetrating response. There is an approximate factor of 2 difference in dosimeter response between these two sources and this is shown in this table (i.e., for ^{90}Sr/^{90}Y source irradiation, 690 mrem for film versus 315 mrem for TLD) [17].

6.4.4.2 Workplace Beta/Photon Dose Fraction

Essentially all Hanford radiological work areas involved beta/photon radiation covering a wide range of energies characteristic of the radionuclides being handled in the facilities and processes. Radiation beta/photon fields characteristic of Hanford facilities can be generally classified according to the IREP code input, radiation types, and energy ranges based on Hanford field measurements, the types of radionuclides and processes in the Hanford facilities. This is presented in Table 6-7 [18].

6.4.4.3 Neutron Radiation

Work areas at Hanford where there is a potential for neutron exposure include [19]:

- 100 Area
  105-B, 105-C, 105-D, 105-DR, 105-F, 105-H, 105-KE, 105-KW, 105-N reactors

Table 6-5. Hanford workplace photon spectra measurements.[a]

Facility	Description	Measurements	Results[b]			Reference
308 Bldg.	Room background	Gamma	Am-241 (100%)			Fix et al. 1981
	Grinder hood bottom	Gamma	Am-241 (100%)			
	Pellet pressing station	Gamma	Am-241 (100%)			
327 Bldg.	Background A-cell	Gamma	Co-60 (85%), Cs-137 (8%), Mn-54 (8%)			
	Background G-cell	Gamma	Co-60 (79%), Cs-137 (9%), Mn-54 (12%)			
200W, 242S	Evaporator building, NE corner	Gamma	Cs-137 (100%)			
200W, diversion boxes	241-TX-302-C catch tank	Gamma	Cs-137 (100%)			
	K2U	Gamma	Cs-137 (100%)			
	Rigging crew	TLD (beta, gamma)	High energy, indicative of photon radiation			
B-Plant (225 Bldg)	A-Cell	Gamma	Cs-137 (100%)			
	Between B-C cells	Gamma	Cs-137 (100%)			
	Between D-E cells	Gamma	Cs-137 (100%)			
	F-cell	Gamma	Cs-137 (100%)			
	Room background	Gamma	Cs-137 (100%)			
271B	Pipe gallery –cell 9	TLD (beta, gamma)	Indicative of ^{90}Sr/^{90}Y			
324 Bldg.	A-cell gallery	Gamma	Cs-137 (100%)			Fix et al. 1982
	C-cell gallery	Gamma	Cs-137 (100%)			
	Truck dock	Gamma	Cs-137 (100%)			
331 Bldg.	Office	Gamma	Tl-208 (90%), Cs-137 (10%)			
	Change room (SE)	Gamma	Tl-208 (8%), Cs-137 (92%)			
	Change room (toilet)		Tl-208 (64%), Cs-137 (36%)			
	Janitor's closet		Tl-208 (46%), Cs-137 (54%)			
340 Bldg.	340-A outside	Gamma	Cs-137 (100%)			
	Control room	Gamma	Cs-137 (100%)			
	Decon area	Gamma	Cs-137 (100%)			
	Operations office	Gamma	Cs-137 (100%)			
3730 Bldg	Irradiation room	Gamma	Co-60 (100%)			
	Hallway	Gamma	Co-60 (100%)			
234-5	Fluorinator hood	Gamma	<200 keV (99+%) 17 keV (~50%)			Roberson, Cummings, and Fix 1985
			Photon energy, keV			
			<200	**200-2000**	**>2000**	
234-5, Vault 4	Vault 4 entrance	Gamma	13%	55%	33%	Roberson and Cummings 1986
234-5, Vault 1	Phantom	Gamma	42%	55%	3%	
	Floor	Gamma	50%	48%	2%	
	Entrance	Gamma	17%	61%	22%	
234-5, MT Room	At hoods near entrance	Gamma	0%	83%	17%	
234-5, C-Line, Room B	Toward neutron source	Gamma	92%	7%	1%	
	Toward room A	Gamma	0%	98%	2%	
	Near entrance	Gamma	58%	28%	14%	

a. Only measurements that included photon spectra are listed.

b. Measured non-natural radionuclide significant to occupational exposure.

Table 6-6. Workplace measured nonpenetrating and penetrating collective doses (Nichols et al. 1972).

	Nonpenetrating, mrad			Penetrating, mrem		
Facility	**Film**	**TLD**	**CP**	**Film**	**TLD**	**CP**
PUREX	4,260	3,790	3,640	3,480	3,570	2,806
B-Plant	10,550	9,510	13,850	2,250	4,560	4,920
PFP	4,060	4,220	(np)	3,920	4,090	5,410
105-KE[a]	9,390	9,150	10,324	9,390	9,100	10,104
105-N[b]	12,070	13,440	7,880	12,030	13,050	7,350
325-B	1,100	1,250	(np)	1,100	1,250	1,760
325	3,690	5,710	5,100	2,640	2,850	3,220
327	870	1,090	(np)	870	1,090	2,260
Calibration sources						
Ra-226	260	310	(np)	260	310	300
PuF$_4$	60	100	(np)	60	100	(np)
Sr-90/Y-90[c]	690	315	(np)	0	100	275
Cf-252	135	180	(np)	135	180	(np)

np=not provided in Nichols et al. (1972).

a. Plant operating.

b. Plant not operating

c. Film calibrated with uranium slab. TLD is calculated with ^{90}Sr/^{90}Y. There is about a factor-of-2 difference; results in this table illustrate this.

Table 6-7. Beta and photon radiation energies and percentages for Hanford facilities.[a]

Process/ buildings	Description	Operations		Radiation type	Energy selection, keV	%
		Begin	End			
Fuel fabrication	Produced reactor fuel and target assemblies from uranium.			Beta Photon	>15 30–250	100 100
	313, 306, 333	1945	1972			
Reactors	**During Operation:** Highly dispersed fields of higher energy photon radiation fields from fission process, activation and fission product nuclides. Potentially narrow beams of higher energy neutron radiation from test ports, etc., into reactor core. Potential for significant airborne nuclides and there might be significant higher energy beta radiation.			Beta photon	>15 30–250 >250	100 25 75
	Not in Operation: Highly dispersed fields of higher energy photon radiation fields from activation and fission product nuclides. No significant neutron radiation. There might be significant higher energy beta radiation during maintenance work resulting from fission products.					
	B Reactor	9/26/44	3/19/46			
		7/2/48	2/12/68			
	D Reactor	12/17/44	6/26/67			
	F Reactor	2/23/45	6/25/65			
	H Reactor	10/29/49	4/21/65			
	DR Reactor	10/50	12/31/64			
	C Reactor	11/18/52	4/25/69			
	KW Reactor	12/54	2/1/70			
	KE Reactor	2/55	1/28/71			
	N Reactor	12/63	1/6/87			
	FFTF	2/9/80	12/93			

Process/ buildings	**Description**	**Operations**		**Radiation type**	**Energy selection, keV**	**%**
		Begin	**End**			
Processing plants	**Radiochemical Operations:** Highly dispersed fields of higher energy photon radiation fields from activation and fission product nuclides dominant to most exposure profiles. Potential for higher energy beta radiation during sampling and maintenance work from fission products.			Beta photon	>15 30–250 >250	100 25 75
	T Plant	12/26/44	3/56			
	B Plant	4/13/45	1956			
	S Plant (REDOX)	1/51	12/67			
	C Plant	7/52	7/67			
	A Plant (PUREX)	1/56	6/72			
		1983	1988			
	U Plant	3/52	1/58			
	UO$_3$ Plant	56				
Plutonium production	**Plutonium Component Production:** Plutonium is machined into weapon components using glovebox assembly process with predominant close anterior exposure to workers. Radiation characteristics in this area involve significant lower energy photons and neutron radiation.			Photon	<30 30–250	25 75
	Plutonium Storage: Radiation characteristics in this area generally involve dispersed lower energy neutron radiation and scattered photons, including 60-keV Am-241 gamma ray.					
	231-Z	1/16/45				
	Plutonium Finishing Plant (234-5Z)	1949	1980			
Calibrations	Hanford Site calibration of instruments and dosimeters			Beta photon	>15 30–250 >250	100 25 75
	3745-A, 3745-B, 318	1945				
Waste handling	Radiation characteristics highly dependent on source of waste, but typically fission product nuclides (Sr/Y-90, Cs-137) are dominant.			Beta photon	>15 30–250 >250	100 50 50
	200 East and West	1953				

a. Hanford documentation (Roberson, Cummings, and Fix 1985; Roberson and Cummings 1986; Rathbun 1989).

- 200 Area
  271-U facility cinder block building attachment to 221-U
  224-T facility to concentrate plutonium solutions and store sources
  231-Z plutonium isolation facility
  232-Z incinerator and leach facility
  234-5Z primary plutonium handling facility
  236-Z Plutonium Reclamation Facility
  242-Z americium recovery facility
  2736-Z plutonium vaults
- 300 Area
  308 Plutonium Fuels Pilot Plant (PFPP)
  309 Plutonium Recycle Test Reactor (PRTR)
  318 Radiological Calibrations Facility
  324 Chemical and Materials Engineering Laboratory
  3745A Calibrations Laboratory
  3745B Accelerator Facility
- 400 Area
  Fast Flux Test Facility (FFTF)

The circumstances of neutron exposure at these facilities are different and can be divided according to the facility of worker primary employment based on the method of primary neutron radiation generation. At the 200 and 300 Area plutonium facilities, neutron radiation is generated from plutonium either by spontaneous fission or, importantly, by alpha particle interaction with light elements such as oxygen, fluorine, and beryllium. These interactions are commonly referred to as alpha-n reactions. At the Hanford 100 and 400 Area nuclear reactor facilities, neutrons are generated by fission of uranium and plutonium in the reactor core. These two methods of neutron generation comprise the majority of the neutron exposure to workers at the Hanford Site. Therefore, this TBD subdivides neutron exposure of workers according to three general areas: (1)100 Area single-pass cooling reactors, (2) 200 and 300 Area plutonium facilities, and (3) 300 Area and Hanford Site research and development facilities. Potential neutron exposure at the 300 area laboratory facilities covers a broad range of research activities in support of the 100 Area reactor facilities; support of chemical processing of irradiated fuel in the 200 Areas; separation, purification and fabrication of plutonium; accelerator; X-ray diffractometers, medical isotope production, etc.

Attachment A presents selected Hanford measurements of neutron spectra (Fix et al. 1981, 1982; Roberson, Cummings, and Fix 1985; Brackenbush, Baumgartner, and Fix 1991; Endres et al. 1996) and dose (Fix et al. 1981, 1982; Roberson, Cummings, and Fix 1985; Brackenbush, Baumgartner, and Fix 1991; Endres et al. 1996; Scherpelz, Fix, and Rathbone 2000) measured at selected Hanford plutonium facilities on many occasions beginning in the 1970s with the availability of modern instrumentation. These measurements used several methods at different times to measure neutron dose, including Tissue Equivalent Proportional Counters (TEPCs), which are considered to provide an accurate measurement of neutron dose (Brackenbush et al. 1991; Scherpelz et al. 2000), as well as other portable neutron survey instruments (Snoopy, remball, etc.) and dosimeters (i.e., HMPDs, commercial TLDs, and TEDs). Neutron energy spectrum measurements primarily used multisphere (Bonner) sphere spectrometers as well as ^{3}He spectrometers, and NE-213 liquid scintillation spectrometers. Table 6-8 summarizes Hanford reports that included measured neutron spectra.

Table 6-8. Hanford workplace neutron spectra measurements.[a]

Facility	Description	Measurements[a,b]	Reference
308 Bldg.	Fuel storage pit area	MS, TEPC, Rascal, HMPD	Fix et al. 1981
	Plutonium storage vault	MS, TEPC, Rascal	
	Fuel pin storage box area	MS, TEPC, Rascal	
	Bare fuel assembly	MS, TEPC, Rascal, HMPD	
234-5Z	Glovebox H-9A	MS, TEPC, Snoopy, HMPD	
	Glovebox HC-9B	MS, TEPC, Snoopy, HMPD	
2736-Z	Six locations in building	MS, TEPC, Snoopy, HMPD	
324 Bldg	Pu storage vault	MS, He-3, TEPC, HMPD	Fix et al. 1982
FFTF	Operating deck	MS, He-3, TEPC, HMPD, Snoopy	
234-5Z	Hood HA-23 Area		
2736-Z	Storage vault, Room 1	MS, TEPC, HMPD	Roberson, Cummings and Fix 1985
	Storage vault, Room 4		
236-Z	Miscellaneous Treatment		
234-5Z	Process line C, Room B		
234-5Z	Pu metal, PuF$_4$ and PuO$_2$ with selected thicknesses of acrylic shielding	MS, TEPC, HMPD	Brackenbush et al. 1991
234-5Z	Frontside–storeroom	MS, TEPC, TLD, TED	Endres et al. 1996
	Frontside–near shops		
	Backside–glovebox		
	Backside–glovebox		
	Pu metal, PuF$_4$ and PuO$_2$ with selected thicknesses of acrylic shielding		

a. Only measurements that included neutron spectra are listed.
b. MS = multisphere, TEPC = Tissue Equivalent Proportional Counter.

6.4.4.4 Workplace Neutron Dose Fraction

The AEC held a series of Personnel Neutron Dosimetry Workshops to address problems experienced by its sites concerning accurate measurement of neutron dose. The first workshop was held September 23–24, 1969 (Vallario, Hankins, and Unruh 1969), with the stated concern: “for intermediate energy (i.e., >0.4 eV to <700 keV) ... neutron sources, NTA personnel neutron dosimeters cannot be effectively used. This leaves a gap in the personnel dosimetry program which at many installations may be quite serious.” The workshops were generally limited to representatives from sites with active personnel neutron dosimetry programs and continued for a number of years. The 11th Workshop was held in 1991 (Rabovsky, Jones, and Pettengill 1991). The significance of the underestimated neutron dose became evident with studies being conducted to implement TLDs.

The HMPD was implemented on January 1, 1972. Hanford dosimetrists conducted detailed field measurements in the early 1970s to base the calibration of the TLD on the neutron energy spectra in the work environment. Studies reported by Nichols et al. (1972) involved the simultaneous placement of NTA dosimeters and TLDs on 2-gal polyethylene jugs filled with water and placed at selected workplace locations. A TEPC was used to measure the dose from fast neutrons. Data from Nichols et al. (1972), which are summarized in Table 6-9, indicate wide variability between the results for the different measurement techniques. However, the data illustrate the general under-response of the NTA film dosimeter results compared with the TEPC and TLD results [20].

Table 6-9. Parallel workplace measured NTA and HMPD neutron dose (Nichols et al. 1972).

Location	Fast neutron dose, mrem			
	Snoopy	TEPC	NTA	TLD
105-KE				
X-1	60	270	0	530
Top #23	1,400	1,700	470	4,100
Mon	0	0	0	60
Front face	50	900	0	250
308 Bldg.				
Rm 208	2,000	2,700	270	3,700
Corr #7	4,200	14,100	1,270	11,100
Vent rm	30	30	0	0
Rm C	700	730	70	870
234-5Z Bldg.				
17 DC	340	NM[a]	0	100
HC-11	280	NM	0	180
9B top stairs	410	NM	100	440
9B under stairs	280	NM	60	450
Rm 221	410	790	170	460
Rm 192	510	620	950	490
Rm 192-C	150	230	310	240
Rm 193	380	500	770	600
2731-Z	200	NM	60	50

a. NM = not measured.

Following implementation of the HMPD on January 1, 1972, AEC headquarters staff conducted a detailed review of recorded neutron dose for Hanford personnel using a committee of technical experts from Hanford, Savannah River Site (SRS), and other AEC facilities (Biles 1972). Central to this investigation was the selection of 18 long-term Hanford workers for detailed evaluation. The AEC study concluded that for plutonium facility workers the neutron dose was underestimated. The study concluded also that no Hanford worker exceeded the WB dose limit of 5 × (N-18) rem using the neutron-to-photon (NP) dose ratios shown in Table 6-10. The study also concluded that because

Hanford was using the best available dosimeter technology there would be no change in the recorded dose of record. The AEC study also concluded that the gamma radiation dose as measured by the film dosimeter was reasonably accurate and comparable with the photon dose measured by the TLD.

Table 6-10. AEC Study NP dose ratios (Biles 1972).

Period	NP dose ratio		Comment
	Plutonium workers	**Maintenance workers**	
1961–1972	2.01	1.60	NP ratio as measured by the TLD during the period of use, January 1–July 1, 1972, is reasonably representative of production conditions since introduction of heavy shielding materials (i.e., lead, lead glass, water walls). [21]
1956–1960	1.36	1.00	NP ratio determined by applying a one-third reduction in the ratio for the period from 1956 through 1960 based on the use of less shielding to reduce exposure from lower energy X-ray and gamma radiation emitted by plutonium. As stated in the report, there was an approximate one-third reduction in photon dose during the period following 1960 when heavy shielding was installed and production was comparable.
1948–1955	1.23	1.00	NP ratio determined by applying another reduction of 10% in the ratio for the period from 1948 through 1955 when essentially no shielding other than thin plastic hood windows were used in the process areas. In the report, it was estimated that low-energy photons contributed about 10% of the penetrating gamma dose.

Attachment A contains neutron spectra measurement results for several Hanford facilities including separation of the dose fraction according to the IREP input energy classifications. A summary of the analysis of the neutron dose fraction for the Hanford facilities with neutron radiation exposure is shown in Table 6-11. For several particularly early facilities extensive effort would be required to retrieve workplace survey data that, even if available, might not contain sufficient neutron spectra data comparable to the measurements done in later years at Hanford with much improved instrumentation. Therefore, the neutron category of 0.1 to 2 MeV was selected on the basis that typically this provides the highest organ dose conversion factors in Appendix B of NIOSH (2007b).

6.5 Monitored Hanford Workers–Measured Dose

Hanford workers were assigned personnel dosimeters on entry into radiologically controlled areas. Workers with one or more recorded dose of record are considered to be monitored. The facilities where work was performed is evaluated from the DOE-provided documentation. Workplace location information usually according to work area only is interpreted from several types of claim documentation, as available, such as:

- Earlier handwritten dosimetry log sheets
- Dosimeter change request sheets
- Temporary dosimeter forms, might have building along with area
- Incident or contamination reports if available
- Maybe training records, but this usually just gives an area
- Computer Aided Telephone Interview
- X-ray examination documentation

If it is not feasible to identify the workplace then “default” facilities are assumed that maximize the calculated dose.

Table 6-11. Hanford facility neutron dose fractions [22].

Process	Description/buildings	Neutron energy (MeV)	Default dose fraction (%)
Reactors	During reactor operation: low-level neutron exposure through shielding on the face of the reactors and through test ports.		
	100 Area B, D, F, H, DR, C, KW, KE, N	0.1–2	100
	300 Area 305, 309, 318 (prior to 1985), 326	0.1–2	100
	400 Area FFTF	0.1–2 2–20	50 50
Plutonium	Plutonium finishing process: plutonium enters the process as PuF_4 and is then fired into production pucks. Work is primarily conducted in gloveboxes with predominant close anterior exposure to workers. Radiation levels at the beginning of the process are fairly constant while levels at end of process are closely related to production levels.		
	Plutonium facilities (200 Areas) (202-A, 224-B, 224-T, 233-S, 231-Z, 232-Z, 234-5Z, 236-Z, 242-Z, 2736-Z)	0.1–2 2–20	90 10
	Plutonium handling facilities (300 Area) (308, 309, 325)		
Research	Hanford 300 Area facilities and some miscellaneous Hanford Site facilities such as the critical mass laboratories were used to test and evaluate processes to be used in the reactor, processing and plutonium production facilities. The 305 test reactor was used to test structural materials and fuel used in the Hanford 100 Areas and 300 Area accelerator and calibration sources were used to test and calibrate Hanford radiation detection instrument and dosimeter systems. A wide range of potential neutron spectra would be expected. However, the selection of the 0.1-to-2-MeV category provides the highest organ dose conversion.		
	100 Area–120 Bldg.	0.1–2	100
	200 Area 209-E, 271-U		
	300 Area 309, 318, 321, 324, 3745A, 3745B		

6.5.1 Photon Dose Adjustments

No adjustment in the recorded neutron dose is considered necessary. The 1972 AEC study stated that the photon dose of record was reasonably comparable between the film and thermoluminescent dosimeters (Biles 1972). The IARC study (Theirry-Chef et al. 2002) and Wilson et al (1990) studies have shown reasonable comparison in the recorded photon dose with the historical Hanford dosimeters with the general observation that generally earlier doses measured with the two-element film dosimeter were likely too high. Hanford did incorporate practices to account for the potential underestimate of the deep dose with the two-element from the low-energy photon dose component in Hanford plutonium facilities. There was also significantly higher energy photon radiation associated with fission product contamination of the plutonium that tends to minimize the potential underestimate.

6.5.2 Photon Organ Dose Conversion Factors

The measured photon dose is used with the dose conversion factors (DCFs) to calculate organ doses of interest using the external dose reconstruction implementation guidelines (NIOSH 2007). For measured photon dose for all years (film badge and TLD), the DCFs from deep dose equivalent to organ dose should be used. Wilson et al. (1990) states “workers are typically facing the work being done, and for routine radiation exposure over long time periods, the front of the torso can be expected to receive the largest cumulative exposure.” As such, it is recommended that the 100% AP (front-to-back) geometry should be assumed for the irradiation geometry and for conversion to organ dose.

6.5.3 Neutron Dose Adjustments

Adjustments to the Hanford recorded neutron dose are necessary to arrive at a favorable-to-claimant dose considering the uncertainty associated with the recorded dose as follows: [23].

- Neutron doses determined prior to January 1, 1972 with the NTA film dosimeter are likely too low and an NP dose ratio as discussed in Section 6.7.3 should be used to assign a favorable dose to the claimant.

- Neutron dose measurements with the workplace performance-validated TLD implemented in 1972 are considered accurate with the exception of a period when the recorded neutron dose was too low due to use of a four-chip Hanford TLD as follows:

  1978 through 1983. Adjusted neutron dose = 1.35 × recorded neutron dose

6.5.4 Neutron Weighting Factor

Adjustment to the neutron dose is necessary to account for the change in neutron quality factors between historical and current scientific guidance as described in NIOSH (2007b). Hanford neutron calibration factors determined from National Institute of Standards and Technology (NIST)-calibrated sources are used directly without modification for field conditions (Brackenbush, Baumgartner, and Fix 1991). The quality factor is incorporated in the NIST calibration methodology, which used flux-to-dose-rate conversion factors for varying neutron energies for each calibration source. Flux-to-dose-rate conversion factors were based on NCRP Report 38 (NCRP 1971). The NCRP report lists both flux-to-dose-rate conversion factors and associated quality factors. Table 6-12 summarizes historical changes in the quality factors, the average NCRP 38 quality factor for the neutron energy groups used as input to IREP, the associated ICRP Publication 60 (ICRP 1991) weighting factor and the ratio to convert from NCRP Report 38 to ICRP Publication 60 (see ORAUT-OTIB-0055, ORAUT 2006a).

Table 6-12. Conversion from NCRP Report 38 (NCRP 1971) neutron quality factors to ICRP Publication 60 (ICRP 1991) weighting factors.

Neutron energy (MeV)	Historical dosimetry guidelines[a]	NCRP Report 38 group averaged quality factor[b]	ICRP Publication 60 neutron weighting factor	Ratio[c]
Thermal	3	2.35	5	2.13
0.5 eV–10 keV	10			
10 keV–100 keV		5.38	10	1.86
100 keV–2 MeV		10.49	20	1.91
2 MeV–20 MeV		7.56	10	1.32
20 MeV–60 MeV		6.96[d]	5	1.00[e]

a. First Tripartite Conference at Chalk River in 1949 (Warren et al. 1949; Fix, Gilbert, and Baumgartner 1994); National Bureau of Standards Handbook 59 (NBS 1954; also known as NCRP Report 17; and Taylor 1971.

b. See Figure 3-1.

c. Ratio of the ICRP Publication 60 weighting factor to the group averaged NCRP 38 quality factor each neutron energy group.

d. “Not applicable” is usually inserted here rather than the NCRP group averaged value of 6.96, which is larger than the ICRP Publication 60 weighting factor of 5 for 20-to-60-MeV neutrons and results in a non-favorable-to-claimant reduction in the corrected dose for this neutron energy group.

e. Ratio for adjusting neutron dose from NCRP Report 38 quality factor to ICRP Publication 60 weighting factor is set equal to unity instead of 0.7 (i.e., 5/6.96) to avoid a reduction in the recorded neutron dose for this neutron energy group.

DOE is in the process of implementing ICRP Publication 60 (ICRP 1991) neutron weighting factors into the routine determination of the recorded neutron dose. For Hanford, this is scheduled to begin effective January 1, 2010. Thereafter, no adjustment in the recorded neutron dose will be necessary. NIOSH is in the process of confirming these dates with DOE for the respective DOE sites.

6.6 MONITORED HANFORD WORKERS – MISSED DOSE

Wilson (1960b) conducted a detailed examination of the LOD for the Hanford dosimetry system used in 1960. The design of the Hanford multielement film dosimeter implemented in 1957 included the OW and 1-mm silver filtered region design of the two-element film dosimeter used at Hanford from

1944 to 1957. Therefore, in the Hanford studies, dose results with these different dosimeter systems could be evaluated as described in Wilson et al. (1990). Wilson (1960b) described three changes in 1960 that led to a lower detection level of about 15 mrem at the 90% confidence level involving: (1) elimination of nonisotropic effect of calibration source, (2) automated film processing and (3) change to the more sensitive DuPont 508 film. He noted in this report a detection level of 40 mrem at the 95% confidence level for the Hanford two-chip dosimeter system with the DuPont 502 film used prior to these changes. An important consideration in this analysis concerned the level of potential missed dose. Wilson describes the analysis of 49 batches of Hanford routine calibration results that indicated a 25% standard deviation at the 30-mrem calibration level based on the optical density readings. Based on an analysis of the capabilities of the densitometer used to process the film, he estimated a likelihood of 0.33 (1/3) that a dose of 15 mrem would not be detected. The likelihood that this would occur for each successive monthly exchange for an entire year would be $(0.33)^{12}$ or about 1 in a million. Based on the 13 exchanges during the year at that time, he estimated a maximum potential missed dose of 195 mrem (i.e., 15 × 13). Conversely, Wilson estimated that about 8% of the time a positive dose would be recorded for dosimeters that received no exposure. A similar analysis could be performed for the dosimeter used prior to 1960 with an estimate that about 30 mrem would be detected one-third of the time.

Hanford did use a practice of locating dosimeters at the badge control building for each operating area for each person expected to routinely enter. Therefore, some Hanford workers had dosimeters simultaneously located at several different Hanford areas. Dosimeters from each of these areas were processed and a dose assigned to the worker. In many cases, a zero dose was recorded for all the dosimeters. Assuming a worker had dosimeters at seven Hanford work areas and using the 40-mrem LOD noted in the previous paragraph for the two-element dosimeter with 502 film, a potential missed dose of 140 mrem (i.e., 7 × 40/2) using OCAS-IG-001 (NIOSH 2007b) for each exchange period or, if this occurred throughout the year, potential missed dose of 1,680, 3,360 and 6,720 mrem for monthly, biweekly, and weekly exchange periods, respectively, could have occurred. Often, the assigned missed dose for a monitored worker with zero recorded dose will unrealistically exceed the dose for other workers with recorded positive dose. It is recommended in this TBD that the guidance of OCAS-IG-001 (NIOSH 2007b) be applied to the recorded dose for each exchange period regardless of the number of dosimeters assigned to a worker (i.e., one for each operating area). Using the analysis of Wilson et al. (1990), the likelihood of all dosimeters reading zero for an exchange period when there is positive dose can be calculated as $(0.33)^y$ where y is the number of areas [24].

The analysis of missed recorded dose for Hanford workers has been separated according to photon and neutron missed dose [25].

6.6.1 Photon Missed Dose

Missed photon dose for Hanford workers occurs when a zero dose is recorded for the dosimeter measured dose for any response less than the site dose recording threshold. Methods to be considered if there are periods during a working career for which no doses were recorded have been examined by Watson et al. (1994). In general, estimates of the missed dose can use dose results for coworkers or the recorded dose for the same worker before and after the period of missed dose. However, these situations require careful examination. The missed dose for dosimeter results is particularly important for earlier years when recording thresholds were higher and dosimeter exchange was more frequent.

NIOSH (2007b) describes options to calculate the missed dose. The recommended option is to estimate a potential missed dose where LOD/2 is multiplied by the number of zero or less than LOD/2 dose results. LODs for the Hanford beta and photon dosimeters normally cited are based on laboratory irradiations. Actual LODs are higher because of additional uncertainty in actual field use and the use of dose recording thresholds. Table 6-13 summarizes the potential missed dose.

Reasonable LODs are listed in this table for most applications for film dosimeters based on Wilson (1960b, 1987), NIOSH (1993), National Research Council (1989), and Wilson et al. (1990) and for TLDs from Fix et al. (1982) and Rathbone (2002).

Table 6-13. Hanford beta/photon dosimeter period of use, type, LOD, exchange frequency, and potential annual missed dose.

Period of use[a]	**Dosimeter**	**LOD[b] (rem)**	**Exchange frequency**
Hanford beta/photon dosimeters			
Prior to October 1944	PIC	0.005	Daily[c] (n=250)
October 1944–December 1950	Hanford two-element film	0.040	Weekly (n=52)
January 1951–March 1957		0.040	Biweekly (n=26)
April 1957–May 1957	Hanford multielement film	0.030	Biweekly (n=26)
May 1957–December 1971		0.030	Monthly (n=12)
January 1972–December 1994	Hanford TLD	0.020	Monthly (n=12)
		0.020	Quarterly (n=4)
January 1995 to 2003 (ongoing)	Harshaw TLD	0.010	Monthly (n=12)
		0.010	Quarterly (n=4)

a. For many years, Hanford workers had a dosimeter assigned to each operating area where they worked.
b. Estimated LODs for each dosimeter technology in the workplace. Dose values were recorded at levels less than the LOD
c. Not routinely exchanged.

6.6.2 Neutron Missed Dose

Neutron radiation was present in the Hanford 100 Area reactors; 400 Area FFTF; 300 Area accelerator (3754B) and neutron source calibrations (3745A, 318 and U-271 Buildings); and 200 and 300 Area plutonium facilities. There is potential for significant missed neutron dose among workers in the plutonium facilities where workers separated and finished plutonium (i.e., 202-A, 224-B, 224-T, 231-Z, 232-Z, 233-S, 234-5Z, 236-Z, 242-Z, 2736-Z, 271-U, 308 Plutonium Fabrication Pilot Plant, 309 PRTR, and 324 laboratory) for use in nuclear weapons. Workers were close to the plutonium and in the early years actually physically moved the plutonium from one work location to the next. The approach recommended for use to calculate the neutron missed dose can be divided into two periods: (1) prior to 1972, and (2) after 1971 as follows:

Prior to 1972: During this period the recorded neutron doses were too low. The missed neutron dose is calculated by multiplying the dosimeter missed photon dose by an NP dose ratio (see Section 6.7).

After 1971: During this period the Hanford TLD was used. In this case, the missing dose is based on the LOD of the dosimeter. Table 6-14 summarizes the reported limits of detection and the calculated annual missed dose for the periods.

6.7 UNMONITORED HANFORD WORKERS

There should generally not be any occupationally exposed unmonitored Hanford workers because Hanford procedures (Parker 1948b) required that any worker entering a radiological controlled area be assigned a dosimeter. However, there might be some situations regarding work activities outside the 100, 200, 300 and 400 Operating Areas that might involve comparatively low-level exposure.

6.7.1 Coworker Assigned Photon Dose

An estimated photon dose to unmonitored Hanford workers can be determined from monitored coworkers. ORAUT-OTIB-0020 (ORAUT 2008a) provides general instructions to evaluate the

Table 6-14. Hanford neutron dosimeter period of use, type, LOD, exchange frequency, and potential annual missed dose.

Period of use	Dosimeter	Exchange frequency	LOD (rem)[a]
October 1944–December 1949	PICs with B-10 enriched liners	Daily[b] (n=250)	0.010
January 1950–December 1950	NTA	Weekly (n=52)	0.080
January 1951–March 1957		Biweekly (n=26)	0.080
April 1957–May 1957		Biweekly (n=26)	0.080
May 1957–December 1971		Monthly (n=12)	0.080
TLD			
January 1972–December 1994	HMPD–4 or 5 chips	Monthly	0.050
January 1995–present	Harshaw TLD	Monthly	0.015

a. Estimated film dosimeter photon radiation detection levels before 1972 and neutron dosimeter LODs after 1971.

b. Dosimeter not routinely assigned.

measured and missed doses for monitored Hanford workers to arrive at a favorable-to-claimant dose to be assigned to unmonitored workers. Attachment B contains the details of the evaluation of Hanford coworker dose to be assigned to unmonitored workers. These measured doses do include an analysis of the missed dose which is particularly significant for the earlier years with higher LODs and frequent dosimeter exchanges (weekly or biweekly). Attachment B, Table B-2 provides the 50th-, 95th-, and 99th-percentile coworker penetrating (gamma) and nonpenetrating doses. Figure 6-5 shows the trend in the coworker assigned 95th percentile in comparison with the 95th percentile for the measured penetrating WB dose.

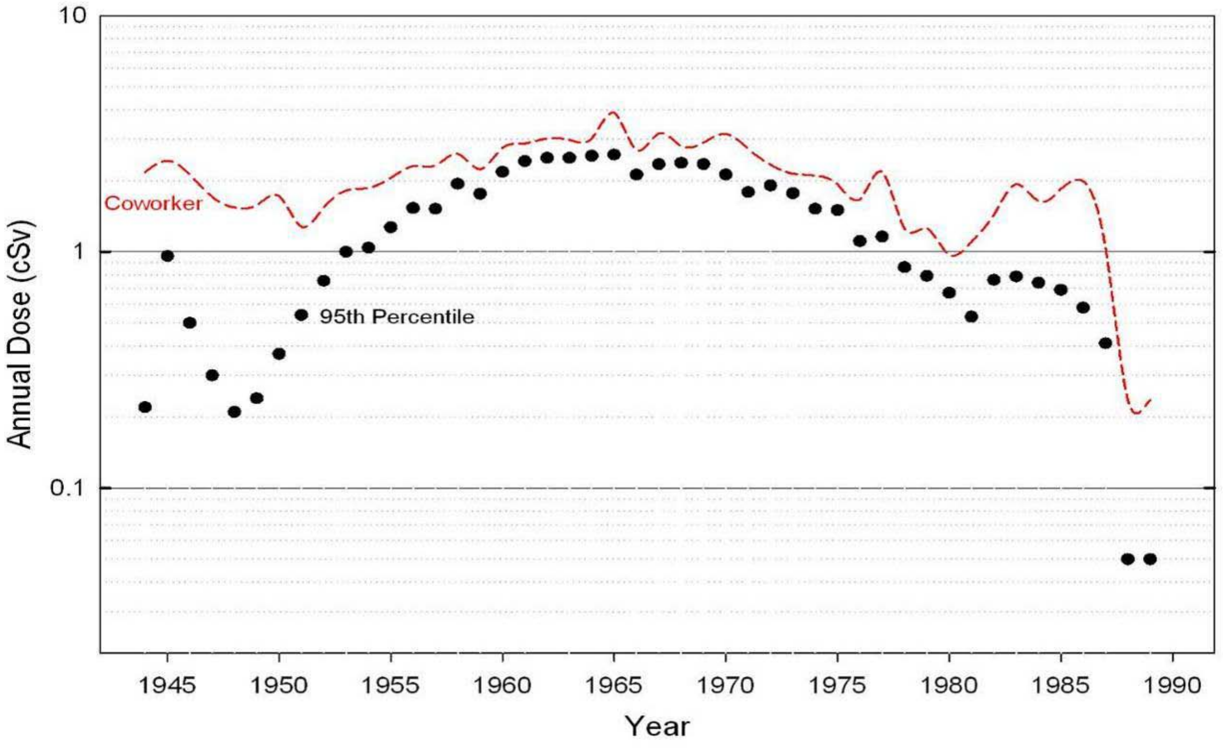

Figure 6-5. Annual Hanford external coworker 95th-percentile penetrating doses modified to account for missed dose in comparison with 95th-percentile measured dose (rem).

6.7.2 Construction Trade Workers

Construction Trade Workers (CTWs) measured doses are increased to account for uncertainty for reasons described in ORAUT-OTIB-0052 (ORAUT 2007b). For extended employment periods without a measured dose, consideration is necessary as to whether to assign an unmonitored dose using the coworker doses presented in Attachment B. In this case, the measured coworker penetrating annual dose has been multiplied by a factor of 1.4 (per ORAUT-OTIB-0052) and the missed dose determined using OCAS-IG-001 guidance. Attachment B, Table B-3 provides the 50th-, 95th-, and 99th-percentile CTW doses to be assigned. Figure 6-6 illustrates the annual dose to be assigned in comparison with the 95th-percentile assigned coworker penetrating (gamma) doses and the 95th-percentile measured doses.

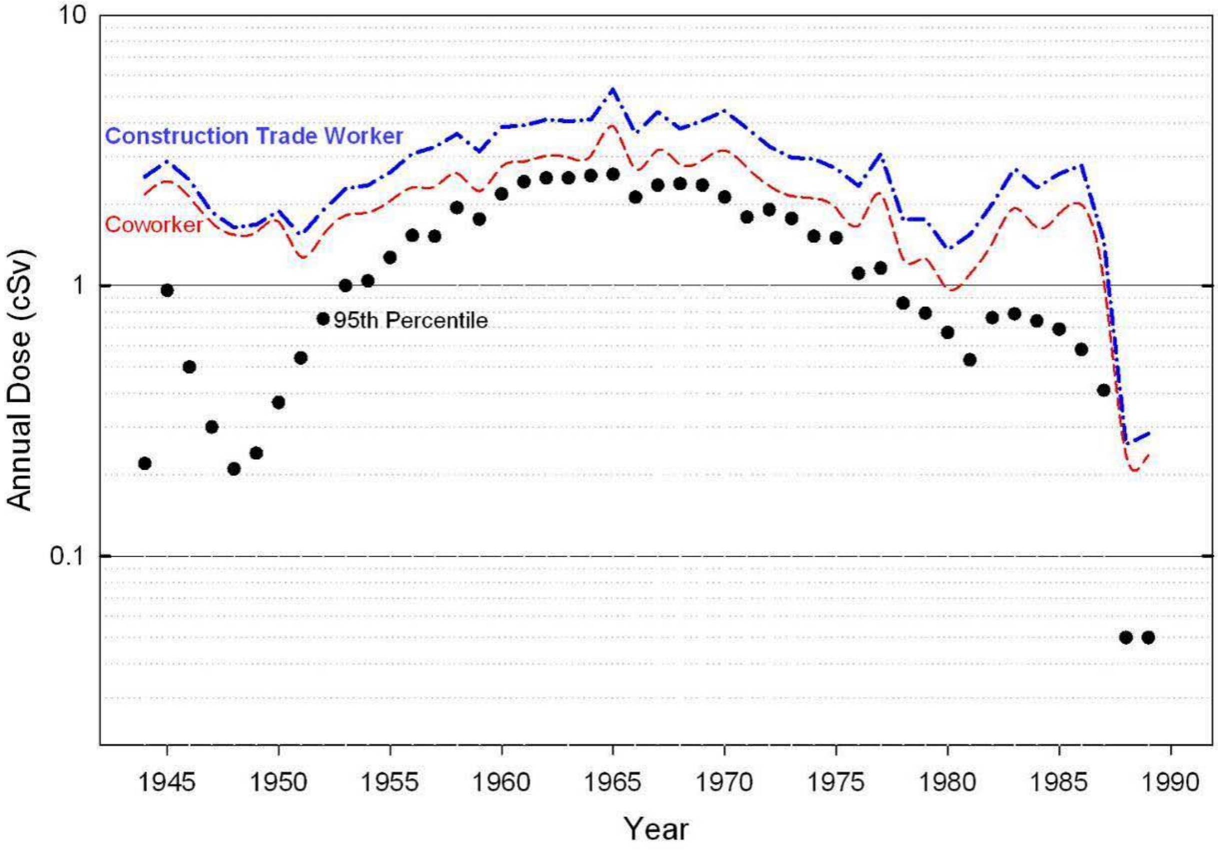

Figure 6-6. Annual Hanford 95th-percentile penetrating CTW assigned doses in comparison with 95th-percentile coworker assigned and measured doses (rem).

6.7.3 Neutron-to-Photon Dose Ratio

There are numerous examples of workers exposed to neutron radiation prior to 1972 in which zero neutron dose results were recorded and particularly prior to implementation of the multielement neutron dosimeter in 1958 (Buschbom and Gilbert 1993). A spreadsheet (Yamauchi 2006) of Hanford worker NTA processing results during the period from 1950 to 1961 was developed by DOE in the preparation of PNNL-11196 by Fix, Wilson and Baumgartner (1997b). The decision to stop assignment of NTA film personnel neutron dosimeters to Hanford single-pass cooling production reactor and N Reactor workers was made effective during April 1966 (DUN 1966). Therefore, this can be considered an unmonitored exposure and an estimate of the dose based on NP dose ratio distributions determined from workplace instrument measurements of paired neutron and photon doses and using post-1971 TLD measurements of paired neutron and photon measured doses. A substantial effort was made to obtain relevant survey records from the DOE Richland Operations Office (RL) archives. In the process of doing this, an extensive list of relevant historical documents was collected and developed into a timeline of radiation-associated events. The timeline was used in the analyses for the Hanford 100, 200 and 300 Area facilities. The timeline is presented in Attachment D, Table D-2. This approach to reconstruct dose to Hanford workers is consistent with the 1972 AEC review (Biles 1972) of pre-1972 NTA neutron dose results in Hanford plutonium facilities. The photon dose was reliably measured and essentially any significant Hanford neutron dose was accompanied by significant photon dose.

Issues to be considered to arrive at a favorable-to-claimant ratio for pre-1972 Hanford facility operations with potential neutron exposure of workers are presented for each of the primary operating areas in the following sections.

6.7.3.1 100 Area Single-Pass Cooling Reactors.

All of the Hanford single-pass cooling reactors (B, C, D, DR, F, H, KE, KW) were shut down as of January 1971 prior to the implementation of the HMPD in 1972. As described in Taulbee et al. (2008) Hanford neutron and photon radiation survey records were collected and used to evaluate and subsequently develop an NP ratio to reconstruct neutron doses to workers around Hanford's single-pass reactors that operated from 1945 to 1972. A total of 5,773 paired neutron and photon measurements extracted from 57 boxes of survey records were used in the development of the NP ratio, Figure 6-7. The development of the NP ratio enables the use of the recorded photon radiation dose from an individual's personnel dosimeter to be used to estimate the unmonitored neutron dose. The Pearson rank correlation between the neutron and photon measurements was 0.71, indicating a reasonable degree of correlation (i.e., values approaching 1.0 show strongest correlation) between increasing photon dose and increasing neutron dose.

The NP ratio was found to be somewhat higher in the upper levels of the reactor compared to the front face, ground, and the experimental levels. Information obtained through an interview with a retired radiological control technician (Fix 2007a; Bihl 2008a) indicated that the upper levels were not frequented by workers, and the relatively large number of measurements made was due to routine monitoring requirements for the higher exposure areas. Based on the information provided in an interview (Fix 2007a), the most plausible NP ratio is on the order of 0.6. Giving the benefit of the uncertainty to the claimant, the assumption is made that the distribution of measurements is a reasonable favorable-to-claimant assumption. Therefore the overall NP ratio is calculated to be 0.8.

The NP ratio was examined across all of Hanford's single-pass reactors and across the period from 1945 through 1971 (Taulbee et al. 2008). There did not appear to be any major differences in the ratio across reactors or time. Even though the power level and the dose rate increased over time, the NP ratio remained relatively constant. As a result the application of the NP ratio can be considered reasonable across all of the Hanford single-pass reactors from 1944 through 1971.

NP Ratio Application

The NP ratio should be applied to all reactor area workers who wore a film dosimeter (i.e., issued a dosimeter) to estimate the neutron dose. The NP ratio data best fit a lognormal distribution with a geometric mean (GM) of 0.8, a geometric standard deviation (GSD) of 3.0, and the upper 95th percentile of this distribution was 4.8 (Figure 6-8). This distribution is combined with measured and missed dose distributions using Monte Carlo methods described in ORAUT-OTIB-0012, *Technical*

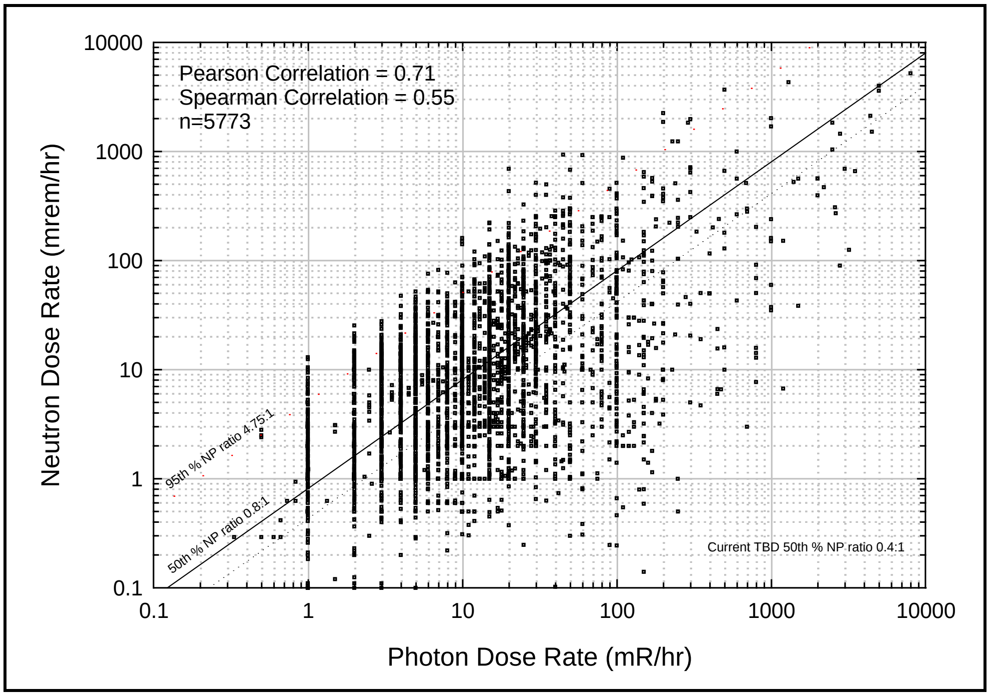

Figure 6-7. Single-pass reactor paired neutron and photon survey measurements.

Information Bulletin: Monte Carlo Methods for Dose Uncertainty Calculations (ORAUT 2005a). The resulting total neutron dose should be partitioned for input into IREP assuming that 10% is < 10 keV, 10% is due to neutrons between 10 and 100 keV and 80% is from neutrons from 0.1 to 2 MeV (Taulbee et al. 2008).

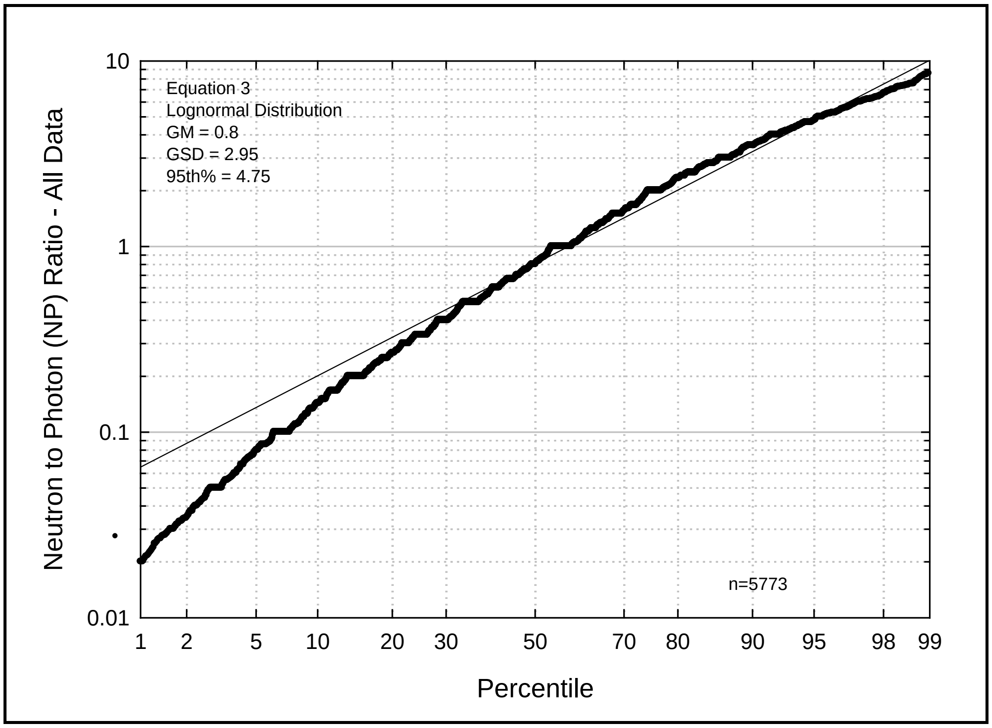

Figure 6-8. Probability distribution of the NP ratio. The thin solid line represents the equation 3 fit.

Construction Workers

Based on interviews with former workers, workers on minor construction projects at Hanford would sometimes work in neutron zones when the reactor was operating. They would, however, have received a photon dosimeter prior to commencing work. Therefore, if a construction worker received a dosimeter from the 100 Area, the dose reconstructor should assume neutron exposure occurred unless there is other information indicating the construction work was only conducted while the reactor was shut down or in a non-neutron radiation exposure area [i.e., work area was not conducted in the process monitoring room, front face (C elevator), assembly work area, outer rod rooms, viewer, experimental levels, top of the unit, balcony, C or D machinery rooms, or the winch level]. Most notably, if the work was conducted only in the disassembly basin area, no neutron dose should be assigned.

Specific Locations

Generally the standard NP ratio with a GM of 0.8 with a GSD of 3.0 should be used for all workers unless an individual's records indicate that they worked in an area with only photon exposure such as in refueling when the reactor was not in operation or in a specific area of the reactor. For example, if records indicate a worker was assigned to a special project such that they were on the X levels for their full shift for multiple weeks, the measured lognormal distribution with a GM of 0.5 and a GSD of 2.97 (Table 6-15) should be used for dose reconstruction. When a dose reconstructor has information that an individual's work was only on the top of the reactor during operations, the measured NP ratio with a GM of 2.33 and a GSD of 1.84 should be applied.

Table 6-15. Lognormal parameters of NP ratio for Hanford reactors (Taulbee et al. 2008).

Work location	**NP ratio**		
	GM	**GSD**	**95th percentile**
General work location			
General	0.8	3.0	4.8
Specific work locations			
-9-ft level	0.83	1.70	
Front face	0.50	2.79	
X levels	0.50	2.97	
Upper levels	2.33	1.84	

The eight Hanford 100 Area single-pass cooling reactors (B, D, F, H, DR, C, KW, and KE, in order of startup) were operated between September 1944 and January 1971, as summarized in Table 6-16 (DeNeal 1970).

Table 6-16. Operating history of Hanford single-pass production reactors (DeNeal 1970).

Reactor	**Startup**	**Deactivation**	**Max power level**[a]
B	09-26-1944	02-12-1968	2210
D	12-17-1944	06-26-1967	2165
F	02-25-1945	06-25-1965	2040
DH	10-29-1949	04-21-1965	2140
DR	10-03-1950	12-30-1964	2015
C	11-18-1952	04-25-1969	2500
KW	01-04-1955	02-01-1970	4400
KE	04-17-1955	01-29-1971	4400

a. Power in megawatts, held for 24 hours.

6.7.3.2 100 Area N Reactor

Attachment E contains a technical basis for neutron dose reconstruction for Hanford 100 Area N Reactor Workers during the period of its operation from December 1963 through January 1987. The design of the N Reactor was different from the 100 Area single-pass reactors in that primary coolant water was recirculated under pressure, allowing for much higher operating temperatures and, as is typical of commercial light-water reactors, substantial buildup in the coolant system of neutron activation and fission product nuclides resulting in increased significance of penetrating photon radiation fields generally, and of beta/photon radiation fields in maintenance work of reactor components. The N Reactor core was surrounded by special layers of reflector graphite, water-cooled thermal shields constructed of boron steel and cast iron, and by a primary shield of high-density concrete. Helium gas formed the pile atmosphere within a sealed system that prevented worker access without reactor operator knowledge while the reactor was operating. A fog spray system at both the front and rear reactor faces was provided for contamination control and cooling in case of a loss of contaminated steam from the core. These design features tended to limit opportunities for worker neutron radiation exposure. Throughout the years of N Reactor operation extensive administrative and technical limits were in effect such as in the form of operating safety limits and process standards. Startup of the reactor was particularly complex, involving a complete building radiation survey at stated levels of power ascension (Berrett and Hall 1964). The radiation environment at N Reactor was divided into five protective zones with different shielding and entry requirements (Bunch, 1962).

- Zone 1, which is adjacent to the charge face, the discharge face, and the top of the reactor. No access is possible to this zone during operation. Monitored access is possible during reactor shutdown. This zone is operated at a negative pressure relative to Zone 2.

- Zone 2, which includes secondary radiation areas such as the inner and outer rod rooms, the gas system, the flux and rupture monitor room, the ball system, and the ventilation exhaust system from Zone 1. Normally, no access to the restricted areas of Zone 2 will be required during operation but limited emergency access is possible. Zone 2 is operated at a negative pressure relative to Zone 3.

- Zone 3 is a normal access or buffer zone with free access at all times except perhaps for quite abnormal conditions. This zone includes most of the work regions and corridors around the reactor in which metal handling and other routine operations are conducted.

- Zone 4 is an unlimited access area with essentially no elevated radiation exposure during normal operations.

- Zone 5 is defined as a warranted access area in which continuous access is maintained at all time including emergencies. Zone 5 is limited to the main control room and the main instrument room beneath the main control room.

Interestingly, although Hanford had available portable radiation protection instrumentation to readily measure neutron exposure in the workplace (WHC 1988) and there were requirements for surveys when there was a potential for significant exposure, few of the hundreds of Hanford survey forms examined actually included results of surveys for neutron radiation exposures. There were requirements for neutron surveys during startup at defined power levels in power ascension testing. Nearly 1 year of testing during 1964 was necessary for the N Reactor to achieve the design power of 4,000 MW (thermal) on December 9, 1964 (WHC 1988, Chapter 14). During testing in 1964, elevated photon and neutron radiation levels were measured (Greenborg and Berry 1964) emerging through N Reactor steam vent penetrations that are located in the bottom shield of the reactor and open to the southeast and southwest corners of the ball hopper retrieval system. The corrective action consisted of adding a pipe offset to achieve a labyrinth design and providing additional shielding. This action was required for purposes of radiation protection and to reduce the possibility of neutron activation of system components in the ball recovery room (Hall 1964).

A collaborative effort with DOE Hanford Radiological Records was conducted with the objective to select only the N Reactor worker recorded neutron and photon doses (i.e., actually shallow, deep, neutron, X-ray, eye dose categories) from 1964 through 1987 separately from doses for workers at the other single-pass reactors (which stopped operations in January 1971) and other Hanford operating areas. The methods used to select this data are described in Attachment E. The query resulted in dose results for a total of 592 selected workers for whom there were a total of 4,825 dose records with a collective dose of 3,301,070 mrem of photon penetrating dose. A scatter plot of the recorded annual shallow, neutron and extremity dose normalized to the recorded deep (photon) dose for each worker and each year is shown in Figure 6-9. The shallow and deep doses are closely associated as would be expected because the majority of the shallow dose results from penetrating photon radiation. As noted in Attachment E, there is essentially no correlation between the recorded neutron and photon doses overall. There were only 30 annual dose records with photon and neutron doses ≥30 mrem, respectively; and only 14 records for TLD-only results. The explanation is likely that there are few occasions when workers receive a measurable neutron exposure, whereas significant photon dose is received in many routine work tasks including when the reactor was not operating and there was no neutron exposure. This lack of correlation between photon and neutron recorded doses was also observed by investigators analyzing a large amount of commercial power reactor neutron and photon measured doses (Eisenhauer and Schwartz 1983).

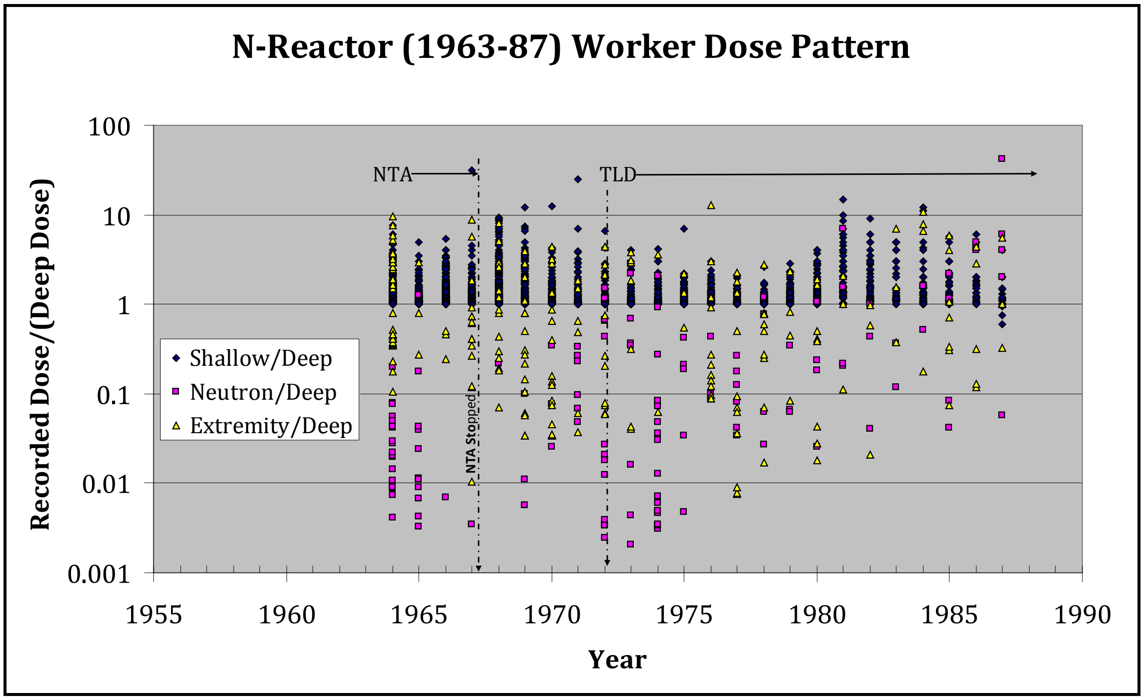

Figure 6-9. Trend of 100-N worker recorded shallow, neutron, and extremity annual dose to recorded deep dose for 4,777 records with deep annual dose >0.

The ratio of the collective neutron dose measured with the TLD system during 1973 and 1974 was 0.002 and 0.004, respectively, of the collective measured photon dose. There was a single worker who had TLD-measured neutron dose during 4 years (1972–0.027 rem, 1974–0.003 rem, 1977–0.042 rem, 1978–0.027 rem) and for the other years there was no measured neutron dose (1973, 1975, 1976, 1979, 1980, 1981, 1982, 1983, 1984, 1985 and 1986). Attachment E describes the logic for two identified options. One option is to base the NP ratio on the single worker who had TLD-measured neutron dose during 4 years (1972–0.027, 1974–0.003, 1977–0.042, 1978–0.027) and for the other years there was no measured neutron dose (1973, 1975, 1976, 1979, 1980, 1981, 1982, 1983, 1984, 1985 and 1986). In this option the 50th-percentile (i.e., GM) is equal to 0.04 and to the maximum NP ratio a factor of 2 greater (i.e., 0.08) which is assumed in this analysis to be approximately the 95th-percentile. The second option is to utilize the statistical parameters for a lognormal distribution of the 14 TLD results. There is a large difference in the assigned neutron dose between these two options (i.e., Option #1: GM = 0.04, 95th percentile = 0.08; Option #2: GM = 0.06, 95th Percentile = 0.4) as shown in Table E-5. Certainly, the most favorable to claimant option is provided using Option #2. The assigned neutron doses must also incorporate the ICRP Publication 60 weighting factor, which for the neutron category of 0.1 to 2 MeV is equal to 1.91 (ICRP 1991), and thus a further increase in assigned neutron dose of nearly a factor of 2 will occur. Attachment E illustrates the significant assigned neutron dose that would be assigned in the 1972–1986 TLD period compared to the TLD-measured dose if this approach was applied in dose reconstruction.

NP Ratio Application

For the period prior to January 1, 1972, to estimate the assigned neutron dose, a NP ratio should be applied to all N Reactor area workers with a DOE-reported dose (including zero) at Hanford to estimate the neutron dose. The distribution of NP dose ratios recommended to result in a favorable-to-claimant neutron dose estimate has a GM of 0.06, a GSD of 3.1, and an upper 95th percentile of 0.4. This distribution is combined with measured and missed dose distributions using Monte Carlo methods described in ORAUT-OTIB-0012 (ORAUT 2005a). The resulting total neutron dose should be partitioned for input into IREP assuming that 100% is associated with neutron energies from 0.1 to 2 MeV.

Construction Workers

Based on interviews with 100-N workers including persons who worked at 100-N throughout its entire operating history, all workers including construction workers were subject to controls regarding entry and exit from identified workplace zones. Protective practices were described in Special (or Radiation) Work Permits (SWPs), including requirements for assigned personnel dosimeters and other worker protective actions as needed (extremity dosimeters, respirator, full-time monitoring support, etc.). During the period from 1964 through 1971 when the Hanford neutron dosimeters were not assigned, if a construction worker had a DOE-reported dose at the N Reactor, the dose reconstructor should assume neutron exposure occurred unless there is other information indicating the construction work was conducted only while the reactor was shut down or in a non-neutron exposure area (i.e., in the 100-N area outside of the reactor building 105 or outside of steam generator building 109).

Specific Locations

Considering that 100-N Area reactor workers might have worked at one or more of the other reactor areas, determining that a worker worked solely at the 100 Area N Reactor could be difficult. General Electric Corporation (GE), Douglas United Nuclear (DUN), and United Nuclear Industries (UNI) were responsible at different times for operation of all the 100 Area reactors. The last of the single-pass reactors, KE and KW, terminated operations during January 1971 (see Attachment D, Table D-2). The general 100 Area single-pass reactor NP ratio (i.e., GM = 0.8, GSD = 3.0) should be used if there is doubt as to the location of employment of a worker in the Hanford 100 Area reactors prior to January 1971. If it can be determined that a worker was employed only at the N Reactor, the NP dose ratio distribution parameters shown in Table 6-17 should be used.

The assigned neutron doses determined using the NP ratios in Table 6-17 must also incorporate the ICRP Publication 60 weighting factors for the 0.1 to 2 MeV neutron category (ICRP 1991). This requires multiplication of the assigned dose by a factor of 1.91 for the IREP Parameter 1 input.

Table 6-17. Lognormal parameters of NP ratio for Hanford N Reactor (Attachment E).

Work location	NP ratio		
	GM	GSD	95th percentile
General work location			
N Reactor	0.06	3.1	0.4

6.7.3.3 200 Area Plutonium Facilities

Attachment F contains a technical basis for neutron dose reconstruction for Hanford 200 Area Plutonium Facilities. A team of health physicists examined many boxes of DOE Hanford archives to identify and retrieve workplace radiation survey records particularly the records with paired photon and neutron measurements and the technical references of historical radiation-associated events as shown in Attachment D, Table D-2. The selected records are included in the SRDB and the SRDB references are included in the analysis files. Table 6-18 summarizes the types of records, the records selected for analysis of the NP ratio for the 200 Area Plutonium Facilities and the basis for the selection.

Table 6-18. Hanford 200 Area plutonium facility NP ratio survey records (see Attachment F).

Description	No. of records	Selected for NP analysis	Basis for selection
2003 claim TLD data	186	186	Paired post-1971 TLD measurements with neutron and photon dose, respectively ≥ 20 mrem.
1972 AEC study, film data	189	0	Paired pre-1972 NTA data are suspect.
1972 AEC study, TLD data	113	113	Paired post-1971 TLD measurements with neutron and photon dose, respectively ≥ 20 mrem.
1962–1971 Radiation Control Reports, film data	177	0	Paired pre-1972 NTA data are suspect.
1972–1976 Radiation Control Reports, TLD data	16	0	TLD data are suspect because of comparatively low measured neutron dose. The presence of an albedo material, which is essential for TLD performance, in the measurements is not known.
1962-1976 Radiation Control Reports, instrument data	161	161	All of the instrument measured doses by trained health physics technicians are considered to be of good quality.
Technical reports, instrument	113	114	
Workplace surveys, instrument	1,195	845	
Total	2,150	1,419	

Hanford plutonium facility operations involve substantial sensitive information particularly during the period of construction and operation during the 1940s to 1960s and even today information is still classified. An important consideration in the retrospective analysis of neutron exposure to workers in relation to the measured photon dose concerns the specifics of the isotopic mix of plutonium and also fission product contamination. The fission product contamination resulted in significant higher energy photon exposure to plutonium facility workers (Smith 1958; Chitwood 1960; Hopkins and Crocker 1961; Watsen 1964; Slind 1966). Type of fuel (i.e., uranium natural or level of ^{235}U enrichment, mixed uranium and plutonium oxide or thorium) and the reactor irradiation time in megawatt-days is directly associated with the isotopic composition of the plutonium handled at PFP. There are also issues associated with the effectiveness of the T-Plant, B-Plant, REDOX, and PUREX processing with respect to the type and concentration of potential fission product contaminants (zirconium, ruthenium, etc.) as well as inventories handled at PFP associated with Buy-Back Program and various national and international research activities. Broadly speaking, the plutonium is categorized as weapons or reactor (or fuel) grade as shown in Attachment F, Figure F-2. Worker neutron exposure is highly associated with the concentration of ^{240}Pu, which increases in the irradiated fuel with the total reactor exposure (i.e., megawatt-days). Reactor-grade fuel typically receives much higher exposures as compared to weapons-grade fuel and will result in higher exposures to workers.

As described in Attachment F, 1,346 Hanford 200 Area Plutonium Facility neutron and photon radiation survey records were collected as shown in Figure 6-10 and used to evaluate and subsequently develop an NP ratio to reconstruct neutron doses to workers. The Pearson rank correlation between the neutron and photon measurements was 0.76, indicating a reasonable degree of correlation between increasing photon dose and increasing neutron dose. A total of 1,419 measured NP ratio measurements (i.e., one reference did not provide measured neutron and photon dose rates but only the NP ratio measured values) extracted from several sources as listed in Table 6-18 were used in the development of the NP ratio shown in Figure 6-11.

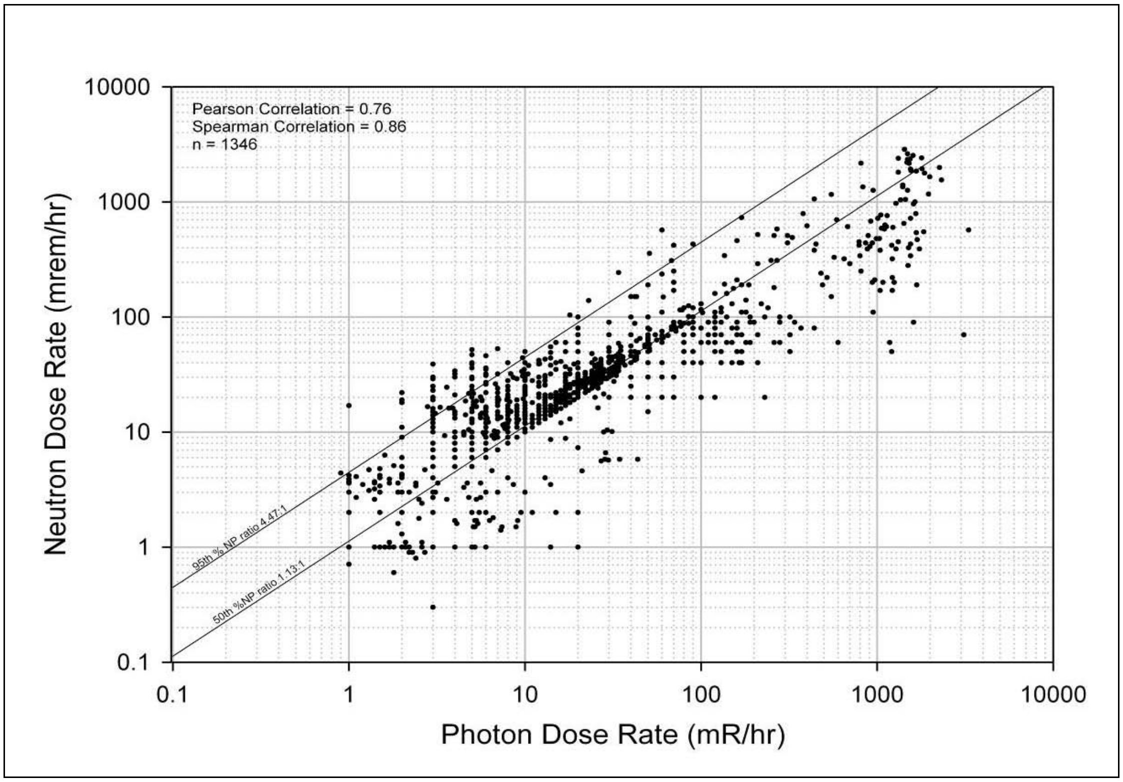

Figure 6-10. Hanford 200 Area plutonium facility NP ratio measurements.

As described in Attachment F, the NP ratio was found to be dependent on the workplace and measurement method. As noted in previous evaluations of neutron dose levels, the fluorination hood area showed the highest measured photon (and neutron) dose rates and NP dose ratios. As noted in the documents in Attachment D, Table D-2, it was Hanford practice to monitor worker exposures and to rotate workers if cumulative doses approached regulatory limits. The AEC investigation in 1972 of Hanford worker neutron doses concluded that no worker exceeded regulatory dose limits (Biles 1972). This is consistent with the interview information for several Hanford Site Experts described in Attachment F.

NP Ratio Application

The NP ratio should be applied to all Hanford 200 Area plutonium handling facilities workers who wore a film dosimeter (i.e., issued a dosimeter) to estimate the neutron dose. This distribution is combined with measured and missed dose distributions using Monte Carlo methods described in ORAUT-OTIB-0012 (ORAUT 2005a). The resulting total neutron dose should be partitioned for input into IREP

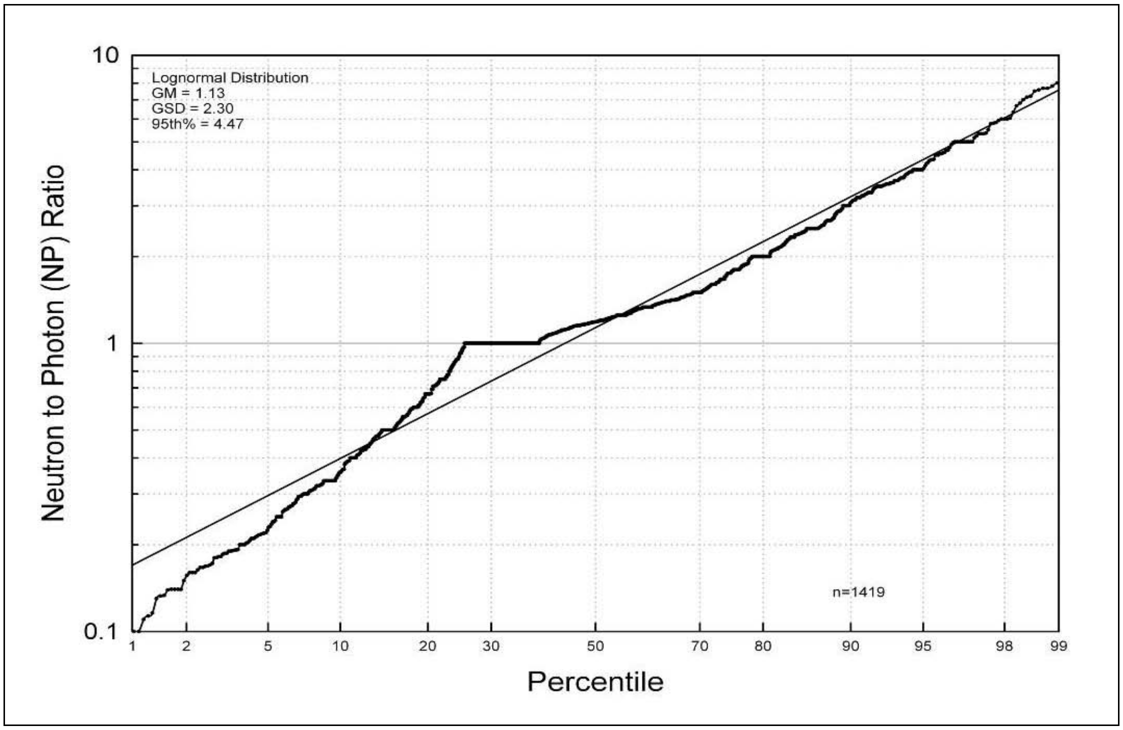

Figure 6-11. Probability distribution of the 200 Area plutonium facility NP ratio for instruments and dosimeters (Attachment F).

assuming that 10% is due to neutrons between 10 AND 100 keV and 90% is from neutrons from 0.1 to 2 MeV (Attachment F).

Construction Workers

Based on interviews with persons who worked at Hanford plutonium facilities beginning as early as 1947 and with collective work experience extending essentially throughout the entire operating period of PFP operations, all workers (including construction workers) were subject to controls regarding entry and exit from identified workplace zones. Protective practices were described in Special or Radiation Work Permits. All workers in this facility were assigned personnel dosimeters and for all years the assigned NTA dosimeters were processed. All PFP work areas involved some potential for neutron radiation exposure. Therefore, if a construction worker had a DOE-reported dose at the Hanford 200 Area plutonium facilities, the dose reconstructor should assume neutron exposure occurred.

Specific Locations

Any worker in a 200 Area plutonium facility should be considered to have received potential neutron exposure. In Attachment F, analysis of 1,419 NP ratio measurements is described and a summary presented in Table 6-19 for various selections of the data. The data for all 1,419 NP measurements shows a NP dose ratio distribution with a GM of 1.13, a GSD of 2.30, and a 95th percentile of 4.47. The plutonium fluorination hood shows the highest instrument measured neutron and photon dose ratio distribution with a GM of 1.68, a GSD of 2.57 and a 95th percentile of 7.94 but when combined with the 1972 and later TLD data shows an overall NP ratio distribution with a GM 0f 0.82, a GSD of 2.56 and a 95th percentile of 3.85. The TLD data show much less variability than the instrument measured photon and neutron doses, which are made with different instruments.

Table 6-19. Lognormal parameters of NP ratios for Hanford 200 Area plutonium facilities (Attachment F).

Workplace measurements	No.	GM	GSD	95th%	Fit[a]
All data: TLDs + Instruments	1,419	1.13	2.30	4.47	0.18
TLD data–ALL	299	0.69	2.36	2.83	0.06
TLD data–2003 claims	186	0.73	2.10	2.47	0.09
TLD data–AEC study	113	0.63	2.77	3.37	0.06
Instrument data–all	1,120	1.29	2.17	4.64	0.22
Instrument data–radiation control reports	161	1.23	2.74	6.45	0.13
Instrument data–fluorination hoods 7A/9A & 7C/9B	71	1.68	2.57	7.94	0.19
Instrument data–hood 7A/9A	17	1.95	2.61	9.47	0.23
Instrument data–hood 7C/9B	54	1.60	2.57	7.56	0.20
Instrument data–technical reports	113	0.53	2.83	2.94	0.06
Instrument data–workplace surveys	846	1.47	1.80	3.85	0.23
Fluorination hoods instrument plus TLD worker measured	370	0.82	2.56	3.85	0.07

The 7A/9A and 7C/9B fluorination hoods represent a bounding Hanford plutonium facility workplace condition because of the higher measured NP dose ratio but also significantly because of the significantly greater measured photon (and neutron) radiation dose rates as shown in Table 6-20. This workplace location shows a measured neutron dose rate distribution with a GM of 14.41 mrem/hr, a GSD of 1.17 mrem/hr, and a 95th percentile of 32.86 mrem/hr.

Table 6-20. Measured neutron dose rates for Hanford 200 Area plutonium facilities.

Workplace	No. of points	Neutron dose rate, mrem/hr		
		GM	GSD	95th percentile
Fluorination Hoods	71	14.41	1.65	32.86
Button line	62	2.90	1.53	5.82
Other	28	1.00	1.17	1.29

For glovebox workers, the guidance in OCAS-TIB-010 (NIOSH 2005) for plutonium glovebox workers should be applied as needed. The assigned neutron doses determined using the NP ratios in Table 6-20 must also incorporate the ICRP Publication 60 weighting factors for a default neutron dose fraction of 10% and 90% (ICRP 1991) for the 0.01-to-0.1-MeV and 0.1-to-2-MeV neutron categories, respectively. This requires multiplication of the assigned dose by factors of 1.86 and 1.91, respectively, for the IREP parameter 1 input. This approach will result in significant assigned neutron dose for the period prior to January 1, 1972.

6.7.3.4 300 Area Reactor, Plutonium and Miscellaneous Hanford Research Facilities

The Hanford 300 Area Reactor and Plutonium research, development, and testing facilities, the 300 Area Radiological Calibrations facilities, and the site critical mass laboratory facilities did involve neutron radiation exposure of workers as evidenced by (1) the types of operations, (2) routine assignment of nuclear track emulsion (i.e., NTA) film, and (3) information in the routine radiation monitoring periodic reports listed in Attachment D, Table D-2. Operations in these facilities supported the much larger 100 Area reactor and 200 Area chemical processing and plutonium chemical-metallurgical facilities. Extensive radiation surveys were taken of these facilities because Hanford radiation safety standards applied to all facilities in the 100, 200, and 300 Area facilities. Events in these facilities are included in the various Hanford routine reports noted in Attachment D, Table D-2. Attachment G contains a technical basis for neutron dose reconstruction for Hanford 300 Area reactor and plutonium facilities and Hanford miscellaneous research facilities other than the 100 Area reactor and 200 Area plutonium facilities.

NP Ratio Application

The recommended dose reconstruction parameters to be applied for 300 Area reactor, plutonium, and miscellaneous Hanford facility research workers based on workplace information and the extensive instrument and TLD measurements obtained for the 100 Area single-pass reactors and the 200 Area Plutonium facilities are:

- TLD-measured neutron dose should be used from January 1, 1972 to date.
- Prior to 1972, the measured (and missed) photon dose should be multiplied by an NP dose ratio to arrive at an assigned neutron dose. The selection of the NP dose ratio is based on comparison of 300 Area Facility Process with the 100 or 200 Area production facilities. For example, the 305 test reactor would utilize the distribution of measured NP dose ratios for the single-pass cooling production reactors and the Building 308 plutonium fuels facility would utilize the distribution of measured NP dose ratios for the 200 Area plutonium finishing plant. In this approach, NP ratios determined from extensive workplace measurements in the 100 Area reactor and 200 Area plutonium facilities, respectively, would be applied to workers in the 300 Area reactor and plutonium facilities based on favorable-to-claimant judgment by the dose reconstructor. Neutron exposures in the 120 Building and 209-E critical mass laboratories to workers did occur but were relatively insignificant for routine operations because of the significant shielding and remote operation. Under all circumstances there was substantial photon radiation that was reasonably accurately measured in all facilities and for all periods that accompanied the neutron radiation. The parameters of the NP dose distribution are shown in Table 6-21.

Table 6-21. Summary of measured neutron dose rates for application to Hanford 300 Area and Hanford facilities with some potential for neutron exposure.

Process	Reference	Neutron to photon dose ratio		
		GM	GSD	95th percentile
100 Area single-pass cooling reactors	Taulbee et al. 2008	0.8	3.0	4.8
100 Area N Reactor	Attachment E	0.06	3.1	0.4
200 Area plutonium–Not a glovebox worker	Attachment F	1.1	2.3	4.5
200 Area process line–glovebox worker	Attachment F	1.7	2.6	7.9

For glovebox workers, the guidance in OCAS-TIB-010 (NIOSH 2005) for plutonium glovebox workers should be applied as needed. These NP ratios must be adjusted to incorporate the ICRP Publication 60 weighting factors (ICRP 1991). The assumed neutron energy IREP input category is assumed to be 0.1 to 2 MeV. Therefore, the values in the above table are multiplied by a factor of 1.91. It is evident that using this approach will result in significant assigned neutron dose for the period prior to January 1, 1972.

Construction Workers

Based on interviews with persons who worked in the Hanford 300 Area facilities (308, 318, 321, 3745) beginning in the early 1950s with collective work experience extending essentially throughout the entire period of 300 Area Facility operations, all workers, including construction workers, were subject to controls regarding entry and exit from identified workplace zones. Construction workers at critical mass and miscellaneous facilities in the 100 and 200 Areas had similar requirements. Protective practices were described in Special or Radiation Work Permits including the assignment of personnel dosimeters as well as other worker protective needs such as respirators, other dosimeters and monitoring support. Many 300 Area facilities involved some potential for neutron radiation exposure. Therefore, if a construction worker had a DOE-reported dose in a facility in the Hanford 300 Area, the dose reconstructor should assume neutron exposure occurred.

Specific Locations
The majority of workers in the Hanford 300 Area and Hanford Site supporting research facilities did not have potential for significant neutron radiation exposure relative to potential photon radiation exposure. However, there was potential neutron exposure in many different facilities from a wide variety of causes including neutron-emitting radioactive nuclides, reactors, and fissile materials. Therefore, it is particularly important to determine if a neutron exposure was physically possible (i.e., potential neutron radiation from reactor, accelerator, alpha emitting nuclides, or neutron emitting nuclides) based on workplace processes and job activities for a worker to determine if a neutron dose should be assigned. Once the TLD was used beginning on January 1, 1972, the neutron dose was reliably measured along with potential beta and photon radiation.

6.7.3.5 NP Dose Ratio Summary

NP dose ratio distributions developed in previous sections for Hanford reactor and plutonium facility workers are summarized in Table 6-22. The assigned neutron dose is calculated by applying these ratios to the recorded photon dose and the calculated missed photon dose, respectively. It should be noted that if the Energy Employee has recorded neutron dose, the assigned neutron dose should be compared with the recorded neutron dose and the assigned dose used only if it is greater [26].

Table 6-22. Hanford NP dose ratio summary [27].

Process	Description/buildings	NP ratio		
		GM	GSD	Upper 95th %
Reactors	During reactor operation: low-level neutron exposure through shielding on the face of the reactors and through test ports.			
	B, D, F, H, DR, C, KW, KE Reactors	0.8	3.0	4.8
	N Reactor	0.06	3.1	0.4
	300 Area Test Reactors (305, 309, 318, 326)	0.8	3.0	4.75
	400 Area FFTF	N/A		
Plutonium production	Plutonium finishing process: plutonium enters the process as PuF_4 and is then fired into production buttons. Work is primarily conducted in gloveboxes with predominant close anterior exposure to workers. Radiation levels at the beginning of the process are fairly constant while levels at the end of the process are closely related to production levels.			
	Plutonium Facilities (200 Areas) (224-T, 231-Z, 232-Z, 234-5Z, 236-Z, 242-Z, 2736-Z, 271-U)			
	Plutonium Laboratories (300 Area) (308, 309, 324)			
	Non-glovebox worker	1.1	2.3	4.5
	Glovebox worker	1.7	2.6	7.9
Critical Mass Laboratory	Highly shielded laboratory facilities used to test limits of criticality reactor and geometry conditions.			
	120, 209E	1.1	2.3	4.5
Research and Development	Wide variety of Hanford 300 Area facilities used to test and evaluate processes used in the 100 Area reactor and 200 Area chemical processes and plutonium separation, purification, and handling. Hanford Site instrument and dosimeter development, testing and calibration was done in 300 Area facilities.			
	3745A, 3745B, 318,	1.1	2.3	4.5

a. Applicable to facilities with significant potential for neutron exposure and prior to TLD use.

6.8 UNCERTAINTY

Uncertainty in the reconstructed organ dose encompasses a wide array of sources such as incomplete monitoring, measurement error, and the effectiveness of Hanford radiation safety practices. IREP organ dose input for a claimant for each year of employment consists of the annual dose in Parameter 1 and measures of uncertainty in Parameters 2 or 3 depending on the selected probability distribution. Judgment has been used to achieve favorable-to-claimant organ dose estimates as described in the following sections.

6.8.1 Measured Photon Dose

Uncertainty in the measured dosimeter photon radiation dose for Hanford historical dosimeters has been evaluated in several studies as highlighted in the following:

- Wilson (1960b) conducted a detailed examination of the LOD for the Hanford dosimetry system based on the analysis of 49 batches of Hanford routine calibration results that indicated a 25% standard deviation at the 30-mrem calibration level based on optical density readings. Based on an analysis of the capabilities of the densitometer used to process the film, he estimated a likelihood of 0.33 (1/3) that a dose of 15 mrem would not be detected. The likelihood that this would occur for each successive monthly exchange for an entire year would be $(0.33)^{12}$ or about 1 in a million. Based on the 13 exchanges during the year at that time, he estimated a maximum potential missed dose of 195 mrem (i.e., 15 × 13). Conversely, Wilson estimated that about 8% of the time, a positive dose would be recorded for dosimeters that received no exposure. A similar analysis could be performed for the dosimeters used prior to 1960 with an estimate that about 30 mrem would be detected one-third of the time.

- BNWL-542, *The Establishment and Utilization of Film Dosimeter Performance Criteria* (Unruh et al. 1967), contains discussion of proposed personnel film performance criteria that includes statistical analysis of Hanford calibration dosimeters during the period from 1950 to 1964, which included more than 600 measurements on each of several exposures levels of gamma, beta and 17-keV X-ray radiations. The records evaluated and tabulated in Table 6-23 were for 11 exposure levels of gamma and 8 for X-ray radiation.

Table 6-23. Bias and variance features for Hanford film dosimeter records.

Type of radiation	Exposure (mrem)	Mean	Relative error	Percent of measurements within ±2 sigma
Gamma	0	5.18	430	95.4
	15	14.50	186	99.0
	30	29.53	35	94.3
	60	57.96	19	95.8
	90	88.87	14	96.0
	120	120.74	10	95.0
	180	179.24	8	97.6
	240	237.72	6	95.7
	300	301.46	5	96.0
	500	499.36	4	99.1
	750	749.82	0.7	99.1
X-ray	0	-9.49	-34	96.6
	10	10.13	28	95.8
	20	20.34	17	94.9
	40	39.85	11	95.7
	60	59.93	8	96.0
	80	79.68	8	96.6
	120	120.27	4	96.4
	160	159.60	4	99.0

The criteria in this document were used to develop performance testing criteria used in a study of 35 government, military and commercial dosimeter processors at that time.

- PNL-7447, *Description and Evaluation of the Hanford Personnel Dosimeter Program From 1944 Through 1989* (Wilson et al. 1990), contains several results of quality evaluations of Hanford dosimeters to include examination of the results of blind audit dosimeters. The authors identified bias factors for the Hanford facilities using each of the Hanford dosimetry systems. They defined the bias factor to be a ratio of the $H_p(10)$ dose to the recorded dose. These factors are presented in Table 6-24.

Table 6-24. Uncertainty in beta/photon $H_p(10)$ in Hanford facilities (Wilson et al. 1990).

Facility type	Beta/photon field description	Dosimeter type	Bias factor range[a]		Comments
			Min.	Max.	
Fuel fabrication	Uranium beta and gamma radiation	Two-element film	0.5	1.6	Recorded WB dose approximates $H_p(10)$ response results noted in this TBD.
		Multiple-element film	0.7	1.3	
		TLD	0.8	1.2	
Reactor	High-energy beta and photon radiation.	Two-element film	0.5	1.7	Recorded WB dose approximates $H_p(10)$ response results noted in this TBD because predominant photon energy >100 keV.
		Multiple-element film	0.7	1.4	
		TLD	0.8	1.2	
Fuel reprocessing	Generally mixed beta and photon radiation	Two-element film	0.5	1.6	Recorded WB dose approximates $H_p(10)$ response results noted in this TBD because predominant photon energy >100 keV.
		Multiple-element film	0.7	1.3	
		TLD	0.7	1.3	
Plutonium finishing	Predominant photon energy <100 keV.	Two-element film	(b)	(b)	Significant uncertainty is associated with dose estimates in low-energy photon fields with the two-element dosimeter.
		Multiple-element film	1.0	2.0	
		TLD	0.6	1.4	
Waste and laboratory	Generally mixed beta and photon radiation	Two-element film	0.5	1.6	Recorded WB dose closely approximates $H_p(10)$ response results noted in this TBD because predominant photon energy >100 keV.
		Multiple-element film	0.7	1.3	
		TLD	0.8	1.2	

a. Bias factor defined as ratio of $H_p(10)$ to recorded WB photon dose.
b. No estimate provided by the authors.

- PNL-10066, *An Assessment of Bias and Uncertainty in Recorded Dose from External Sources of Radiation for Workers at the Hanford Site* (Fix et al. 1994), involving irradiation of Hanford film and thermoluminescent dosimeters on a phantom to a selection of photon radiation exposures with energy >100 keV at selected angles of 0°, ±45°, ±90°, ±135°, and 180°. This information along with measured beta and photon radiation dosimeter responses on phantom in PNL-7447 (Wilson et al. 1990) provided information used to estimate uncertainty in measured dose for workplace AP, rotational, and posterior-anterior exposures for predominant photon energies. The approach used in this report was considered to be an elaboration of the approach used to quantify the bias and uncertainty in estimated doses for personnel exposed to radiation as a result of atmospheric testing of nuclear weapons between 1945 and 1962 (National Research Council 1989). The approach was developed by the National Research Council Committee on Film Badge Dosimetry in Atmospheric Tests. It involved quantifying both bias and uncertainty from four sources and then combining them to obtain an overall assessment using methods used in the evaluation of bias and uncertainty for persons exposed to radiation from an atmospheric nuclear detonation (National Research Council 1989). In this approach, uncertainty is evaluated from laboratory uncertainty (i.e., calibration, processing), radiological uncertainty (i.e., spectrum, wearing, and backscatter), environmental uncertainty (i.e., consequences of light, moisture, and high temperatures), and uncertainty resulting from converting recorded measurements of exposure to estimates of deep dose. The assessment was based on the assumption that uncertainties from individual sources followed independent lognormal distributions. For each uncertainty source, a factor is assigned reflecting bias (B) and a 95% uncertainty factor (K); the uncertainty factor was determined so that the interval obtained by dividing and multiplying by this factor would include 95% of all observations. Assessment of these factors was based on careful evaluation of the available evidence but, because evidence was not adequate for rigorous statistical treatment of most uncertainties, subjective judgments were also required. Once the individual sources were evaluated, an overall bias factor was obtained by multiplication and an overall uncertainty factor obtained through lognormal propagation of errors. The results of this analysis for Hanford workers (for facilities other than plutonium facilities) are presented in Table 6-25.

Table 6-25. Overall bias and uncertainty due to variation and uncertainties regarding energy levels and geometry in recorded dose as an estimate of deep dose (Fix, Gilbert, and Baumgartner 1994).

	Bias magnitude and range		**Uncertainty factors**	
Hanford dosimetry system	**Overall bias**[a]	**Range in bias**[b]	**Systematic**[c]	**Random**[d]
Two-element film (1944–56)	1.27	1.13–1.60	1.2	1.8
Multielement film (1957–71)	1.02	0.86–1.12	1.1	1.4
Multielement thermoluminescent (1972–83)	1.12	1.04–1.16	1.05	1.2
Multielement thermoluminescent (1984–93)	1.01	0.95–1.05	1.05	1.2
Commercial TLD[e] (1995-2003)	1.00	0.95-1.05	1.05	1.2

a. Based on the distribution of energy levels and geometry judged most likely. Divide recorded dose by the table's bias value to calculate deep dose. Note that this use of bias factor does not apply to plutonium facilities.
b. Range of overall bias factors based on alternative distributions of energy levels and geometry.
c. Systematic uncertainty resulting from lack of knowledge regarding actual distributions of energy levels and geometry.
d. Random uncertainty resulting from variation among workers in energy levels and geometry.
e. Performance equal to or better than previous Hanford dosimeters.

- *The Study of a Selection of 10 Historical Types of Dosimeter: Variation of the Response to H_p(10) with Photon Energy and Geometry of Exposure* (Thierry-Chef et al. 2002) was done in support of the IARC 15-Country Epidemiologic Study (Cardis et al. 2005). IARC conducted a dosimeter intercomparison study involving irradiations on-phantom of 10 dosimetry systems used throughout the world in AP, rotational, and isotropic geometries to three selected >100-keV photon beams. Two of the film dosimeter designs were from Hanford. These studies provided similar overall assessments in that for the tested irradiations, the Hanford doses determined with the multielement film and thermoluminescent dosimeters showed reasonable accuracy with the delivered deep dose (i.e., bias factors of 1.01 to 1.12, random uncertainty 95th percentile of 1.2 to 1.4). The Hanford two-element dosimeter used prior to 1957 overestimated the delivered deep dose (i.e., bias factor of 1.27, random uncertainty 95th percentile of 1.2-1.4). As noted in the Wilson et al. (1990) report, the two-element dosimeter will underestimate the deep dose in the low-energy photon plutonium facilities unless Hanford, as noted in Hanford reports, did assign 20% of the nonpenetrating dose to the deep dose.

6.8.2 Measured Neutron Dose

As noted in this report, the recommended dose reconstruction approach is to not use the recorded neutron dose prior to January 1, 1972. The recorded dose is likely too low. The recommended approach is to estimate a favorable-to-claimant neutron dose using the measured and missed photon dose, with adjustments, multiplied by an NP dose ratio. The recommended NP dose ratio is favorable to the claimant. However, there are several studies of measured neutron dose uncertainty for Hanford neutron dosimeters. Uncertainty in the measured dosimeter neutron dose is closely associated with the evaluation of uncertainty in the dosimeter photon or penetrating dose because the accuracy in neutron dose determination is often dependent on the level of photon dose. There is typically greater variability for the measured neutron dose because of the approximate 9-order-of-magnitude range in potential neutron energies (i.e., 0.001 eV to ~ 20 MeV) in the workplace, the energy-dependent response characteristics of the dosimeter, and basically greater variability in the neutron dose response because of a greater number of interaction dependencies.

- BNWL-542, *The Establishment and Utilization of Film Dosimeter Performance Criteria* (Unruh et al. 1967), contains results of applying the proposed personnel film performance criteria to a group of 35 government, military, and commercial dosimetry laboratories. The results as tabulated by the original researchers are shown in Tables 6-26 and 6-27 for thermal and fast neutron results, respectively. Not all laboratories had neutron dose capabilities.

Table 6-26. Test irradiations–thermal neutrons (Unruh et al. 1967).

Processor number	Relative error			Bias as % of dose		
	Given dose (mrem)			Given dose (mrem)		
	60	**120**	**382**	**60**	**120**	**382**
1	225	245	0	17	18	-47
2	495	320	356	267	358	366
3	8	4	5	2	-1	-9
4	347	415	37	417	417	393
5	–	–	–	–	–	–
6	–	–	–	–	–	–
7	17	16	4	13	11	15
8	24	14	6	-8	0	2
9	215	122	14	633	467	419
10	420	527	203	550	500	524
11	174	145	83	617	558	628
12	8	16	10	52	44	39
13	–	–	–	–	–	–
14	–	–	–	–	–	–
15	–	–	–	–	–	–
16	–	–	–	–	–	–
17	–	–	–	–	–	–
18	–	–	–	–	–	–
19	–	–	–	–	–	–
20	68	20	13	83	92	42
21	–	–	–	–	–	–
22	–	–	–	–	–	–
23	–	–	–	–	–	–
24	–	–	–	–	–	–
25	0	0	0	25	-17	-15
26	–	–	–	–	–	–
27	–	–	–	–	–	–
28	–	–	–	–	–	–
29	19	21	22	-75	-82	-81
30	33	32	4	40	-3	-7
31	–	–	–	–	–	–
32	340	212	131	683	633	246
33	–	–	–	–	–	–
34	3,447	122	414	1300	675	340
35	–	–	–	–	–	–
Average	365	139	81	288	229	178

6.8.3 Measured Beta Dose

Uncertainty in the measured dosimeter beta or nonpenetrating dose is closely associated with the evaluation of uncertainty in the dosimeter photon or penetrating dose because the same dosimeter responses are being evaluated. There is typically greater variability for the nonpenetrating or beta component for film dosimeters in particular because of the much greater response (i.e., compared to shielded film response) from lower energy photons. However, the performance of the dosimeter to

Table 6-27. Test irradiations–fast neutrons (Unruh et al. 1967).

Processor number	Percent Relative error				Bias as % of dose	
	Given dose (mrem)				Given dose (mrem)	
	200	262	787	200	262	787
1	27	8	21	-93	-76	-66
2	448	348	105	220	99	-27
3	17	33	41	30	15	14
4	61	86	120	5	3	51
5	21	23	12	8	9	7
6	26	66	22	65	53	62
7	43	26	13	19	8	10
8	–	–	–	–	–	–
9	19	43	54	14	50	25
10	92	79	204	90	99	105
11	12	73	21	55	53	42
12	56	27	15	25	21	15
13	27	12	20	80	92	91
14	17	5	1	49	38	46
15	–	–	–	–	–	–
16	61	21	38	60	69	76
17	–	–	–	–	–	–
18	–	–	–	–	–	–
19	31	28	36	90	111	140
20	11	7	10	12	11	6
21	–	–	–	–	–	–
22	–	–	–	–	–	–
23	31	26	30	115	95	93
24	115	72	57	110	111	89
25	27	23	16	8	-6	18
26	22	25	13	32	28	23
27	12	15	74	41	38	29
28	–	–	–	–	–	–
29	25	51	39	80	92	80
30	7	12	6	-75	-73	-72
31	59	46	31	145	156	152
32	33	55	70	80	61	20
33	16	23	13	-1	14	-2
34	124	315	193	-47	31	12
35	–	–	–	–	–	–
Average	53	57	47	45	45	38

lower energy photons from filtered X-ray sources and beta sources were routinely done. Several studies as highlighted in the following:

Wilson (1960b) conducted a detailed examination of the LOD for the Hanford dosimetry system based on the analysis of 49 batches of Hanford routine calibration results that indicated a 25% standard deviation at the 30-mrem calibration level based on optical density readings. Based on an analysis of the capabilities of the densitometer used to process the film, he estimated a likelihood of 0.33 (1/3) that a dose of 15 mrem would not be detected. The likelihood that this would occur for each successive monthly exchange for an entire year would be $(0.33)^{12}$ or about 1 in a million. Based on the 13 exchanges during the year at that time, he estimated a maximum potential missed dose of 195 mrem (i.e., 15 × 13). Conversely, Wilson estimated that about 8% of the time, a positive dose would be recorded for dosimeters that received no exposure. A similar analysis could be performed for the dosimeter used prior to 1960 with an estimate that about 30 mrem would be detected one-third of the time.

- BNWL-542, *The Establishment and Utilization of Film Dosimeter Performance Criteria* (Unruh et al. 1967), contains discussion of proposed personnel film performance criteria that includes statistical analysis of Hanford calibration dosimeter during the period from 1950 to 1964, which included more than 600 measurements on each of several exposure levels of gamma, beta and 17-keV X-ray radiations. The records evaluated and tabulated in Table 6-28 were for 11 exposure levels for beta radiation.

Table 6-28. Relative error values for electron exposure of Hanford film dosimeters, 1950–1964 (Unruh et al. 1967).

Type of radiation	**Exposure (mrem)**	**Hanford reported doses**		
		Mean[a]	**Percent relative error**	**Percent of measurements within ± 2 sigma**
Beta	0	9.03	460	97.3
	15	14.31	137	95.7
	30	30.42	59	95.1
	60	59.09	31	95.8
	90	87.30	24	94.6
	120	117.88	18	96.3
	180	178.15	16	97.6
	240	241.12	12	96.7
	300	298.93	12	94.2
	500	498.55	5	96.6
	750	749.46	1	98.8

a. Reported doses in mrem.

6.9 SHALLOW DOSE

6.9.1 Assigned Shallow Dose

Hanford practice was to assign to the skin the sum of the penetrating WB dose from photon, neutron, and tritium and to add the nonpenetrating dose from beta and low-energy photon radiation. In this manner, all measured dose components were assigned to the skin. There is uncertainty with respect

to reconstructing the skin dose in workplace situations because of the complex mixed radiation fields and the range of parameter effects associated with geometry, shielding and dosimeter response. Figure 6-12 illustrates that in parallel workplace studies in 1970 and 1971 of thermoluminescent and film dosimeters that the film measured nonpenetrating dose was typically greater than the TLD measured nonpenetrating dose. Guidance on determining the reconstructed skin dose can be obtained from Attachment C for Hanford workers.

6.9.2 Assigned Extremity Skin Dose

There is uncertainty with respect to reconstructed extremity skin dose because of geometry, shielding and dosimeter response parameters. It has been Hanford practice to assign to the extremities all recorded WB skin dose (i.e., beta, photon, neutron and tritium) and also to assign any measured extremity dose. Extremity dosimeters were routinely assigned to Hanford radiation workers who directly handled uranium, plutonium or beta emitting nuclides with a significant potential to result in a significant extremity dose and certainly whenever the extremity dose might be more limiting than the measured WB dose. Hanford dosimeter processing procedures in 1946 clearly describe practices to prepare rings and pads (i.e., film mounted on a rubber pad to be placed in the hands or other places of the body were a ring could not be used) and practices to calibrate these dosimeters using radium, uranium and X-ray (80 kVp) irradiations (HEW 1946). Durum (1946) describes badge and contact exposures in Hanford 300 Area Building 313-314 fuel canning operations. A 7 day weighted average exposure of 776 mrep to the skin of the finger was determined. The maximum hand exposure was

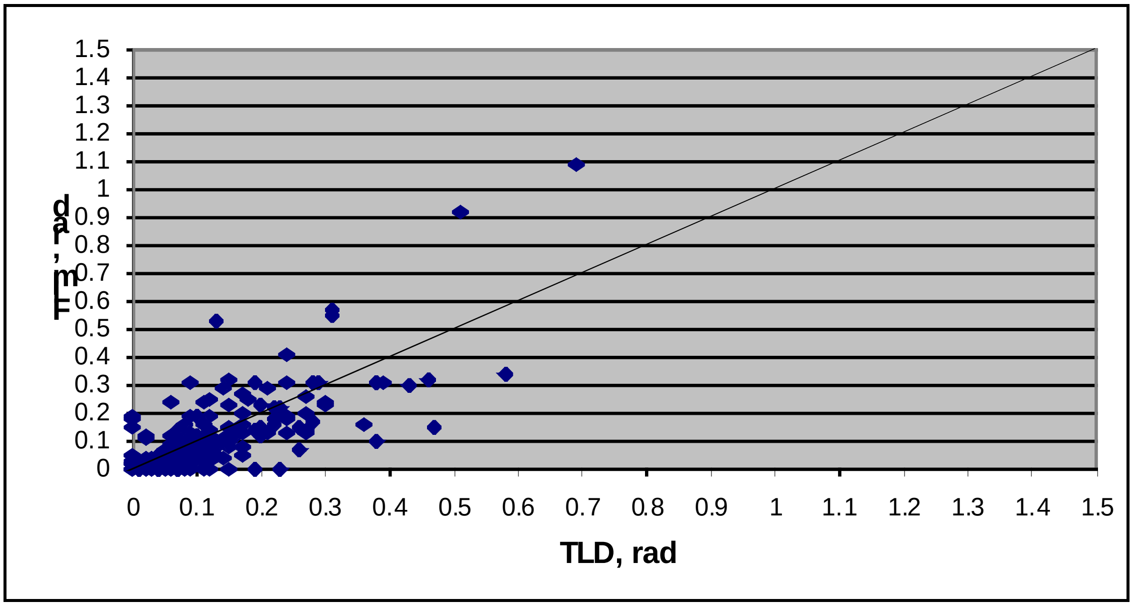

Figure 6-12. Comparison of Hanford film and TLD nonpenetrating dose results (Nichols et al. 1972).

determined to be 234 mrep/day for the finish machining task stated to be a continuous operation. Ongoing concern for potential significant hand exposures is evident in many of the early plutonium finishing plant studies listed in Attachment D, Table D-2. Several reports were prepared by Helgeson. A standard monitoring practice was to establish a factor between WB and extremity exposures to determine when the extremity dose would be limiting and, as such, when extremity dosimeters should be assigned. Hanford did initiate preparation of daily and weekly worker restricted dose lists (HEW 1946) which listed workers with film or PIC results exceeding 100 mR. Analysis of the dose to be assigned to workers on these lists was necessary prior to incurring any further exposure. Certainly this is one factor involved in the policy for each worker to be assigned two PICs and to record the lower dose because of the substantial tendency of the PIC to over-estimate the dose.

The factor is typically based on radiation guidelines for the extremity, skin, and whole body, which have varied over the years. At the 1949 meeting in Chalk River, Canada, among U.S., United Kingdom, and Canadian nuclear weapon development organizations, several aspects of operational health physics were defined (Taylor 1971). The identified limits were:

Whole body–0.3 rem/wk;
Skin–0.5 rem/wk and
Extremity–1.5 R/wk.

Based on comparison of the dose limits, it would not be necessary to monitor the extremity dose unless it was greater than a factor of about 5 multiplied by the WB dose, otherwise the WB dose would be limiting. Therefore, it is recommended that the measured WB dose be increased by a factor of 5 to assign a dose to the extremities based on the premise that extremity dosimeters would have been assigned and the dose reported for any higher exposures [28].

6.9.3 Assigned Pre-October 1944 Extremity and Skin Dose

Natural uranium fuel fabrication for Hanford reactors was begun during 1943 (DuPont 1945). The Hanford film dosimeter was first used at the B Reactor during September 1944 (Wilson 1987). The Hanford PIC was implemented during January 1944 and used to determine the official dose of record until the film dosimeter system was available. However, the Hanford PIC had little response to

Uranium beta radiation. Durum (1946) describes monitoring practices and measurements of the whole body, hand and extremity skin doses received in Hanford Buildings 313 and 314 fuel fabrication operations. These measurements involved the placement of extra film badges on all Bldg. 313-314 personnel for a period of about two-days (Bldg 314 done and then Bldg. 313). Time studies were made using stop watches for those operations known to involve considerable uranium metal contact. Only operations with actual or near-actual contact were considered. Table 6-29 summarizes the maximum assigned doses during a work day. For work with uranium metal prior to October 1944, dose reconstructors should assign a skin dose for the relevant employment period. The equivalent annual dose is presented in Table 6-29 which is approximately the maximum potential dose to be considered for assignment (i.e., October 1943 through September 1944).

Table 6-29. Maximum assigned pre-October 1944 skin dose in Hanford reactor fuel fabrication (Durum 1946).

	Skin dose, mrem	
Dosimeter location	**Per day**	**Per year**
Whole body skin	65	23,725
Hand dose	234	85,410
Finger dose	776	283,240

a. Measured dose from bare metal.
b. Weighted 7-day average exposure.

6.10 NON-SITE-SPECIFIC FACTORS

6.10.1 Adjustment for Glovebox Workers

There is uncertainty with respect to the reconstructed organ dose in the lower abdomen for workers working substantially in a chemical bench top environment such as the Hanford plutonium facility glovebox operators. Guidance in OCAS-TIB-0010, *Best Estimate External Dose Reconstruction for Glovebox Workers* (NIOSH 2005), should be used to adjust the measured photon dose to Hanford workers in identified Hanford 200 and 300 Area plutonium facilities notably 231-Z, 234-5, and 308 where extensive and long-term glovebox work was conducted. Generally this correction should be considered for any worker with a glovebox checked on the Computer Assisted Telephone Claim form and whether the identified places of work did include glovebox or other benchtop work environments.

6.10.2 Construction Trade Workers

There is uncertainty with respect to the reconstructed organ dose for Construction Trade Workers because of the nature of their work activities in maintaining Hanford facilities and equipment. An adjustment factor of 1.4 multiplied by the organ dose components for each year of Hanford employment is recommended as described in ORAUT-OTIB-0052, *Parameters to Consider When Processing Claims for Construction Trade Workers* (ORAUT 2007b).

6.11 ATTRIBUTIONS AND ANNOTATIONS

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

Jack Fix served as the initial Subject Expert for this document. Mr. Fix was previously employed at the Hanford Site; his work involved management, direction, or implementation of radiation protection and/or health physics program policies, procedures, or practices related to atomic weapons activities at the Site. This revision and earlier revisions have been overseen by a Document Owner who is fully responsible for the content, including all findings and conclusions. Mr. Fix continues to serve as a Site Expert for this document because he possesses or is aware of information relevant to the reconstruction of radiation doses experienced by claimants who worked at the Site. In all cases where such information or prior studies or writings are included or relied on by Mr. Fix, those materials are fully attributed to the source. Mr. Fix's Disclosure Statement is available at www.oraucoc.org.

Fred Duncan assumed responsibility as Document Owner for this document in September, 2008. Mr. Duncan replaced Edward Scalsky when Mr. Scalsky's employer declared a new corporate conflict of interest for the Hanford Site. Mr. Scalsky continues to participate on this document team in the appropriate role of Subject Expert in compliance with the NIOSH Conflict or Bias policy.

[1] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
Hanford workers do have recorded nonpenetrating doses of record [see Buschbom and Gilbert (1993)], and this is included in this TBD as Attachment C.

[2] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This judgment is based on Mr. Fix's experience in occupational dose reconstruction.

[3] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The data used to prepare this figure were obtained from statistical tables included PNL-8909 (Buschbom and Gilbert 1993) of the Hanford Health and Mortality Study worker cohort.

[4] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This judgment is based on the dose reconstruction recommendation presented in later sections of this TBD to assign, as appropriate based on claimant work activities, an annual neutron dose for each year of Hanford employment prior to the use of the TLD beginning in 1972, using a distribution of the NP dose ratio.

[5] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This judgment is based on Mr. Fix's perspective on the historical development of personnel dosimetry systems and the performance studies conducted historically leading to the adoption of ANSI/HPS N13-11-1983 (HPS 1983).

[6] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This judgment is based on Mr. Fix's experience in the preparation of Fix, Wilson and Baumgartner (1997b), during which a database of all Hanford NTA processing results from 1950 through about 1961 was developed from the paper records obtained from the Federal Record Center.

[7] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The data for a single claimant were obtained from the DOE dose records for this person for employment at Hanford.

[8] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
Mr. Fix was the Hanford External Dosimetry Program Project Manager in 1995. The commercial Harshaw dosimetry systems became effective with the January 1, 1995, dosimeter issue to Hanford workers.

[9] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
Reference to the routine comparison of pocket ionization chamber PIC and film dosimeter results is based on judgment of the information in the *Manual of Standard Procedures:*

Personnel Meters (HEW 1946), Valentine (1965), and the respective routine organizational reports presented in Attachment D, Table D-2.

[10] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The first computer system for radiological records was introduced in 1958 as described in Wilson (1987). Before this, it was necessary to record the assigned dose manually on forms. Fix, Carbaugh, and MacLellan (2001) enables a person to view the forms used. In addition, DOE provided historical dose forms that provide a means to view these forms for the respective years.

[11] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The methods used to record dose at Hanford are described in Fix, Carbaugh, and MacLellan (2001).

[12] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The precise period of accreditation of the Hanford External Dosimetry Program is a matter of record available from the DOELAP. The stated year of 1989 is based on Mr. Fix's recollection as chair of the DOELAP Oversight Board.

[13] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This statement is based on judgment by Mr. Fix on the challenge presented by mixed beta/ photon radiation fields and neutron radiation and on his experience in accurate measurements of these fields, his role on the DOELAP Oversight Board, and in the content of national dosimeter performance standards such as ANSI/HPS N13.11-1983 (ANSI HPS 1983).

[14] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The judgment presented is based on Mr. Fix's assessment of the association of dosimeter error on dosimeter response and workplace radiation characteristics. For example, see Wilson et al. (1990).

[15] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The judgment of complex radiation fields in the workplace is based on consideration of the types of processes and radionuclides at Hanford. The 10-year review by Parker (1954) could be consulted for a description.

[16] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
These statements are based on judgment by Mr. Fix and require knowledge of the gamma energies associated with the radionuclides in Table 6-9. The prevalent ^{60}Co (1.17 and 1.33 MeV) and ^{137}Cs (0.662 MeV) in several facilities are generally considered to be higher energy gamma radiation, whereas in Hanford plutonium facilities 241Am (59 KeV) is considered to be of low to intermediate energy and the 17-keV radiation (prevalent X-ray from plutonium) is considered to be low- energy.

[17] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This statement is supported in Nichols et al. (1972, pp. 3 and 7) and in Fix et al. (1981, Study 5).

[18] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The radiation dose fractions presented to segregate beta, photon, and neutron dose components into IREP input categories are based on judgment by Mr. Fix.

[19] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The list of Hanford facilities with a potential for neutron exposure was developed from Hanford

Site Profile Section 2 (ORAUT 2007c), experience with Hanford facilities, and historical documentation. The early reactor facility 305 should be included in the 300 Area list.

[20] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The data in Table 6-14 were obtained from Table II of Nichols et al et al. (1972).

[21] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This statement and the judgment identified in this table by Mr. Fix of the effects of angular response on recorded dose is based on Mr. Fix's assessment of the complex interactions that involved dosimeter angular response and workplace radiation fields.

[22] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
Table 6-29 contains summaries of the neutron dose fractions for different facilities, the factor to transform the neutron dose of record to incorporate ICRP Publication 60 weighting factors (ICRP 1991), and the overall factor that can be used by the dose reconstructor. The process is explained in OCAS-IG-001 (NIOSH 2007b) and in ORAUT-OTIB-0055 (ORAUT 2006a).

[23] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This represents the judgment of Mr. Fix and is substantially based on information in Fix, Wilson, and Baumgartner (1997b).

[24] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This statement is originally provided in Wilson (1960b, p. 1) on the potential missed dose for Hanford workers with dosimeters located simultaneously at several Hanford area dosimeter exchange gatehouses.

[25] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
This represents the judgment of Mr. Fix and is substantially based on information in Fix, Wilson, and Baumgartner (1997b) and explained in the succeeding sections.

[26] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The recommendation to use the claim-specific neutron-to-photon NP dose ratio if higher than the recommended default values is to ensure that the neutron dose of record for the claimant is not reduced.

[27] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The neutron-to-photon NP dose ratios are a summary of the values developed in the previous text.

[28] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The information in this section is based on the judgment of Mr. Fix recommending to the dose reconstructor, depending on the target tissue, consideration to assign an extremity dose in the event that monitoring for extremity dose is not performed and an extremity dose is not reported by DOE.

[29] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. December 2009.
The statement that the operation of the PFP has discontinued as of December 2009 is based on judgment by Mr. Fix.

[30] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
The statement about research and development in Hanford 300 facilities in preparation for operation of the 400 Area FFTF is based on judgment by Mr. Fix.

[31] Fix, Jack J. Dade Moeller & Associates. Senior Health Physicist. March 2007.
Appendix A tables summarize neutron spectral information from measurements described in the respective references. The 0.1- to 2-MeV category represents a substantial component in each workplace, and it alone could be used (i.e., assign 100%) as an analysis that is favorable to claimants.

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GLOSSARY

absorbed dose, D

Amount of energy (ergs or joules) deposited in a substance by ionizing radiation per unit mass (grams or kilograms) of the substance and measured in units of rads or grays. See *dose*.

accreditation

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

accuracy

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

albedo dosimeter

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

algorithm

Set of rules or steps for solving a problem, especially for calculating a value.

alpha radiation

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

boron trifluoride (BF_3) chamber or counter

Proportional counter using gaseous boron trifluoride (BF_3) to detect slow neutrons from their interactions with boron.

backscatter

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

beta particle (β)

See *beta radiation*.

beta radiation

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

Bonner Sphere

See *multi-sphere neutron spectrometer*.

calibration blank

Dosimeter not exposed to radiation. This dosimeter establishes the dosimetry system base line or zero dose value.

collective dose equivalent (CDE)

Sum of the dose equivalents of all individuals in an exposed population in units of person-rem or person-sievert. See *dose*.

curie (Ci)

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

Cutie Pie (CP)

Portable radiation survey meter with a pistol grip and a large cylindrical ionization chamber.

deep absorbed dose (D_d)

Absorbed dose in units of rem or sievert at a depth of 1 centimeter (1,000 milligrams per square centimeter) . See *dose*.

deep dose equivalent (DDE, H_d, $H_p(10)$)

Dose equivalent in units of rem or sievert for a 1-centimeter depth in tissue (1,000 milligrams per square centimeter). See *dose*.

densitometer

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

density reading

See *optical density*.

DOE Laboratory Accreditation Program (DOELAP)

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

dose

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

dose equivalent (H, DE)

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

dose equivalent index

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

dosimeter

Device that measures the quantity of received radiation, usually a holder with radiation-absorbing filters and radiation-sensitive inserts packaged to provide a record of absorbed dose received by an individual. See *albedo dosimeter*, *film dosimeter*, *neutron film dosimeter*, *pocket ionization chamber*, *thermoluminescent dosimeter*, and *track-etch dosimeter*.

dosimetry system

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

DuPont 552 film packet

Film packet containing DuPont 502 sensitive film and DuPont 510 insensitive film.

DuPont 558 film packet

Film packet containing DuPont 508 film with sensitive and insensitive emulsions on either side.

element

One of the known chemical substances in which the atoms have the same number of protons. Elements cannot be broken down further without changing their chemical properties. Chemical symbols for the elements consist of either a single letter or a combination of letters, some of which descend from the Latin names [e.g., Au from *aurum* (gold), Fe from *ferrum* (iron)]. This glossary indicates *elements* by their names. Specific *isotopes* appear as their standard chemical symbols with the number of protons and neutrons in the nucleus. For example, the isotope of uranium that contains 92 protons and 143 neutrons can appear as ^{235}U, *U-235*, or *uranium-235*

error

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

exchange period (frequency)

Period (weekly, biweekly, monthly, etc.) for routine exchange of dosimeters. Also called exchange frequency.

exposure

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

exposure-to-dose-equivalent conversion factor for photons (Cx)

Ratio of exposure in air to the dose equivalent at a specified depth in a material of specified geometry and composition. C_x factors are a function of photon energy, material geometry (e.g., sphere, slab, or torso), and material composition (e.g., tissue-equivalent plastic, soft tissue without trace elements, or soft tissue with trace elements).

extremities

The portion of the arm from and including the elbow through the fingertips and the portion of the leg from and including the knee and patella through the toes.

fast neutron

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

favorable to claimants

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

field calibration

Dosimeter calibration based on radiation types, intensities, and energies in the work environment.

film

(1) In the context of external dosimetry, radiation-sensitive photographic film in a light-tight wrapping. See *film dosimeter*. (2) X-ray film.

film density

See *optical density*.

film dosimeter

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

filter

Material used (1) in a dosimeter to adjust radiation response to provide an improved tissue equivalent or dose response and (2) in an X-ray machine to selectively absorb photons from the beam to reduce unnecessary exposure of individuals or to improve radiographic quality.

first collision dose

Measure for neutron radiation that relates dose to neutron flux through a thin layer of tissue. A graph referred to as the first collision curve derives from the assumption that the probability of two or more interactions per neutron is negligible. Because the charged secondary radiation from fast neutrons is short range, the first collision dose in irradiated material is nearly the same as the absorbed dose.

free-field dose equivalent

Dose equivalent for neutron radiation in free space with no background from air and room scattering and no source asymmetry.

gamma radiation

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

Geiger-Müller counter

Most common radiation detection and measuring instrument, usually known simply as a Geiger counter, it is a gas-filled tube containing electrodes between which there is a voltage potential but no current flow. When ionizing radiation passes through, a short, intense pulse of current passes from one electrode to the other. The number of pulses per second (or counts per minute) indicates the rate of ionizing events in the tube.

glovebox

Enclosure with special rubber gloves through which an operator can handle radioactive or toxic material without risk of injury or contamination normally operated at a slightly reduced pressure so that air leakage, if any, is inward.

gray (Gy)

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

helium-3 (^{3}He) spectrometer

Instrument that measures neutron energy spectra based on neutron interactions with ^{3}He to produce a triton (particle with 2 protons and one neutron) and a proton, which are detected by a proportional counter.

induced radioactivity

Radioactivity produced in certain materials as a result of nuclear reactions particularly the capture of neutrons.

intermediate neutron

Neutron with energy between 0.5 electron-volts and 10 kiloelectron-volts. See *fast neutron* and *slow neutron*.

ionizing radiation

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

isotope

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

kiloelectron-volt (keV)

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

limit of detection (LOD)

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

luminescence

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

Manhattan Engineer District (MED)

Subdivision of the U.S. Army Corps of Engineers that administered the World War II Manhattan Project to develop the first nuclear bomb. The word *Manhattan* was chosen to divert attention from the Project’s real purpose. The U.S. Atomic Energy Commission assumed control of MED facilities and activities in 1946.

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. Hanford has generally recorded minimum doses of 10 mrem and at intervals of 10 mrem (i.e., 10, 20, 30, etc.).

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

multiple-collision neutron dose
Dose in relation to the neutron flux through tissue based on the assumption that two or more interactions per neutron occurs and results in greater energy deposition.

multi-sphere neutron spectrometer
Spectrometer that consists of a series of neutron-moderating spheres of tissue-equivalent material with a neutron detector in the middle of the respective spheres. Algorithms are used to calculate the neutron spectra.

nuclear track emulsion, type A (NTA)
Film sensitive to fast neutrons made by Eastman Kodak. The developed image has tracks caused by neutrons that are visible under oil immersion with about 1,000-power magnification.

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

neutron-to-photon dose ratio
Ratio applied to the photon fraction to estimate the unmeasured neutron dose based on knowledge and measurements in a specified location.

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

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

nonpenetrating dose (NP, NPEN)
Dose from beta and lower energy photon (X-ray and gamma) radiation which does not penetrate the skin. It is often determined from the open window dose minus the shielded window dose. See *dose*.

open window (OW)
Area of a film dosimeter that has little to no radiation shielding (e.g., only a holder and visible light protection). See *film dosimeter*.

operating area
Designation of Hanford major operational work areas among the respective fuel fabrication (e.g., 300 Area), reactor operations (e.g., 100B, 100C, 100D, 100DR, 100F, 100H, 100KE, 100KW, and 100N), chemical separations (e.g., U-, T-, B-, UO3, REDOX, and PUREX Plants), plutonium finishing (Z-Plant), research and development (e.g. 300 and 3000 Areas), and transportation, communication, and general site support (e.g., 600, 700, and 1100 Areas).

optical density

Measure of the degree of opacity of photographic or radiographic film defined as *OD* = $\log_{10} (I_0/I)$, the base-10 logarithm of the ratio of the reference light intensity I_0 (without film) to the transmitted light intensity (through the film) Also called film density and density reading.

pencil dosimeters

See *pocket ionization chamber*.

penetrating dose (PEN)

Dose from moderate to higher energy photons and neutrons that penetrates the outer layers of the skin. See *dose*.

plutonium tetrafluoride (PuF_4) source

Neutron source for dosimetry evaluation that duplicates the neutron energies in plutonium facilities. At Hanford it was used in the 200 Area Z-Plant (the Plutonium Finishing Plant).

personal dose equivalent [$H_p(d)$]

Dose equivalent in units of rem or sievert in soft tissue below a specified point on the body at an appropriate depth *d*. The depths selected for personal dosimetry are 0.07 millimeters (7 milligrams per square centimeter) and 10 millimeters (1,000 milligrams per square centimeter), respectively, for the skin (shallow) and whole-body (deep) doses. These are noted as $H_p(0.07)$ and $H_p(10)$, respectively. The International Commission on Radiological Measurement and Units recommended $H_p(d)$ in 1993 as dose quantity for radiological protection.

photon

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

photon dose fraction

Fraction of the measured photon dose that is multiplied by the neutron-to-photon dose ratio to estimate the unmeasured neutron dose.

pocket ionization chamber (PIC)

Cylindrical monitoring device commonly clipped to the outer clothing of an individual to measure ionizing radiation. A PIC can be self-reading or require the use of a outside device to be able to read the dosimeter. Also called pencil, pocket pencil, pencil dosimeter, and pocket dosimeter.

precision

Describes dispersion of measurements in relation to a measure of location or central tendency.

probability of causation (POC, PC)

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

quality factor (Q, QF)

Principal modifying factor (which depends on the collision stopping power for charged particles) that is employed to derive dose equivalent from absorbed dose. The quality factor multiplied by the absorbed dose yields the dose equivalent. See *dose*, *relative biological effectiveness*, and *weighting factor*.

rad

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

radiation

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

radiation monitoring

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

radioactivity

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

random error

When a given measurement is repeated and the values do not agree exactly. The causes of the disagreement between the values must also be the causes of their differences from the true value. See *systematic error*.

relative biological effectiveness (RBE)

Ratio of the absorbed dose of a reference radiation to the absorbed dose of a test radiation that produces the same biological effects, other conditions being equal. A factor applied to account for differences between the amount of cancer effect produced by different forms of radiation.

rem

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

roentgen (R)

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

scattering

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

shallow absorbed dose (Ds)
Absorbed dose at a depth of 0.07 millimeters (7 milligrams per square centimeter) in a material of specified geometry and composition.

shallow dose equivalent [SDE, H_s, $H_p(0.07)$]
Dose equivalent in units of rem or sievert at a depth of 0.07 millimeters (7 milligrams per square centimeter) in tissue equal to the sum of the penetrating and nonpenetrating doses.

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

Sievert (Sv)
International System unit for dose equivalent, which indicates the biological damage caused by radiation. The unit is the radiation value in gray (equal to 1 joule per kilogram) multiplied by a weighting factor for the type of radiation and a weighting factor for the tissue; 1 Sv equals 100 rem.

sigma pile
Device used to obtain thermal neutrons for calibration purposes.

silver shield(s)
Hanford term for 1-millimeter and 0.13-micrometer shields covering the film packet in the early Hanford personnel film dosimeters.

skin dose
See *shallow dose equivalent*.

slow neutron
Neutrons with energy less than 1 electron-volt. See *fast neutron* and *intermediate neutron*.

Snoopy
Portable neutron monitoring instrument with a moderated BF_3 detector. See *boron trifluoride (BF_3) chamber*.

systematic error
When a given measurement is repeated and the values differ from the true value by the same amount. See *random error*.

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

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

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

tissue equivalent

Substance with response to radiation equivalent to tissue. A tissue-equivalent response is an important consideration in the design and fabrication of radiation measuring instruments and dosimeters.

Tissue Equivalent Proportional Counter (TEPC)

Device that measures absorbed dose from neutron radiation in materials nearly equivalent to tissue. Analysis of the counter data determines the effective weighting factor and the dose equivalent for that radiation.

TLD chip

Small block or crystal of lithium fluoride in a thermoluminescent dosimeter. A TLD-600 dosimeter contains a chip made from more than 95% ^{6}Li for neutron radiation detection, and a TLD-700 dosimeter contains a chip made from more than 99.9% ^{7}Li for photon and beta radiation detection. Also called crystals.

track-etch dosimeter (TED)

Device for evaluation of fast neutron dose through examination of traces left by the neutrons on the Columbia Resin Number 39 emulsion.

U.S. Atomic Energy Commission (AEC)

Federal agency created in 1946 to assume the responsibilities of the Manhattan Engineer District (nuclear weapons) and to manage the development, use, and control of nuclear energy for military and civilian applications. The U.S. Energy Research and Development Administration and the U.S. Nuclear Regulatory Commission assumed separate duties from the AEC in 1974. The U.S. Department of Energy succeeded the U.S. Energy Research and Development Administration in 1979.

uncertainty

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

whole-body (WB) dose

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

X-ray

See *X-ray radiation*.

X-ray radiation

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

Z-Plant

Hanford facility consisting of several buildings where plutonium is processed (also known as 234-5-Z Building).

ATTACHMENT A
WORKPLACE NEUTRON SPECTRA MEASUREMENTS

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Hanford researchers have made neutron spectra and dose measurements in several Hanford workplaces as early as the late 1940s using various methods to estimate the neutron spectra. Beginning in the 1960s approximately, more sophisticated methods to measure neutron spectra became available. The measured spectra in this attachment have been used to evaluate the selection of the IREP input energy category (shown in shaded colors on the graphs) for Hanford facilities.

A1. 100 AREA REACTOR FACILITIES

Substantial reactor core neutron energy fluence measurements were routinely collected for the Hanford single-pass cooling production reactors. However, only a few relevant workplace neutron radiation spectra measurements for Hanford single-pass reactors that operated from 1945 (100 B) through 1971 (100 KE) have been located. The measurements of most interest are during reactor operation. Neutron spectrum measurements were made in the early 1980s at two locations at the FFTF in the 400 Area (Fix et al. 1982) as shown in Figure A-1.

The data in Figure A-1 might not be indicative of routine operations. At that time of the measurements, a stainless-steel research thimble in one of the bundle tubes allowed neutrons to stream from the core to the head compartment. The neutron spectrum was highly scattered, resulting in significantly lower neutron energies. Highly scattered neutron fields are likely characteristic of Hanford single-pass reactor workplace fields and this resulted in the relatively low NTA

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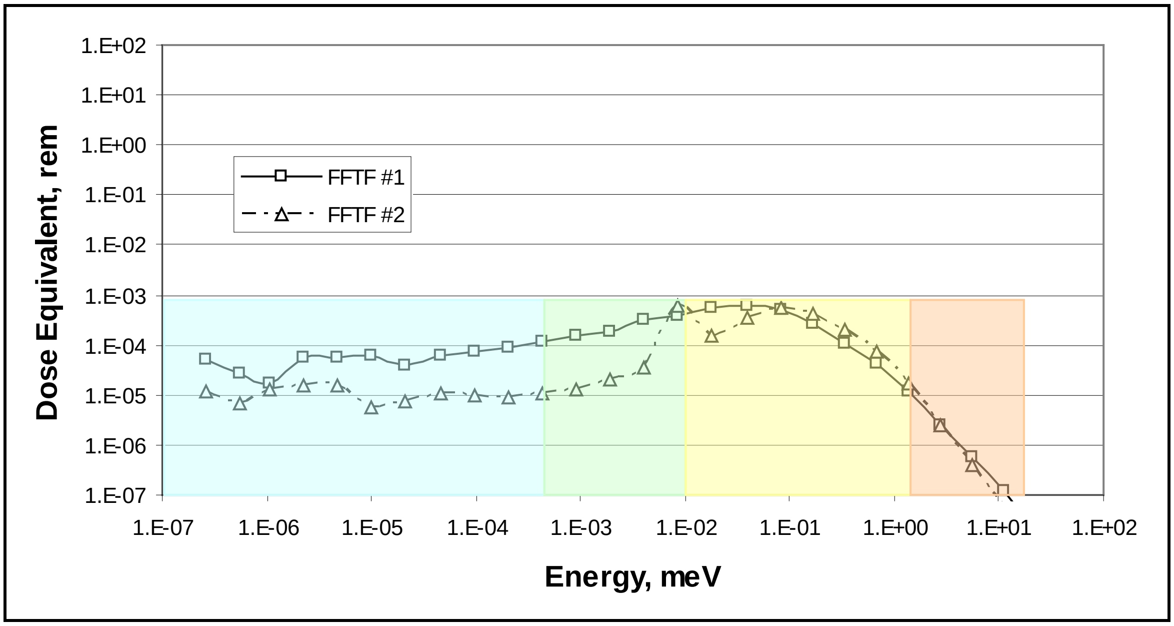

Figure A-1. Neutron spectra for Hanford 400 Area FFTF (Fix et al. 1982).

measurements. The HMPD used in these measurements showed an over-response of about a factor of 6 compared to the multisphere measurements because of the highly degraded neutron spectrum. Although indirectly applicable, measurements of neutron spectra and dose and personnel dosimeter performance in U.S. nuclear power reactors reported by Endres et al. (1981) concluded that NTA emulsions are not sensitive to the leakage spectra that might be present in commercial power reactor plants.

A2. 200 AND 300 AREA PLUTONIUM FACILITIES

Plutonium production at Hanford began January 16, 1945 (Marceau et al. 2002, Chapter 2, Section 4), in what is often called Z-Plant or the PFP 231-Z Plutonium Isolation Facility in the Hanford 200 Area. At that time, Hanford-produced plutonium nitrate was shipped to the Los Alamos National Laboratory for use in producing nuclear weapons. On July 5, 1949, the PFP 234-5Z facility provided the capability for Hanford to convert plutonium nitrate to metallic plutonium. The initial 234-5Z plutonium finishing equipment was termed the “Rubber Glove” line because it depended on personnel working with a series of 28 stainless-steel gloveboxes, 55 m long, to move the plutonium mixtures manually through the finishing process (Fix, Wilson, and Baumgartner 1997b).

On March 18, 1952, a Remote Mechanical A (RMA) Line began operation. The RMA Line performed all the process steps in plutonium metal production and fabrication except Task 1 (feed makeup and purification), which continued in the 231-Z facility. The RMA Line was in six rooms at 234-5Z. In mid-1957, the RMA Line was modified for a continuous calcination and hydrofluorination process that essentially handled the Task 1 activities previously done at 231-Z (i.e., all processing tasks). Many projects were undertaken at PFP 234-5Z from 1957 to 1961 to accommodate the significant increase in throughput. The most significant of these were the construction of the remotely operated series of gloveboxes (RMC) Button Line and the RMC Fabrication Line which still required substantial operator and maintenance personnel contact (Lini 2008). Both of these began operation in the mid-1960s. The RMC Line (button and fabrication components) consisted of a completely self-contained, remotely operated series of gloveboxes similar to the RMA Line areas (Fix, Wilson, and Baumgartner 1997b).

Neutron dose is associated with the overall Hanford plutonium production process in which plutonium from the processing facilities was brought into PFP as a liquid nitrate solution. At the PFP, plutonium was precipitated as an oxalate, converted to a fluoride, and reacted at high temperature with metallic calcium, forming the metal (Ballinger and Hall 1991). Neutron radiation was particularly enhanced during the fluorination step in the process because of plutonium fluoride (PuF_4) alpha neutron (α,n) reactions. As of December 2009, the Hanford 200 Area plutonium facility is no longer in operation [29].

Research and development work with nuclear fuel was conducted in the Hanford 300 Area, particularly at the 308 Building PFPP, 309 Building PRTR, and in the 324 Building chemical and materials engineering hot cell laboratories. Pilot work was performed in the 300 Area facilities in preparation for the 400 Area FFTF construction and operation [30].

A3. NEUTRON ENERGY SPECTRA

PuF_4 is the most significant source, historically, of neutron exposure to workers in the Hanford 200 Area plutonium facilities. Figure A-2 shows measurements by Brackenbush, Baumgartner, and Fix (1991) of a PuF_4 source with no shielding, 2.54 cm of acrylic plastic, and 5.08 cm of acrylic plastic shielding between the source and the detector system to illustrate the effect on the plutonium spectrum of increasing thicknesses of the acrylic in the glovebox sides. A PuF_4 source was used to calibrate Hanford personnel dosimeters beginning in 1958 (Fix, Wilson, and Baumgartner 1997b). This figure shows that, although different neutron spectra were measured, similarities were observed in the general shape of the degraded PuF_4 spectrum. The energy of the dose equivalent peak is centered at approximately 1 MeV. Similar plutonium source and acrylic shielding measurements were reported in Endres et al. (1996) in association with field evaluations of the Harshaw commercial TLD and TED system implemented on January 1, 1995. The results of these measurements led to the eventual elimination of the TED component in routine personnel monitoring because the TED substantially underestimated the neutron dose. This occurred because the TED did not respond to the substantial lower energy neutron spectrum from stored plutonium in the current Hanford PFP operation. There are many similarities between NTA film and TED characteristics, including physical size, direct neutron responding device, angular response, and a lower energy neutron response threshold. The TED has a significantly better energy threshold of about 100 keV compared to the NTA film threshold of about 700 keV, but showed unacceptable capabilities to measure neutron dose.

Neutron radiation spectra measurements in Figure A-3 are documented in Fix et al. (1981, Study 4) and in Roberson, Cummings, and Fix (1985) at the PFP 234-5Z Building “C” Line, Room B, selected gloveboxes, and the 2736-Z plutonium vault. The 234-5Z locations are where plutonium nitrate was converted to plutonium fluoride with the associated high neutron flux rates. This location provided the highest neutron flux rates at Hanford. The original data were depicted as dose equivalent rates; however, for simplicity of calculation, a 1-hour exposure was assumed to use dose equivalent.

As noted in Roberson, Cummings, and Fix (1985), the HMPD was originally calibrated in neutron fields encountered in 234-5Z, and this calibration has been maintained over the years. Therefore, the estimate of personnel neutron dose equivalent has remained tied to the original measurements regardless of the neutron source used to calibrate the dosimeter.

Neutron spectrum measurements were made in the early 1980s at research and development laboratories in the 300 Area (Fix et al. 1982). Figure A-4 shows measurements at selected locations including plutonium storage vaults in the 308 and 324 Buildings.

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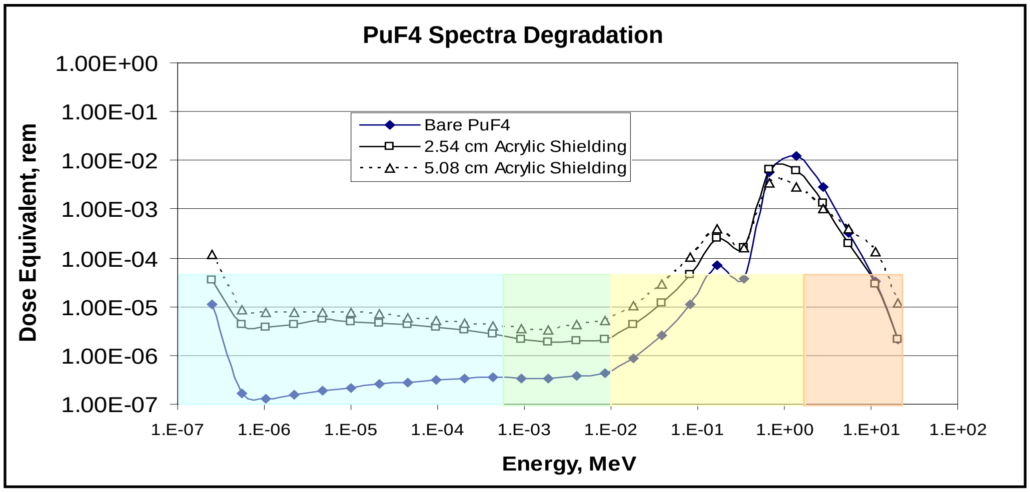

Figure A-2. Degradation in neutron energy spectra for bare, 2.54 cm and 5.08 cm of acrylic plastic shielding with neutron energy groups overlay (Brackenbush, Baumgartner, and Fix 1991).

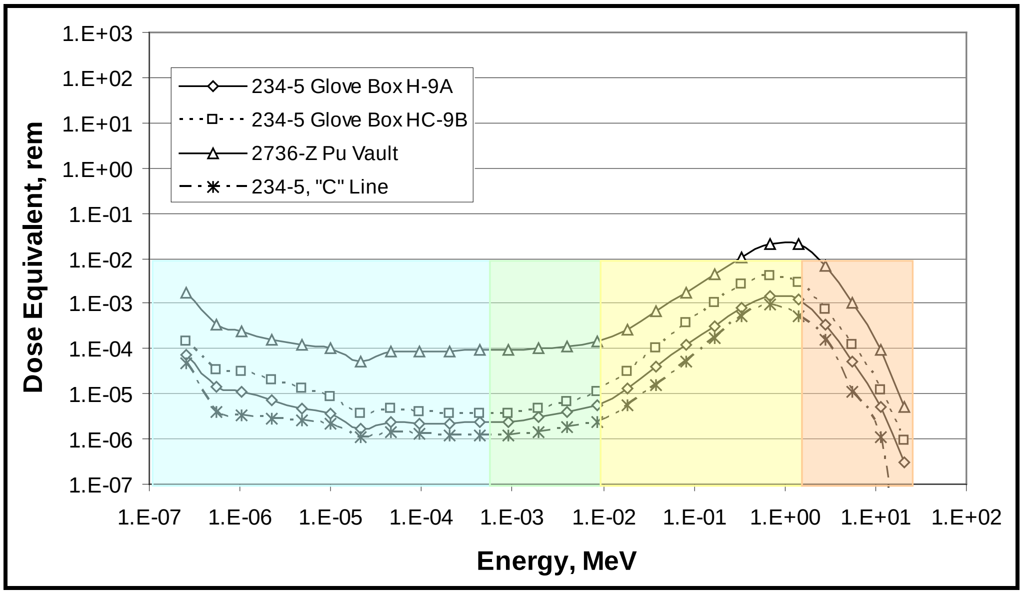

Figure A-3. Neutron energy spectra recorded at Hanford PFP 234-5Z "C" line, glovebox, and plutonium storage vault (Fix et al. 1981, Study 4; Roberson, Cummings, and Fix 1985).

The highest neutron energy group (>20 MeV) was not used because operations at Hanford did not produce a significant component of neutrons of this energy. The dose for each neutron energy group was calculated by multiplying the neutron flux (Ø) provided in the references by Roberson, Cummings, and Fix (1985) and Brackenbush, Baumgartner, and Fix (1991) by the corresponding flux-to-dose-rate conversion factors (DCF) found in NCRP Report 38 (NCRP 1971). The neutron doses in each NCRP 38 energy interval are summed to develop the four neutron group doses. The dose fraction (D_f) for each neutron energy group (n) was calculated by dividing the neutron group dose by the total dose (D_T) using equation A-1.

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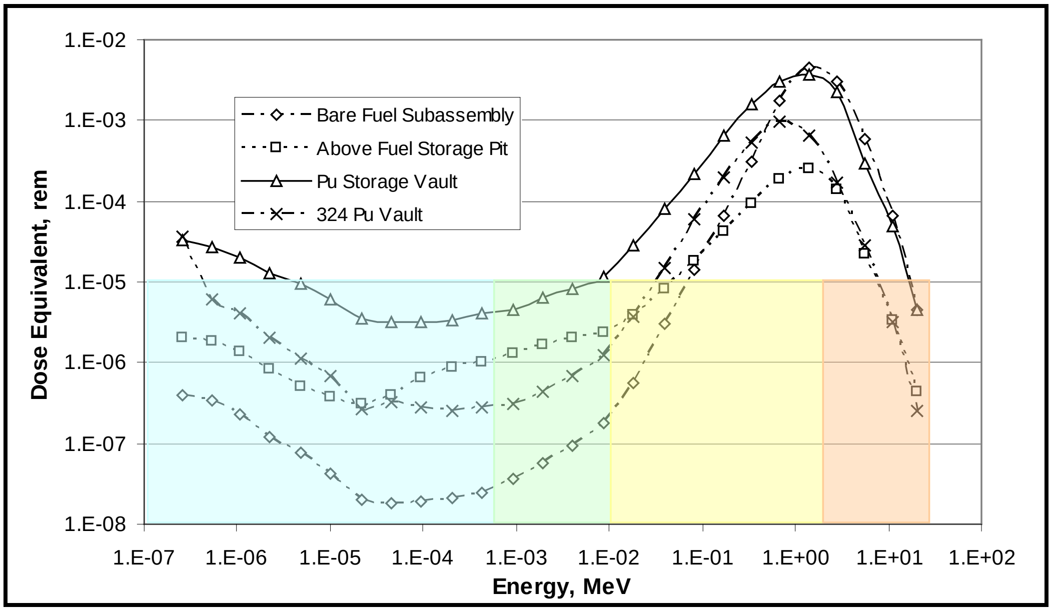

Figure A-4. Neutron spectra for Hanford 308 and 324 facilities (Fix et al. 1982).

$$D_f(E_n) = \frac{\sum_i \phi(E_i)DCF_i}{D_T} \tag{A-1}$$

where:

$Ø(E_i)$ = Neutron flux of the ith energy bin;
DCF_i = NCRP Report 38 flux-to-dose-rate conversion factor for the ith energy bin (NCRP 1971);
D_T = Total dose.

Table A-1 lists the neutron dose fractions by energy group using data measured by Roberson, Cummings, and Fix (1985).

Table A-1. Laboratory-measured dose fractions from PuF_4.

Neutron energy group	Shielding of PuF_4 source[a]		
	0 cm (bare)	2.54 cm	5.08 cm
<10 keV	0.00	0.00	0.01
10–100 keV	0.00	0.00	0.00
0.1–2 MeV	0.06	0.85	0.89
2–20 MeV	0.94	0.15	0.10
	Favorable-to-claimant dose fractions		
0.1–2 MeV	0.1	0.9	0.9
2–20 MeV	0.9	0.1	0.1

a. Thickness of acrylic shielding between source and detector.

Table A-2 lists selected neutron dose fractions by energy group using the measured neutron spectra or 200 Area PFP vault and glovebox locations presented in Fix et al. (1981) and Roberson, Cummings, and Fix (1985). The estimated default dose fractions for these PFP locations are similar to the 2.54- and 5.08-cm acrylic plastic shielded spectra shown in Figure A-2.

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Table A-2. 200 Area measured dose fractions.

Energy group	Glovebox H-9B	Glovebox HC-9B	2736Z Vault	234-5Z C Room B
<10 keV	0.03	0.02	0.05	0.02
10–100 keV	0.04	0.04	0.04	0.03
0.1–2 MeV	0.84	0.87	0.80	0.88
2–20 MeV	0.09	0.07	0.11	0.07
	Favorable-to-claimant dose fraction default values			
0.1–2 MeV	0.9	0.9	0.9	0.9
2–20 MeV	0.1	0.1	0.1	0.1

Table A-3 lists selected neutron dose fractions by energy group using the measured neutron spectra for 300 Area locations presented in Fix et al. (1982).

Table A-3. 300 Area measured dose fractions.

Energy group	308–Bare fuel subassembly	308–Above fuel storage pit	308–Pu storage vault	324 Pu vault
<10 keV	0.00	0.02	0.01	0.02
10–100 keV	0.00	0.04	0.03	0.03
0.1–2 MeV	0.64	0.73	0.75	0.88
2–20 MeV	0.36	0.21	0.21	0.07
	Favorable-to-claimant dose fraction default values			
0.1–2 MeV	0.6	0.8	0.8	0.9
2–20 MeV	0.4	0.2	0.2	0.1

Table A-4 lists selected neutron dose fractions by energy group using the measured neutron spectra for 400 Area FFTF locations presented in Fix et al. (1982). As reported in Fix et al. (1982), these measurements were taken at a time when a stainless steel research thimble was in one of the tubes and allowed neutrons to stream from the core to the head compartment. This is not a usual operating mode. Even with the streaming, the spectra show significantly reduced energy because of scatter.

Table A-4. 400 Area measured dose fractions.

Energy group	FFTF #1	FFTF #2
<10 keV	0.4	0.3
10–100 keV	0.5	0.4
0.1–2 MeV	0.1	0.3
2–20 MeV	0.0	0.0
	Favorable-to-claimant dose fraction default values	
10–100 keV	0.5	0.5
0.1–2 MeV	0.5	0.5

The Radiation Effectiveness Factors used in the IREP to calculate the POC are less for the 10-to-100-keV category compared to the primary fission spectrum energy group (0.1 to 2 MeV) (Kocher, Apostoaei, and Hoffman 2005). Combining neutron energy groups into the primary 0.1-to-2-MeV fission spectrum group is a reasonable and favorable-to-claimant simplification of the dose calculation. The tables described above include the neutron energy favorable-to-claimant default values [31].

ATTACHMENT B
HANFORD COWORKER DOSE ASSIGNMENT

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B1. PURPOSE

The purpose of this attachment is to provide information to allow ORAU Team dose reconstructors to assign doses to workers at the Hanford Site who have no or limited monitoring data, based on site coworker data. The data in this attachment are to be used in conjunction with ORAUT-OTIB-0020, *Use of Coworker Dosimetry Data for External Dose Assignment* (ORAUT 2008a).

B2. BACKGROUND

An analysis of external coworker dose was performed to permit dose reconstructors to complete certain cases for which external monitoring data are unavailable or incomplete Cases not having complete monitoring data can fall into one of several categories, including:

- The worker was unmonitored and, even by today's standards, did not need to be monitored (e.g., a nonradiological worker).

- The worker was unmonitored, but by today's standards would have been monitored.

- The worker might have been monitored but the data are not available to the dose reconstructor.

- The worker might have partial information, but the available information is insufficient to permit a dose reconstruction to occur.

As described in ORAUT-OTIB-0020, some cases not having complete monitoring data can be processed based on assumptions and methodologies that do not involve coworker data (ORAUT 2008a). For example, many cases falling in the first category above can be processed by assigning ambient external and internal doses based on information in the relevant site TBDs.

As described in the body of this TBD, Hanford began operations in 1944 using in-house dosimeter and processing technical support. Routine Hanford practices appear to have required assigning dosimeters to all workers who entered a controlled radiation area. The trends in the number of workers who were monitored, the number of monitored workers with positive recorded dose, and the collective dose do not show any abrupt changes that might be indicative of significant changes in photon dosimetry or assignment of dosimeters. Additionally, there does not appear to be any significant administrative practice that would jeopardize the integrity of the recorded dose of record.

B3. APPLICATIONS AND LIMITATIONS

1. Some Hanford Site workers might have worked at one or more other major sites within the DOE complex during their employment history. The data presented in this attachment are specific to Hanford. Assignment of unmonitored external doses from multiple site employment typically requires the availability of External Coworker Dosimetry Data TIBs for all relevant sites. The Hanford Site worker recorded annual doses do include all measured dose for “rover” workers working at more than one Hanford operational area.

2. Recorded non-penetrating (skin) doses for workers in Hanford Bldg 313-314 fuel fabrication facilities are under-estimated for employment prior to October 1944 when implementation of the Hanford film dosimetry program occurred (Wilson 1987). The Hanford PIC was used during 1944 but was incapable of accurate measurement of the non-penetrating beta dose.

3. Summary statistics based on Hanford dosimetry data presented in this attachment do not extend beyond 1989 because data beyond 1989 were not available from the Comprehensive Epidemiologic Data Resource (CEDR). However, the absence of these data (and the subsequent development of dose distributions) should not interfere with the processing of most Hanford cases having a lack of external dosimetry data because well before 1989 the monitoring and reporting practices at the site ensured that essentially all workers with a potential for external radiation exposure were monitored and the results are readily accessible.

4. The data presented in this attachment address penetrating radiation from gamma radiation and nonpenetrating radiation from beta radiation (or low-energy photons for work involving plutonium and/or chemical processing and waste operations). Neutron data are not presented. However, the locations on the Hanford Site at which neutron exposures were possible are limited to certain site areas and facilities, and the main body of this document establishes a method for assigning neutron doses when relevant. Therefore, the main body should be used as the basis for assigning neutron doses, when relevant, in addition to the photon and/or beta doses assigned in accordance with this attachment.

5. For the years 1972 and later, external onsite ambient doses should not be included in addition to the coworker doses assigned in accordance with this attachment, because any such doses

would have been included in the dosimetry results reported by the site that were used as the basis for the coworker dose distributions presented below. Prior to 1972, coworker doses assigned in accordance with this attachment must be supplemented by the appropriate external onsite ambient dose in accordance with the instructions in ORAUT-PROC-0060 (ORAUT 2006c).

B4. HANFORD COWORKER DATA DEVELOPMENT

Dosimetry data for monitored Hanford workers from the CEDR databases maintained by DOE were selected for this evaluation. The CEDR data evaluated represented primarily annual penetrating and nonpenetrating dosimetry data provided by the Hanford Site, which pertain to the shielded and “open-window minus shielded” dosimetry readings, respectively, and exclude neutron doses. Starting in 1982, multiple badge readings are recorded in CEDR for some Hanford workers; however, this was a relatively small fraction of the total, and the adjustments made for partial years of employment (see Section 7) are likely to account for any data that do not encompass a full year. In addition, starting in 1983 the CEDR data included the reported shallow dose, not the nonpenetrating dose. Thus, for these years, the nonpenetrating doses were derived by subtracting the reported penetrating doses from the reported shallow doses.

Between 1957 and 1971, the Hanford Site film dosimeter included a third measurement (in addition to the standard shielded and open-window measurement) using a special filter covering a portion of the film designed to allow the assessment of X-ray doses. Thus, doses in this period were reported as beta, gamma, and X-ray. A fraction (0.65) of the X-ray dose was assumed to contribute to nonpenetrating dose, and the remainder (0.35) was assumed to contribute to penetrating dose. Because the CEDR data include the X-ray doses reported by the site for this period, the coworker dose evaluations described in this TIB include an upward adjustment of the reported beta and gamma doses during this period by adding 65% and 35% of the reported X-ray doses, respectively, to arrive at the reported nonpenetrating and penetrating doses.

The validity of the CEDR data was confirmed by selecting a sampling of claimant dosimetry data submitted by the site as part of the EEOICPA Subtitle B program and comparing it to the pertinent CEDR data. A review of annual data for 10 claimants covering 297 worker-years of employment at Hanford indicated excellent agreement between the two data sets. Specifically, the reported penetrating and nonpenetrating data in the CEDR database were found to correspond to the reported external and “skin minus external” annual doses reported in the site Radiological Exposure System. It is concluded that the CEDR data are acceptable for the development of coworker doses for the Hanford Site, with adjustments made for the reported X-ray doses as appropriate, as described above.

Adjustment for Missed Dose

According to the *External Dose Reconstruction Implementation Guideline* (NIOSH 2007b), missed doses are to be assigned for dosimeter readings <LOD to account for the possibility that doses were received but not recorded by the dosimeter or reported by the site. Annual missed doses are calculated by multiplying the number of <LOD dosimeter readings by the dosimeter LOD and summing the results. These values are used as the 95th percentile of a lognormal distribution for the purpose of calculating probability of causation; thus, in IREP the calculated annual missed doses are multiplied by 0.5 and entered in Parameter 1, and a value of 1.52 is entered in Parameter 2, to represent the geometric mean and GSD, respectively.

The assignment of missed doses for monitored workers is particularly significant for Hanford claimants prior to 1951 when workers were monitored weekly, and between 1951 and 1957 when workers were monitored biweekly. Table B-1 lists the maximum annual missed dose by era and type of radiation (penetrating gamma and nonpenetrating) based on information for film and thermoluminescent dosimeters presented in the main body and Attachment C, Section C.1(B). Measured doses using PICs during 1943 and 1944 was not included in this analysis.

Special Considerations

Certain aspects of the external dosimetry practices at the Hanford Site documented in the TBD[2] were considered in the analysis of the site data. These include:

- In some cases, values less than the dosimeter LOD were reported by the site. For example, values as low as 10 or 20 mR were reported even though the penetrating LOD was considered to be 40 mrem (or 40 mR) prior to 1972.

Table B-1. Missed external doses based on the main body of this TBD and ORAUT-OTIB-0017 (ORAUT 2005c).

Period	Penetrating LOD (rem)	Non-penetrating LOD (rem)[a]	Exchange frequency	Maximum annual missed dose (rem)	
				Penetrating	Nonpenetrating
1944[a]–1950	0.04	0.05	Weekly	2.080	2.600
1951–1956	0.04	0.05	Biweekly	1.040	1.300
1957	0.04	0.05	Varied[b]	0.720	0.900
1958–1971	0.04	0.05	Monthly	0.480	0.600
1972–1994	0.02	0.03	Monthly[c]	0.240	0.360
1994–present	0.01	0.05	Monthly[c]	0.120	0.600

a. Hanford instituted a routine weekly exchange and the use of film dosimeters in October 1944.
b. The exchange frequency was biweekly through May 1957, then monthly. A total of 18 exchanges were assumed for the year.
c. The TBD indicates that either monthly or quarterly exchange frequencies were used. Monthly exchanges have been assumed here to ensure favorability to the claimant.

- The data available to analyze coworker doses represent annual dose summaries for individual workers. Because these data include partial work years, the average annual doses reported tend to underestimate the average annual doses received by employees who worked an entire year.

As described in Section B.5 below, a favorable-to-claimant approach was adopted in the development of coworker dose summaries, and this approach should account for any underestimate of doses to radiological workers at the Hanford Site based on the considerations described above.

B5. HANFORD COWORKER ANNUAL DOSE SUMMARIES

Based on the information and approaches described above, Hanford coworker annual external dosimetry summaries were developed for use in the evaluation of external dose for certain claimants potentially exposed to workplace radiation, but with no or limited monitoring data provided by DOE. These summaries were developed using the following steps:

1. As described in Section B.4 above, the penetrating and nonpenetrating doses available from CEDR, which represented annual summary data, were modified to account for partial years of employment. This adjustment was made by analyzing the NIOSH-OCAS Claims Tracking System

(NOCTS) employment data for Hanford workers and adjusting the reported doses upward by an appropriate multiplier corresponding to the average fraction of a year an employee worked at the site. For example, if in a particular calendar year the average employment period for all Hanford employees in NOCTS was 11 months, the CEDR annual doses were multiplied by 12/11, or 1.09. This permits the dose reconstructor to assign an appropriate prorated dose to account for partial years of employment or potential exposure. A factor of 4 was applied for the year 1944 when monitoring at the site did not begin until October.

2. For the years 1957 through 1971, when X-ray doses were reported separately in addition to the reported gamma and beta doses, but were not included in the reported annual penetrating and nonpenetrating doses, the penetrating and nonpenetrating doses were modified by adding 35% and 65% of the reported positive X-ray doses, respectively (main text; ORAUT 2005c).

3. The 50th-, 95th-, and 99th-percentile annual penetrating and nonpenetrating doses were derived for two scenarios: excluding and including reported zeroes.

4. The 50th-, 95th-, and 99th-percentile doses based on the exclusion of zeroes were used as the basis for the coworker data set, because these are representative of radiological worker doses which are the principal focus of the coworker studies. However, to ensure favorability to the claimant, for penetrating radiation the percentile doses with zero results included were evaluated, and if the addition of one-half of the maximum annual nonpenetrating missed doses (listed in Table B-1) to these percentile doses resulted in values exceeding the percentile doses based on the exclusion of zeroes, the latter were replaced with the former. Missed doses were not added to both the penetrating and nonpenetrating results because the nonpenetrating results reported by the site reflect the difference between the open-window and shielded measurements, and assigning missed dose to both measurements would result in a double counting because a positive shielded measurement exceeding the nonpenetrating minimum detection level (MDL) would appear as a positive open-window measurement. To ensure favorability to the claimant, the nonpenetrating MDLs were assigned in the calculations (because they exceed the penetrating MDLs), and the values were apportioned to the penetrating doses (because penetrating doses are assigned as gamma radiation, which in IREP cannot have a negative effect because the radiation effectiveness factors for gammas are equal to or greater than for >15-keV electrons).

5. The results are presented in Table B-2 below. These percentile doses should be used for selected Hanford workers with no or limited monitoring data using the methodologies outlined in Section 7.0 of ORAUT-OTIB-0020 (ORAUT 2008a).

Doses to organs impacted only by penetrating radiation (e.g., organs other than the skin, breast and testes) are calculated based only on the “Gamma” columns in Table B-2 combined with the appropriate organ DCFs (NIOSH 2007b). Doses to the skin, breast and testes (and any other cancer location potentially impacted by nonpenetrating radiation) are determined based on both the “Gamma” and “Non-penetrating” columns; gamma doses are assigned as photons with an energy range consistent with information in this document, and nonpenetrating doses are assigned as electrons >15 keV with corrections applied to account for clothing attenuation or other applicable considerations, or photons <30 keV, depending on the employment location and job description.

B6. PENETRATING DOSE VALUES BASED ON ORAUT-OTIB-0052 GUIDANCE FOR SELECTED CONSTRUCTION TRADE WORKERS

Table B-3 contains penetrating dose values that have been adjusted using the guidance given in Section 8.0 of ORAUT-OTIB-0052, *Parameters to Consider When Processing Claims for Construction Trade Workers* (ORAUT 2007b) This guidance is applicable for construction trade workers who meet the criteria given in Section 3.0 of ORAUT-OTIB-0052.

Table B-2. Annual Hanford external coworker doses modified to account for missed dose (rem).

Year	Gamma 99th%	Gamma 95th%	Gamma 50th%	Nonpen 99th%	Nonpen 95th%	Nonpen 50th%
1944	3.096	2.176	1.300	3.363	1.448	0.240
1945	3.294	2.430	1.336	4.215	0.631	0.071
1946	2.917	2.125	1.448	5.944	1.421	0.297
1947	2.113	1.708	1.369	3.130	1.081	0.222
1948	1.805	1.541	1.334	5.400	1.096	0.149
1949	1.818	1.572	1.357	3.895	1.076	0.215
1950	2.107	1.721	1.357	3.222	1.535	0.239
1951	2.263	1.278	0.685	4.276	2.047	0.212
1952	2.504	1.541	0.721	2.782	1.046	0.155
1953	2.691	1.815	0.779	2.828	1.477	0.188
1954	3.053	1.863	0.720	2.438	1.260	0.175
1955	3.246	2.059	0.717	2.230	1.287	0.200
1956	3.344	2.306	0.682	2.262	1.189	0.141
1957	3.325	2.318	0.650	1.755	0.942	0.119
1958	3.236	2.599	0.321	1.326	0.695	0.074
1959	2.867	2.237	0.300	2.120	1.122	0.127
1960	3.276	2.756	0.311	2.622	1.419	0.162
1961	3.293	2.877	0.364	1.938	1.001	0.075
1962	3.406	3.018	0.452	1.695	0.805	0.108
1963	3.389	2.981	0.406	1.715	0.760	0.050
1964	3.437	3.018	0.505	1.954	0.690	0.042
1965	4.849	3.880	0.881	2.338	0.905	0.098
1966	3.574	2.690	0.524	1.881	0.841	0.056
1967	4.118	3.179	0.385	3.161	1.476	0.073
1968	3.473	2.801	0.436	2.253	0.890	0.084
1969	3.529	2.905	0.354	2.147	0.923	0.075
1970	3.689	3.159	0.323	2.623	1.267	0.092
1971	3.776	2.726	0.394	2.978	1.237	0.165
1972	3.458	2.339	0.293	1.060	0.565	0.090
1973	3.380	2.142	0.246	1.729	0.535	0.055
1974	3.473	2.099	0.283	1.253	0.513	0.068
1975	3.337	1.933	0.283	1.201	0.549	0.080
1976	3.091	1.667	0.226	0.741	0.359	0.069
1977	3.748	2.188	0.206	1.026	0.365	0.052
1978	2.934	1.252	0.214	0.530	0.237	0.034
1979	2.967	1.257	0.202	0.662	0.276	0.044
1980	2.658	0.968	0.203	0.551	0.293	0.045
1981	2.596	1.103	0.191	0.620	0.425	0.092
1982	2.980	1.432	0.191	0.533	0.329	0.057

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HANFORD COWORKER DOSE ASSIGNMENT

Year	Gamma 99th%	Gamma 95th%	Gamma 50th%	Nonpen 99th%	Nonpen 95th%	Nonpen 50th%
1983	3.081	1.933	0.180	0.603	0.261	0.045
1984	2.785	1.643	0.191	0.723	0.321	0.034
1985	2.911	1.849	0.180	0.834	0.297	0.034
1986	2.851	1.985	0.180	0.714	0.312	0.022
1987	2.260	1.048	0.195	0.403	0.135	0.015
1988	0.360	0.236	0.180	0.101	0.045	0.011
1989	0.508	0.236	0.180	0.124	0.034	0.011

Table B-3. Annual Hanford external penetrating coworker doses (rem) modified in accordance with ORAUT-OTIB-0052 (ORAUT 2007b).

Year	Gamma 99th %	Gamma 95th %	Gamma 50th %
1944	3.814	2.526	1.300
1945	4.092	2.882	1.350
1946	3.564	2.455	1.508
1947	2.439	1.871	1.397
1948	2.007	1.637	1.348
1949	2.025	1.681	1.379
1950	2.430	1.889	1.380
1951	2.909	1.529	0.699
1952	3.246	1.898	0.750
1953	3.507	2.281	0.831
1954	4.014	2.348	0.748
1955	4.284	2.622	0.743
1956	4.421	3.076	0.695
1957	4.395	3.245	0.650
1958	4.411	3.639	0.329
1959	3.900	3.132	0.310
1960	4.466	3.859	0.315
1961	4.490	3.907	0.389
1962	4.649	4.106	0.512
1963	4.625	4.054	0.449
1964	4.692	4.106	0.588
1965	6.669	5.312	1.114
1966	4.883	3.645	0.614
1967	5.645	4.381	0.420
1968	4.742	3.801	0.491
1969	4.820	4.068	0.375
1970	5.081	4.422	0.332
1971	5.166	3.817	0.432
1972	4.770	3.269	0.338
1973	4.661	2.964	0.273
1974	4.790	2.939	0.324
1975	4.600	2.706	0.324
1976	4.327	2.334	0.245
1977	5.177	3.063	0.216
1978	4.108	1.753	0.227
1979	4.154	1.760	0.211
1980	3.649	1.355	0.212

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HANFORD COWORKER DOSE ASSIGNMENT

Year	Gamma 99th %	Gamma 95th %	Gamma 50th %
1981	3.634	1.544	0.196
1982	4.172	2.005	0.196
1983	4.313	2.706	0.180
1984	3.899	2.300	0.196
1985	4.075	2.589	0.180
1986	3.991	2.780	0.180
1987	3.165	1.467	0.201
1988	0.456	0.259	0.180
1989	0.712	0.283	0.180

ATTACHMENT C
SKIN DOSE ASSIGNMENT FOR HANFORD CASES
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The guidance in this attachment is currently contained in Appendix C of ORAUT-OTIB-0017, *Interpretation of Dosimetry Data for Assignment of Shallow Dose* (ORAUT 2005c), which will be withdrawn at an appropriate time.

C1. GENERAL INFORMATION

A. In the film badge era, the OW reading exhibits a significant over-response to low-energy photons; however, starting in April 1957, an additional dosimeter element was included in the badge design to facilitate an accurate measurement of X-ray dose. Therefore, prior to April 1957, measured doses assigned as <30-keV photons should be multiplied by 0.6 only if evidence exists indicating that the recorded doses were not adjusted downward by the site to account for the over-response.

B. Missed doses should be calculated based on the following LODs:

- 1944–1971: 50 mrem for nonpenetrating (OW), 40 mrem for penetrating (S)
- 1972–1994: 30 mrem for nonpenetrating, 20 mrem for penetrating
- 1995–present: 50 mrem for nonpenetrating, 10 mrem for penetrating

C. Hanford used a variety of dosimetry types and reporting schemes during its history. The dose reconstructor must ensure that the nonpenetrating and penetrating doses have been adequately interpreted from the data reported. For example, when beta and gamma doses are reported by the site, these typically represent the nonpenetrating and penetrating doses, respectively, and collectively represent the total skin dose. However, when the data are reported as open-window and shielded, the open-window measurement represents the total skin dose and the shielded measurement represents only the penetrating component.

D. Hanford used a variety of measurement techniques and reporting schemes for neutron dose. These doses might or might not have been included in the reported skin (or shallow) or WB (or deep) doses. As is the case for reconstructing doses for organs not impacted by nonpenetrating radiation, the calculation of dose to the skin requires that any neutron doses have been separated from the reported dose quantities and treated separately in IREP.

E. As described in the Hanford Occupational Environmental Dose TBD (ORAUT 2007d), workers from the mid-1940s to the mid-1950s might have been exposed to radioactive particles emitted from facility stacks.

C2. PROCEDURE

Measured Dose

1944–March 1957

1. Determine the nonpenetrating dose by subtracting the reported S reading from the reported OW reading.

2. Assign the nonpenetrating dose as either electrons >15 keV (corrected for attenuation, if applicable), or photons <30 keV if the employee worked primarily with or near plutonium, such as in PFP. In the latter case, a correction factor of 0.6 should be applied to account for film over-response, if a correction by the site is not evident in the claim records as described above and in TBD Section 6.4.

3. Assign the penetrating photon dose as photons, partitioned by energy according to the Hanford TBD.

4. Assign the reported neutron dose (if applicable) partitioned by energy and corrected for neutron quality according to the TBD (using an organ DCF of 1).

April 1957–1971

5. Assign the nonpenetrating dose as the reported beta dose (assigned as >15-keV electrons, which should be corrected for attenuation, if applicable) and 65% of the reported X-ray dose (assigned as <30-keV photons). Note: If the employee worked primarily with or near plutonium, such as in PFP, the reported beta dose should normally be zero during this era because the nonpenetrating component should have been identified as X-rays by the algorithm; however, in instances in which a positive beta dose was reported, as a favorable-to-claimant measure the dose should be considered <30-keV photons.

6. Assign the penetrating dose as the reported gamma dose (assigned as photons, partitioned by energy according to the Hanford TBD) and 35% of the reported X-ray dose (assigned as 30- to 250-keV photons).

7. Assign the reported neutron dose (if applicable) partitioned by energy and corrected for neutron quality according to the TBD (using an organ DCF of 1).

1972–1994

8. Determine the nonpenetrating dose by subtracting the reported penetrating reading (typically reported as deep or whole body) from the reported nonpenetrating reading (typically reported as shallow or skin).

9. Assign the nonpenetrating dose as either electrons >15 keV (corrected for attenuation, if applicable), or photons <30 keV if the employee worked primarily with or near plutonium, such as in PFP.

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10. Assign the penetrating photon dose as photons, partitioned by energy according to the Hanford TBD.

11. Assign the reported neutron dose (if applicable) partitioned by energy and corrected for neutron quality according to the TBD (using an organ DCF of 1).

1995–Present

12. Determine the nonpenetrating dose by subtracting the reported deep photon reading from the reported shallow reading.

13. Assign the nonpenetrating dose as either electrons >15 keV (corrected for attenuation, if applicable), or photons <30 keV if the employee worked primarily with or near plutonium, such as in PFP.

14. Assign the penetrating photon dose as photons, partitioned by energy according to the Hanford TBD.

15. Assign the reported neutron dose (if applicable) partitioned by energy and corrected for neutron quality according to the TBD (using an organ DCF of 1).

Missed Dose

16. For any badge cycle with a zero result in any of the element readings, assign a single missed dose.

17. If only the OW (or beta, or nonpenetrating) reading was reported as zero, the missed dose assigned should be the appropriate nonpenetrating LOD for that era (divided by 2, treated as lognormal) and considered electrons (corrected for attenuation, if applicable) or low-energy photons (multiplied by 0.6 prior to 1957). For the period 1957 to 1971, when X-ray doses were reported separately, a nonzero value reported for X-rays indicates that the missed dose should be considered electrons, and a zero value reported for X-rays indicates that the missed dose should be considered 30- to 250-keV photons.

18. If only the S (or gamma, or penetrating) reading was reported as zero, the missed dose assigned should be the appropriate penetrating LOD for that era (divided by 2, treated as lognormal) and considered 30- to 250-keV photons.

19. If both the OW and S readings were reported as zero, the missed dose assigned should be the appropriate nonpenetrating LOD for that era (divided by 2, treated as lognormal) and considered 30- to 250-keV photons.

20. During the film-badge era, for a person potentially exposed to neutrons, assign unmonitored neutron dose based on neutron-gamma ratios per the TBD (using an organ DCF of 1).

21. During the TLD era, for a person potentially exposed to neutrons, if a zero neutron result was recorded, assign missed dose per the TBD (using an organ DCF of 1).

Tables C-1 and C-2 provide examples of skin dose assignments for Hanford badge readings in 1980 and 1970, respectively, assuming no clothing correction.

ATTACHMENT C
SKIN DOSE ASSIGNMENT FOR HANFORD CASES

Table C-1. Examples of skin dose assignments for Hanford badge readings in 1980 (assuming no clothing correction) (mrem).[5]

Shallow reading	Deep reading	Measured dose assigned	Missed dose assigned
50	0	50 (electrons or <30-keV photons)	20/2 = 10 (30- to 250-keV photons)
0	0	None	30/2 =15 (30- to 250-keV photons)
100	60	40 (electrons or <30-keV photons) AND 60 (photon energy per TBD)	None
100	100	100 (photon energy per TBD)	None
0	40	40 (photon energy per TBD)	30/2 = 15 (electrons or low-energy photons)

Table C-2. Examples of skin dose assignments for Hanford badge readings in 1970 (assuming no clothing correction) (mrem).[5]

Beta reading	X-ray reading	Gamma reading	Measured dose assigned	Missed dose assigned
50	0	0	50 (electrons or <30-keV photons)	40/2 = 20 (30- to 250-keV photons)
0	0	0	None	50/2 =25 (30- to 250-keV photons)
100	20	60	100 (electrons or <30-keV photons) AND 20 × 0.65 = 13 (<30-keV photons) AND 20 × 0.35 = 7 (30-250-keV photons) AND 60 (photon energy per TBD)	None
100	0	100	100 (electrons or <30-keV photons) AND 100 (photon energy per TBD)	50/2 = 25 (30- to 250-keV photons)

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

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This attachment contains a summary of Hanford Radiation Protection practices and an abbreviated historical timeline used in the preparation of the analyses of 100, 200, and 300 Area radiation protection practices and workplace measurements and controls.

D1. RADIATION PROTECTION

The basic elements of Hanford radiation protection were generally well defined at the beginning of Hanford operations. The early history of the MED included formation of a medical occupational safety program and its implementation at Hanford is described by Wilson (1987). Basic elements of the Hanford Engineer Works (HEW) radiation protection program included:

- Clear designation of operations management as responsible for worker safety and formation of the “Health Instrument” organization’s role to be responsible to management for radiation safety. This organization was responsible for development of radiation protection instruments and implementing site-wide dosimetry capabilities.

- A dedicated radiation protection organization of Health Physicists to measure radiation levels in the facilities and to control worker exposures in collaboration with operations management.

- Incorporation of a site training program to inform workers of radiation risks in a series of “Special Hazards Bulletins.”

- Adoption of a system of preplanning work tasks to minimize worker exposure using Special Work Permits (SWPs) that required approval by Radiation Protection and Operating Divisions responsible for the planned work.

- Incorporation of operational limits for Hanford worker exposures that were less than the official limits to provide an additional measure of safety.

Special Hazards Committee
A Special Hazards Committee (a subcommittee to the Hanford Central Safety Committee) was designated in November 1944 to review various phases of radiation hazards. This committee issued a series of Special Hazard Bulletins beginning during 1945 to serve as guidance as follows:

- Procedures for Work in Danger Zones
- Procedures for Suspected or Known Overexposures or Contamination
- Contaminated Waste Disposal
- Procedures for Injuries in a Product Work Zone
- Procedure for Inter-Area and Off-Plant Transfer of Special Process Materials
- Investigation and Reporting of Unsafe Practices or Incidents Arising from Special Hazards
- Procedure for Releasing Equipment from Areas Wherein Contamination is Possible.
- Procedure for Fire Fighting in Radiation Danger Zones.

In the years that followed, many additional Hazards Bulletins were issued describing specific hazards and procedures to be followed. These were used in site training programs.

Special Work Permit
The SWP was implemented to ensure against doing work in "Radiation Danger Zones" until each job has been properly analyzed from a personnel safety standpoint and approved by responsible representatives of the Health Instrument Organization, the Operational Division, "P" or "S" Division, and the division doing the work (GE 1949, Special Hazards Bulletin #1). The SWP form in 1949 is shown in Figure D-1.

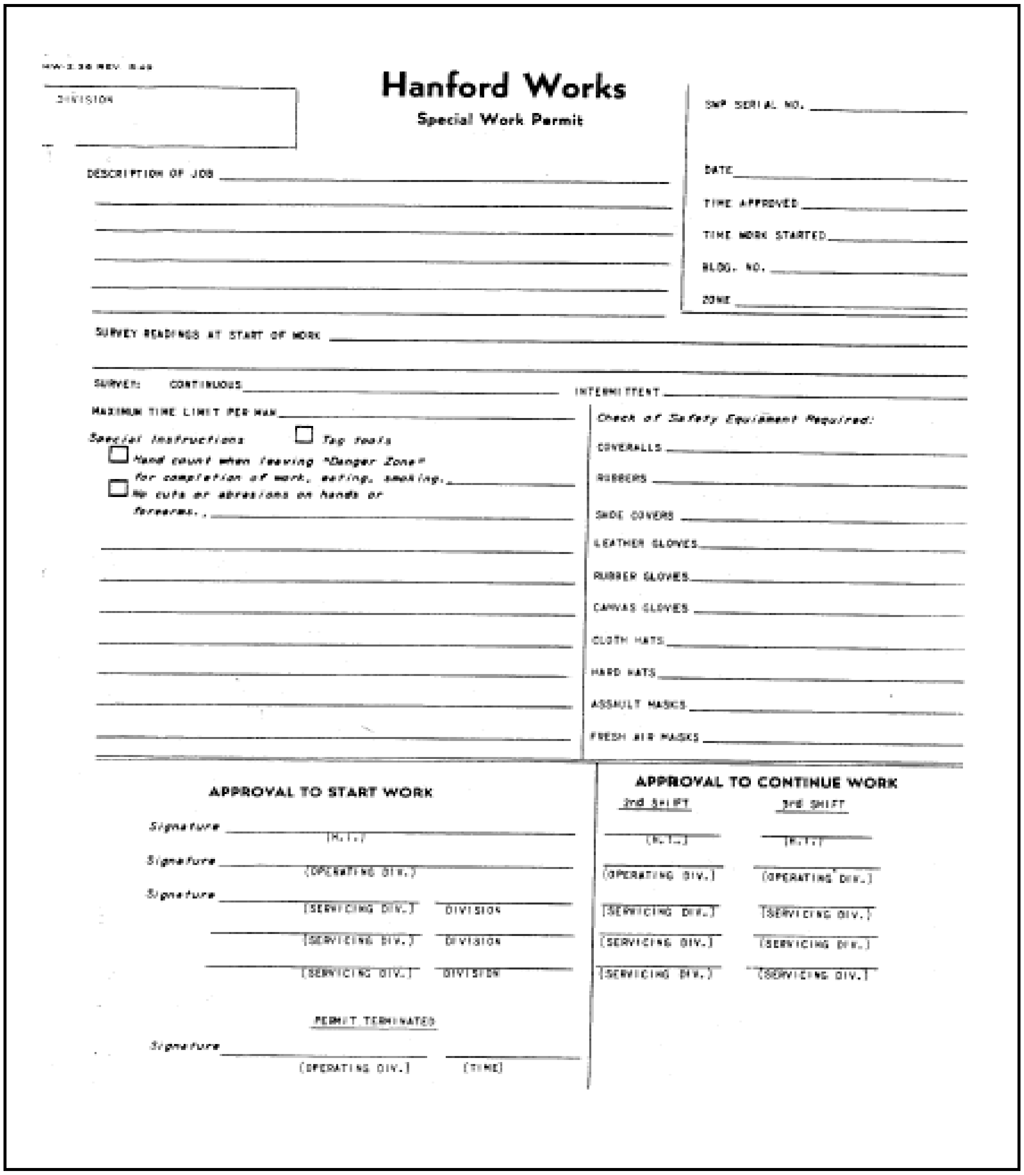
Radiation Protection Standards
The basic elements of Hanford radiation protection practices were defined in the earliest years of operating Hanford 100, 200 and 300 Area facilities. In the earliest years of Hanford operations, the MED and AEC used radiation protection guidance provided by national and international organizations. Generally, Hanford had operational limits that were less than the allowed national guidance. Pertinent Hanford Standards or Manuals of Radiation Protection include:

- HW-7-2602, *Tolerance Limits*, contains a table which identifies tolerance values to be used in the control of special hazards at Hanford (Cantril 1945).

- HW-25457, *Manual of Radiation Protection Standards*, December 15, 1954 (GE 1954). This manual contains policies for control of radioactive materials and radiation hazards at Hanford. These Hanford standards were formulated from national policies on radiation protection, AEC requirements for control of radioactive materials, and working limits that were adopted over a period of years.

- HW-25457, Rev. 2, *Manual of Radiation Protection Standards*, March 1, 1960 (GE 1960). This manual contains Hanford policies relevant to control of work with ionizing radiation and radioactive material.

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD



DIVISION

Hanford Works

Special Work Permit

SWP SERIAL NO. ____

DESCRIPTION OF JOB ____

DATE ____

TIME APPROVED ____

TIME WORK STARTED ____

BLDG. NO. ____

ZONE ____

SURVEY READINGS AT START OF WORK ____

SURVEY: CONTINUOUS ____ INTERMITTENT ____

MAXIMUM TIME LIMIT PER MAN ____

Special Instructions ☐ *Tag tools*

☐ *Hand count when leaving "Danger Zone" for completion of work, eating, smoking.* ____

☐ *No cuts or abrasions on hands or forearms.* ____

Check of Safety Equipment Required:

COVERALLS ____

RUBBERS ____

SHOE COVERS ____

LEATHER GLOVES ____

RUBBER GLOVES ____

CANVAS GLOVES ____

CLOTH HATS ____

HARD HATS ____

ASSAULT MASKS ____

FRESH AIR MASKS ____

APPROVAL TO START WORK

Signature ____ (H.I.)

Signature ____ (OPERATING DIV.)

Signature ____ (SERVICING DIV.) ____ DIVISION

____ (SERVICING DIV.) ____ DIVISION

____ (SERVICING DIV.) ____ DIVISION

PERMIT TERMINATED

Signature ____ (OPERATING DIV.) ____ (TIME)

APPROVAL TO CONTINUE WORK

2nd SHIFT	3rd SHIFT
(H.I.)	(H.I.)
(OPERATING DIV.)	(OPERATING DIV.)
(SERVICING DIV.)	(SERVICING DIV.)
(SERVICING DIV.)	(SERVICING DIV.)
(SERVICING DIV.)	(SERVICING DIV.)

Figure D-1. HEW Special Work Permit Form (HEW 1949).

- *AEC Manual*, Chapter 0524, "Standards for Radiation Protection," (AEC 1963). Prior to the issue of Chapter 0524, Hanford worker occupational radiation exposures were limited based on guidance from the NCRP. Several facets of radiation protection are addressed in this document. About January 1, 1965, Hanford operations were divided among several contractors. Each of the Hanford contractors was expected to formalize company-specific requirements that complied with the AEC/ERDA/DOE guidance.

The limits and chronology are shown in Table D-1.

There are also several radiation protection program procedures documents that provide detailed descriptions of the conduct of the programs. These are described in the following:

Table D-1. Chronology of radiation standards: occupational external WB dose equivalent limits.

	ICRP		**NCRP**		**AEC/ERDA/DOE**		**Hanford Radiation Protection Guidance**	
Year	**Criteria**	**Ref.**	**Criteria**	**Ref.**	**Criteria**	**Ref.**	**Criteria**	**Ref.**
1945							γ–0.1 R/d β–0.1 rep/d FN–0.02 rep/d SN–0.025 rep/d	Cantril 1945
1947	0.2 rad/d 1.0 rad/wk		0.1 rad/d 0.5 rad/wk	NBS Handbook 18 (NCRP 1934)	0.1 rad/day	NBS Handbook 18 (NCRP 1934)		
1949	0.2 rad/d 1.0 rad/wk		0.3 rad/wk	NBS Handbook 42 (NBS 1949)	0.1 rad/day		(as above)	GE 1949
1950	0.3 rad/wk		0.3 rad/wk		0.3 rad/wk 3.9 rad/13 wk	NBS Handbook 47 (NBS 1950)		
1954	0.3 rad/wk		3.0 rad/13 wk 0.3 rad/wk 15 rem/yr	NBS Handbook 59 (NBS 1954	3.0 rad/13 wk 0.3 rad/wk max, 15 rem/yr	NBS Handbook 59 (NBS 1954)	γ–3 R/yr Nt–3 rem/yr	GE 1954
1957	0.3 rad/wk		5 rem/yr avg 12 rem/yr Max	Addendum to NBS Handbook 59 (NBS 1958)	3.0 rad/13 wk 0.3 rad/wk max 15 rem/yr			
1958	0.1 rem/wk, 3.0 rem/13 wk, 5 (N-18) rem*	ICRP Publication 1 (ICRP 1959)	0.3 rem/wk 3 rem/13 wk, 12 rem/yr max, 5 (N-18) rem*	Addendum to NBS Handbook 59 (NBS 1958	0.3 rem/wk, 3.0 rem/13 wk 12 rem/yr 5 (N-18) rem*	NBS Handbook 59 (NBS 1954)		
1960	0.1 rem/wk, 3.0 rem/13 wk, 5 (N-18) rem*		0.3 rem/wk 3 rem/13 wk, 12 rem/yr 5 (N-18) rem*		3 rem/13 wk, 5 rem/yr avg 5 (N-18) rem*	Federal Radiation Council Report 1 (FRC 1960)	Total–5 rem/yr, γ–3 R/yr	GE 1960
1963					Prospective: Qtr–3 rem Year–5 rem Retrospective Accumulated Dose: 5(N-18)	*AEC Manual*, Chapter 0524 (AEC 1963)	Prospective: Qtr–3 rem Year–5 rem Retrospective Accumulated Dose: 5(N-18)	
1965	3 rem/13 wk 5 rem/yr	ICRP Publication 9 (ICRP 1966)	0.3 rem/wk 3 rem/13 wk 12 rem/yr 5 (N-18) rem*		3 rem/13 wk 5 rem/yr avg 5 (N-18) rem*			
1971	3 rem/13 wk 5 rem/yr		3 rem/13 wk 5 rem/yr	NCRP Report 38 (NCRP 1971)	3 rem/13 wk 5 rem/yr avg 5 (N-18) rem*			
1974	3 rem/13 wk 5 rem/yr		3 rem/13 wk 5 rem/yr		3 rem/13 wk 5 rem/yr	NCRP Report 38 (NCRP 1971)		
1977	5 rem/yr acceptable risk	ICRP Publication 26 (ICRP 1977)	3 rem/13 ws 5 rem/yr		3 rem/13 wk 5 rem/yr			

- HW-7-4282, *Medical Department, Health Instrument Section, Manual of Standard Procedures, Personnel Meters*, May 1, 1946 (HEW 1946). The procedures in this manual primarily pertain to administration of the Hanford pencil meter and beta/photon film dosimeter programs. Many routine Hanford activities are described such as the “weekly restricted report” that was used to summarize personnel with higher recorded doses. The issue of monitoring doses for rover (working at more than one area routinely) is described in this document.

- HW-46104, *Manual of Standard Procedures for 100, 200, and 300 Area Survey Work*, December 1, 1949 (GE 1949). This is an extensive document that describes Hanford portable radiation detection instrumentation, calibration, survey methods, radiation protection limits, the first eight Hazards Bulletins, and general radiation protection considerations for each of the primary controlled 100, 200 and 300 Areas. The use and purpose of the SWP is described. This document also includes an index.

- *External Dosimetry Operation, Operation Procedures Manual*, March 23, 1963 (GE 1963a). This is the dosimeter section from a formal procedures manual describing dosimeter assignment, processing, calibration and dose determination. Section I concerns the beta-gamma film dosimeter and Section II concerns the neutron film dosimeter. Procedure 2.7, Section 3.c., states that “in essentially all facilities other than 200-W Area a positive fast neutron dose almost never occurs without an accompanying gamma dose of at least 100 mr (Watson 1959).”

Levels of beta, photon and neutron radiation have been monitored by health physics staff using personnel dosimeters, pocket ionization chambers, and portable radiation detection instruments. Personnel dosimeters represent the usual method to measure and record the official dose for a worker. However personnel dosimeters are assigned to workers typically for a specified period (i.e., weekly, monthly or quarterly depending on potential for radiation exposure), and exchanged for new dosimeters according to an established monthly or quarterly schedule. Dosimeters on return are typically processed and doses assigned as part of the Hanford site-wide group of dosimeters. Typically the official dose based on the dosimeter is not received by the worker or their supervision until many days after a dosimeter has been routinely exchanged and certainly well after radiation exposure to the worker has occurred. Administrative control of worker exposures is based on results of PICs or portable instruments and timekeeping. These are the real methods used day-to-day to limit worker radiation exposures. Basically, a cumulative administrative radiation exposure record is maintained for each worker for use in tracking and, as necessary, limiting exposures. Dose results from the personnel dosimeters for each exchange cycle are used to update the administrative exposure record. The dosimeter exchange cycle is selected based on the exposure potential for each worker and, in case of an incident, personnel dosimeters can be special-processed at any time. This process requires close attention by supervision and radiation safety personnel to the total exposure accumulated by each worker.

D2. HISTORICAL TIMELINE

Because of the number of relevant references, Table D-2 contains a timeline of historical radiation associated events at Hanford. This was prepared as an aid in examining the issues and practices. As feasible, pertinent information has been transcribed from the references that are contained in the NIOSH Project Site Research DataBase (SRDB). The document number, as applicable, and the SRDB reference identification are also provided. These references do not necessarily appear in the main reference list for this document.

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Table D-2. Abbreviated timeline of significant Hanford radiation exposure associated events.

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td colspan="2">1944</td></tr>
<tr><td>PNL-6125
SRDB 262</td><td>First use of dosimeters (PICs and film) described in Wilson (1987). The first pencil dosimeter program was started in January 1944 in the 100 area. Film badges were used at the 100-B reactor beginning September 1944.</td></tr>
<tr><td>WHC-MR-0440
SRDB 34730
DUN-6888
SRDB 333</td><td>Hanford 305 Test reactor begins operation during March 1944 as described in <i>Multiple Missions: The 300 Area in Hanford Site History</i> (September 1993). This reactor was constructed to provide testing of each lot of graphite, uranium, aluminum tubes, etc., to be used in the Single-Pass Production reactors and in the fabrication of fuel for these reactors. The 305 Test Reactor was located above ground and operated at very low power level usually less than 50 W. The 305 Test Reactor was operated nearly continuously when necessary to support construction of Hanford plutonium production reactors because of the magnitude of components to be tested. Test reactor operations were stopped during 1972.</td></tr>
<tr><td>HW-3-39
SRDB 38385</td><td>Letter, G. L. Veil to G. H. Sanford, entitled “Radiation Leakage Through Overlapping Joints in Charging Face Shield of 305 Test Pile,” concerning calculation of potential radiation doses at a point directly in front of one of the cracks through the front shield for the case of continuous operation at 10 W. Tolerance fluxes corresponding to a dose of 0.01 R in 8 hours were established as:
<table>
<tr><th>Radiation</th><th>Tolerance[a]</th></tr>
<tr><td>Fast neutrons</td><td>$20/\text{cm}^2 \times \text{sec}$</td></tr>
<tr><td>Slow neutrons</td><td>$1{,}300/\text{cm}^2 \times \text{sec}$</td></tr>
<tr><td>Gamma–quanta</td><td>$300/\text{cm}^2 \times \text{sec}$</td></tr>
</table>
a. Dose of 0.01 R in 8 hours.
Estimated fraction of tolerance (in 8 hours)
<table>
<tr><th>Radiation</th><th>Fraction of tolerance in 8 hours</th></tr>
<tr><td>Fast neutrons</td><td>0.001</td></tr>
<tr><td>Slow neutrons</td><td>0.00002</td></tr>
<tr><td>Gamma–quanta</td><td>0.00002</td></tr>
</table></td></tr>
<tr><td>HW-7-103
SRDB 5025</td><td>Hanford Engineer Works April 1944 monthly report. Routine reports continue throughout the years by numerous organizations. Report series “Health Instruments Report on the 200 Areas and Associated Laboratories for the week Ending MM/.DD/YY” contains in particular PFP-associated information regarding T or B Plant concentration (224 Bldg) and isolation building (231) issues.</td></tr>
<tr><td>HW-7-189
SRDB 5026</td><td>Hanford Engineer Works June 1944 monthly report. Routine report of status for the variety of facility construction and testing underway. 305 Test pile operations continued to test graphite and other materials for construction and operations use.</td></tr>
<tr><td>HW-3-356
SRDB 49244</td><td>“Chambers for Health Monitoring to be used with Beckman Locations” (July 16). This memorandum states objections to the wall thickness and use of steel in the design of a portable ionization chamber instrument because of its inability to measure low-energy photons. The proposed solution is to redesign the instrument using aluminum or plastic and to provide prototypes for testing.</td></tr>
<tr><td>PNNL-13524
SRDB 12856
DUN-6888
SRDB 333</td><td>First of Hanford single-pass cooling reactors, B Reactor, begins operation (September 27).</td></tr>
<tr><td>HW-7-819
SRDB 60625</td><td>Letter, R. S. Stone, MD, to Dr. D. W. Norwood, MD, Kadlec Hospital, “Exposures Exceeding Tolerance,” dated October 25, 1951. This letter describes possible worker assignments in the event of a radiation exposure exceeding tolerance limits.</td></tr>
</table>

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-3-1120 SRDB 31615	*Fast Neutron Survey Meter* (November 20). A portable fast neutron survey meter was developed that measures the current in a methane-filled chamber due to the reaction of fast neutrons on the methane. Two chambers are employed, one filled with argon and the other with methane. The two chambers are operated in a differential manner, and if the pressures are properly adjusted in the two chambers the currents due to photon radiation is balanced leaving only the current due to neutrons.
HW-7-703, Parts I and II SRDB 38394	HEW Operating Standards–100, 200, and 300 Areas, 1943–1946. The Hanford Engineer Works Operating Standards Manual, which was issued in 1944, consists of standards that outline the limits and broadly define certain important criteria by which it was decided that the operation of the 100, 200, and 300 Areas should be guided, based on the best available knowledge at the time. Each standard was approved by the representatives of the Metallurgical Project, the HEW Technical and Process Groups, and HEW Management. Level 300 procedures in Part II pertain to 300 Area activities to prepare and test reactor fuel and various reactor components.
HW-7-750 SRDB 5039	Hanford Engineer Works September 1944 monthly report (October 10). Routine report regarding overall plant status. 100-B Pile achieved initial operation at 11:50 p.m. on September 26. Report states that PICs had been provided to the 100-B area since the start of operations. The use of PICs was restricted to people who had access to the 105 Restricted Area. Report also states that film badges were in use for all people eligible to enter the 100 Areas.
HW-7-863 SRDB 38394	*Summary of HI Surveys Obtained at Power Level of 38 MW–100-B Area* (October 12). Report describes the extent and findings of Health Instruments (HI) group startup surveys of the 100-B facility. This was anticipated to be one of several power ascension surveys conducted at specified power levels. Neutron and photon radiation exposures were detected at specific reactor locations.
HW-7-870 SRDB 5041	Hanford Engineer Works October 1944 monthly report (November 10). Routine report regarding overall plant status. Report describes collaboration among Industrial Medical, HI, and Production Superintendent appointed committee to develop a work permit procedure for work to be done in hazardous zones. This procedure is outlined in “Special Hazards Bulletin No. 1,” which was expected to greatly increase safety in that responsibilities and procedures were now formalized.
DUN-6888 SRDB 333	Startup of D Reactor (December 17).
PNNL-13524 SRDB 12856	T-Plant begins (December 26) chemical separation of B Reactor irradiated fuel
1945	
HW-7-3090 SRDB 439	*Comparison of Badge Film Readings at the Metallurgical Laboratories, Clinton Laboratories and the Hanford Engineering Works*. This report describes quality review of Hanford beta/photon film dosimetry and densitometer systems in comparison with systems used at what are now Argonne National Laboratory and ORNL, respectively.
DOE/RL-97-1047 SRDB 27666	Receipt of plutonium nitrate in 231-Z Building to begin efforts to prepare plutonium nitrate to be delivered to Los Alamos (January 16, 1945).
HW-3-1774 SRDB 37871	*Portable Beckman Survey Meter, Final Report*, IDS-29 (February 24). The Beckman Portable Survey Meter is a portable battery-powered instrument capable of measuring gamma or beta radiation. The instrument was developed by Chicago and the National Technical Laboratories of South Pasadena, California, which manufactured the meters. It consisted of a d.c. amplifier and an ion chamber with a thin window to permit soft radiation measurements; this window could be covered with a thicker slide when measurement of gamma radiation was desired.
PNNL-13524 SRDB 12856	First shipment (February 5) of Hanford-produced plutonium nitrate ($PuNO_3$) to Los Alamos for final processing.

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
DUN-6888 SRDB 333	F Reactor startup (February 25)
PNNL-13524 SRDB 12856	B-Plant begins (April 13) chemical separation of irradiated fuel.
PNNL-13524 SRDB 12856	Hanford-produced plutonium used (August 9) in Fat Man bomb exploded over Nagasaki.
HW-7-2602 SRDB 13428	Correspondence from S. T. Cantril dated October 18, 1945, entitled “Tolerance Limits,” that contains a table that identifies tolerance values to be used in the control of special hazards at HEW. In particular, the following values are identified: (table below)

Tolerance limits for prolonged exposures

Hazard	Tolerance	Reference
External gamma and X-radiation	0.1 R/d	(a)
External beta radiation	0.1 rep/d	(a)
Fast neutron radiation	0.02 rep/d	(a)
Slow neutron radiation	0.025 rep/d conversion gamma rays	CH-2808

a. “The Tolerance Dose”, CH-2812, S. T. Cantril and H. M. Parker, January 1945.

Reference	Description
HW-7-1635 SRDB 31345 pg 2	#1 H. I. Report on the 100 Areas and 300 Area for Week Ending May 6, 1945
HW-3-2420 SRDB 31345 pg 9	#2 H. I. Report on the 100 Areas and 300 Area for Week Ending May 16, 1945
HW-3-2464 SRDB 31345 pg 13	#3 H. I. Report on the 100 Areas and 300 Area for Week Ending May 19, 1945
HW-7-1709 SRDB 31345 pg 16	#4 H. I. Report on the 100 Areas and 300 Area for Week Ending May 26, 1945
HW-7-4193-DEL SRDB 36779	Hanford Works Monthly Report May 1946
HW-7-1748 SRDB 31345 pg 20	#5 H. I. Report on the 100 Areas and 300 Area for Week Ending June 2, 1945
HW-7-1783 SRDB 31345 pg 23	#6 H. I. Report on the 100 Areas and 300 Area for Week Ending June 9, 1945
HW-7-1826 SRDB 31345 pg 26	#7 H. I. Report on the 100 Areas and 300 Area for Week Ending June 16, 1945
HW-7-1856 SRDB 31345 pg 30	#8 H. I. Report on the 100 Areas and 300 Area for Week Ending June 23, 1945
HW-7-1934 SRDB 31345 pg 36	#9 H. I. Report on the 100 Areas and 300 Area for Week Ending June 30, 1945
HW-7-1993 SRDB 31345 pg 41	#10 H. I. Report on the 100 Areas and 300 Area for Week Ending July 7, 1945
HW-7-2016 SRDB 31345 pg 48	#11 H. I. Report on the 100 Areas and 300 Area for Week Ending July 13, 1945
HW-7-2064 SRDB 31345 pg 54	#12 H. I. Report on the 100 Areas and 300 Area for Week Ending July 20, 1945
HW-7-2097 SRDB 31345 pg 60	#13 H. I. Report on the 100 Areas and 300 Area for Week Ending July 27, 1945
HW-3-2988 SRDB 31345 pg 67	#14 H. I. Report on the 100 Areas and 300 Area for Week Ending August 3, 1945
HW-3-3017 SRDB 31345 pg 69	Supplement to Report #14 H. I. Report on the 100 Areas and 300 Area for Week Ending August 3, 1945

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Reference	Description
HW-3-3018 SRDB 31345 pg 71	#15 H. I. Report on the 100 Areas and 300 Area for Week Ending August 10, 1945
HW-3-3054 SRDB 31345 pg 74	#16 H. I. Report on the 100 Areas and 300 Area for Week Ending August 17, 1945
HW-7-2326 SRDB 31345 pg 77	#17 H. I. Report on the 100 Areas and 300 Area for Week Ending August 25, 1945
HW-7-2330 SRDB 31345 pg 79	#18 H. I. Report on the 100 Areas and 300 Area for Week Ending September 1, 1945
HW-7-2405 SRDB 31345 pg 83	#19 H. I. Report on the 100 Areas and 300 Area for Week Ending September 8, 1945
HW-7-2434 SRDB 31345 pg 89	#20 H. I. Report on the 100 Areas and 300 Area for Week Ending September 15, 1945
HW-7-2442 SRDB 31345 pg 95	#21 H. I. Report on the 100 Areas and 300 Area for Week Ending September 22, 1945
HW-7-2497 SRDB 31345 pg 100	#22 H. I. Report on the 100 Areas and 300 Area for Week Ending October 1, 1945
HW-7-2516 SRDB 31345 pg 102	#23 H. I. Report on the 100 Areas and 300 Area for Week Ending October 8, 1945
HW-7-2548 SRDB 27349	Hanford Engineer Works, Monthly Report, September 1945 (Oct 17). Report mentions the use of special neutron sensitive films (i.e., NTA) to be worn by personnel working in the vicinity of the piles has been steadily increased, and should become stabilized as the regular film procedure from now on. No high reading has been noted during the development stages. This is of interest because formal use of NTA film to assign neutron dose has not been observed until 1950.
HW-7-2577 SRDB 31345 pg 106	#24 H. I. Report on the 100 Areas and 300 Area for Week Ending October 15, 1945
HW-7-2633 SRDB 31345 pg 110	#25 H. I. Report on the 100 Areas and 300 Area for Week Ending October 22, 1945
HW-7-2682 SRDB 31345 pg 113	#26 H. I. Report on the 100 Areas and 300 Area for Week Ending October 29, 1945
HW-7-2721 SRDB 31345 pg 117	#27 H. I. Report on the 100 Areas and 300 Area for Week Ending November 5, 1945
HW-7-2758 SRDB 31345 pg 121	#28 H. I. Report on the 100 Areas and 300 Area for Week Ending November 12, 1945
HW-7-2852 SRDB 31345 pg 125	#29 H. I. Report on the 100 Areas and 300 Area for Week Ending November 19, 1945
HW-7-2897 SRDB 31345 pg 129	#30 H. I. Report on the 100 Areas and 300 Area for Week Ending November 26, 1945
HW-7-2982 SRDB 31345 pg 133	#31 H. I. Report on the 100 Areas and 300 Area for Week Ending December 3, 1945
HW-7-3017 SRDB 31345 pg 137	#32 H. I. Report on the 100 Areas and 300 Area for Week Ending December 10, 1945
HW-7-3076 SRDB 31345 pg 143	#33 H. I. Report on the 100 Areas and 300 Area for Week Ending December 17, 1945
HW-7-3076 SRDB 31345 pg 148	#34 H. I. Report on the 100 Areas and 300 Area for Week Ending December 24, 1945
HW-7-3144 SRDB 31345 pg 153	#35 H. I. Report on the 100 Areas and 300 Area for Week Ending December 31, 1945

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-7-3171
SRDB 5098</td><td>Hanford Engineer Works, Monthly Report, December 1945 (Jan 6, 1946). Site wide pencil and film badge processing results for December follow:
<table>
<tr><th>Description</th><th>100-B</th><th>100-D</th><th>100-F</th><th>200E&N</th><th>200-W</th><th>300</th><th>Total</th></tr>
<tr><td>Total pencils read</td><td>10,435</td><td>9,633</td><td>10,049</td><td>25,767</td><td>30,064</td><td>8,470</td><td>94,327</td></tr>
<tr><td>No. of single readings (100 to 200 mr)</td><td>30</td><td>48</td><td>71</td><td>131</td><td>220</td><td>36</td><td>536</td></tr>
<tr><td>No. of paired readings (100 to 200 mr)</td><td>1</td><td>1</td><td>1</td><td>6</td><td>10</td><td>0</td><td>19</td></tr>
<tr><td>No. of single readings: 200 mr</td><td>35</td><td>72</td><td>49</td><td>165</td><td>224</td><td>63</td><td>608</td></tr>
<tr><td>No. of paired readings: 200 mr</td><td>0</td><td>0</td><td>1</td><td>1</td><td>2</td><td>0</td><td>4</td></tr>
<tr><td colspan="8">Badge results by areas</td></tr>
<tr><td>Total badges processed</td><td>3,386</td><td>3,303</td><td>3,477</td><td>4,568</td><td>4,430</td><td>2,935</td><td>22,099</td></tr>
<tr><td>No. of readings (100 to 300 mrep)</td><td>3</td><td>0</td><td>5[a]</td><td>14</td><td>9[b]</td><td>64</td><td>95</td></tr>
<tr><td>No. of readings (300 to 600 mrep)</td><td>0</td><td>0</td><td>5[a]</td><td>0</td><td>0</td><td>0</td><td>5</td></tr>
<tr><td>No. of readings (600 mrep)</td><td>2</td><td>0</td><td>2[a]</td><td>0</td><td>0</td><td>0</td><td>4</td></tr>
<tr><td>No. of film packets lost in processing</td><td>4</td><td>2</td><td>8</td><td>12</td><td>4</td><td>2</td><td>32</td></tr>
</table>
a. All fogged
b. One fogged</td></tr>
<tr><td colspan="2">1946</td></tr>
<tr><td>HW-3-3358
SRDB 76791]</td><td>Report from W. H. Durum to C. M. Patterson, dated Jan 1, 1946, entitled “Badge and Contact Exposure in Bldgs. 313-314 Operations. Report describes results of studies involving the placement of extra film badge on all Bldg. 313-314 personnel for a period of about two-days (Bldg 314 done and then 313). Time studies were made using stop watches for those operations known to involve considerable metal contact. Only operations with actual or near-actual contact were considered. A maximum of 65 mrep per day was determined for the various work activities. The dose received on the skin through the gloves from the bare metal handling was determined by placing finger rings in the fingers of a right and left glove, which were then laid over the pieces such that they approximated operating conditions. Exposures of 3.5 and 7 hours were then made and doses determined from standard T-metal calibrations. A 7 day weighted average exposure of 776 mrep to the skin of the finger was determined. The maximum hand exposure was determined to be 234 mrep/day for the finish machining task which is a continuous operation.</td></tr>
<tr><td>HW-7-3194
SRDB 31554</td><td>#53 H.I. Report on the 200 Areas and Environs for the Week Ending January 9, 1946 (Jan 11).</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-7-3686 SRDB 37868	Brief Review of Health Instruments for Fast and Slow Neutrons (Mar 21). This document concerns Neutron Measurements and Instruments in Health Physics. Organized measurements of neutron doses received by personnel were virtually nonexistent before the potential demands of the Project developed. The design and construction of good neutron meters for Health Physics therefore lagged behind other aspects of Health Instrumentation. In addition, early operating experience in the production branches of the Project indicated this need for limited neutron monitoring instruments such that emphasis on this feature was not required. Many of the provisional neutron instruments used were identical with instruments for pure physics. These are briefly mentioned in this document to indicate the compromises required in the absence of true “health physics” or tissue absorption systems. This document describes 1) Chang and Eng, 2) Hydrogen Pressure Chambers, 3) Boron Lined Lauritsen Electroscope, 4) Spherical Ion Chamber and 5) Proton Recoil Chamber.
DUN-6888 SRDB 333	B Reactor shutdown from March 19, 1946 to July 2, 1948.
HW-7-3748 SRDB 37823	Experimental Justification of the Two-Pencil Policy (Apr 1). The policy of wearing pencil meters in pairs was developed in the early days of the project when individual pencils gave unreliable results, and the number of lost records was naturally reduced by the lower probability of the failure of both members of a pair. Three years of operating experience have shown slow but steady gains in the reliability of pencils. It was therefore becoming pertinent to inquire into the following two points: 1. Is it still desirable to operate pencils in pairs? 2. The principle that the lower reading of a pair is the valid record has been assumed throughout. To what degree is this approximation valid? This document addresses these issues.
HW-7-5078 SRDB 31561	#89 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 9/25/46 (Sept 26).
HW-7-4211 SRDB 15201	Document entitled “Review of Personnel Monitoring at Hanford Engineering Works” prepared by HM Parker sometime during 1946 describing pertinent aspects of the assignment, collection and processing of pocket ionization chambers and film badge dosimeters, as well as many other aspects of workplace radiological controls.
HW-7-4425 SRDB 31493	#64 H. I. Report for the 100 Areas and 300 Area for Week Ending July 22, 1946. Report states there was no high pencil reading in the 300 Area confirmed by a badge reading. There were 29 badges for 300 Area people who do not wear pencils, which had readings between 100 and 260 mrem. Seventeen 300 Area badges were not marked, but none of these readings were high. Two badge readings were lost, one because it was exposed to X-ray and one was light struck.
HW-7-5009 SRDB 31494	#71 H. I. Report for the 100 Areas and 300 Area for Week Ending September 9, 1946. Report states there was no high pencil readings confirmed by a badge reading. There were 11 badge readings for 300 Area personnel who are not required to wear pencils with readings between 100 and 200 mrep.
HW-7-5113 SRDB 31495	#74 H. I. Report for the 100 Areas and 300 Area for Week Ending September 30, 1946. Report states there was no high pencil readings confirmed by a badge reading and there was no high badge reading. There were 12 badge readings for 300 Area personnel not required to wear pencils, between 100 and 200 mrep.

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-7-5184
SRDB 31496</td><td>#76 H. I. Report for the 100 Areas and 300 Area for Week Ending October 14, 1946. Report states there was no high pencil readings confirmed by a badge reading and there was no high badge reading. There were 13 badge readings for 300 Area personnel not required to wear pencils, between 100 and 200 mrep.
300 Area–October<table><tr><th>Description</th><th>No.</th></tr><tr><td>Special work permits processed</td><td>10</td></tr><tr><td>Air monitoring samples</td><td>9</td></tr></table></td></tr>
<tr><td>HW-7-5276
SRDB 31497</td><td>#78 H. I. Report for the 100 Areas and 300 Area for Week Ending October 28, 1946</td></tr>
<tr><td>HW-7-5289
SRDB 31566</td><td>#94 H. I. Report for the 200 Areas and Associated Laboratories for Week Ending October 30, 1946.</td></tr>
<tr><td>HW-7-5302
SRDB 37166</td><td>#79 H. I. Report for the 100 Areas and 300 Area for Week Ending November 4, 1946</td></tr>
<tr><td>HW-7-5343
SRDB 31498</td><td>#80 H. I. Report for the 100 Areas and 300 Area for Week Ending November 11, 1946</td></tr>
<tr><td>HW-7-5351
SRDB 31567</td><td>#97 H. I. Report for the 200 Areas and Associated Laboratories for Week Ending November 13, 1946.
300 Area Facilities<table><tr><th>Description</th><th>No.</th></tr><tr><td>Special work permits processed</td><td>9</td></tr><tr><td>Air monitoring samples</td><td>3</td></tr><tr><td>Routine and special surveys</td><td>11</td></tr><tr><td>Smear samples for alpha counts</td><td>200</td></tr><tr><td>Smear samples for beta counts</td><td>155</td></tr></table></td></tr>
<tr><td>HW-7-5368
SRDB 31499</td><td>#81 H. I. Report for the 100 Areas and 300 Area for Week Ending November 18, 1946.
300 Area Facilities<table><tr><th>Description</th><th>No.</th></tr><tr><td>Special work permits processed</td><td>8</td></tr><tr><td>Air monitoring samples</td><td>12</td></tr><tr><td>Routine and special surveys</td><td>11</td></tr><tr><td>Smear samples for alpha counts</td><td>35</td></tr><tr><td>Smear samples for beta counts</td><td>35</td></tr></table></td></tr>
<tr><td>HW-7-5397
SRDB 31500</td><td>#82 H. I. Report for the 100 Areas and 300 Area for Week Ending November 25, 1946</td></tr>
<tr><td>HW-7-5488
SRDB 31501</td><td>#84 H. I. Report for the 100 Areas and 300 Area for Week Ending December 9, 1946</td></tr>
</table>

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-7-5545 SRDB 31502	#86 H. I. Report for the 100 Areas and 300 Area for Week Ending December 23, 1946. Report states there was no high pencil readings confirmed by a badge reading and there was no high badge reading. There were 11 badge readings for 300 Area personnel not required to wear pencils, between 100 and 400 mrep.
HW-7-3933 SRDB 7786	H. I. Section Report for April 1946
HW-7-4699 SRDB 31603	H. I. Section Report for August 1946
HW-7-3517 SRDB 36868	H. I. Section Report for February 1946
HW-7-3322 SRDB 36865	H. I. Section Report for January 1946
HW-7-4312 SRDB 31604	H. I. Section Report for June 1946
HW-7-5428 SRDB 37387	H. I. Section Report for November 1946
HW-7-5301 SRDB 52812	H. I. Section Report for October 1946
HW-7-5145 SRDB 37496	H. I. Section Report for September 1946
SRDB 15199	Manual of Standard Procedures: Personnel Meters, Part 16, Film Calibration and Batch Assignments
HW-7-4262 SRDB 38352	Manual of Standard Procedures, Laundry Monitoring (May 1). The stated purpose of this standard procedure is to outline the approved method of monitoring laundry and to standardize the methods and procedures required.
HW-7-4282 SRDB 15199	Medical Department, Health Instrument Section, Manual of Standard Procedures–Personnel Meters (May 1). The procedures in this manual primarily pertain to administration of the Hanford pencil meter and beta/photon film dosimeter programs. Many routine Hanford activities are described such as the weekly restricted report that is used to summarize personnel with higher recorded doses. The issue of monitoring doses for rover (working at more than one area routinely) is described.
HW-7-5289 SRDB 31566	#94 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 10/30/46 (Nov 1).
HW-7-5351 SRDB 31567	#97 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 11/13/46 (Nov 14).
HW-7-5409 SRDB 31569	#99 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 11/27/46 (Nov 29).
HW-7-5465 SRDB 31570	#100 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 12/4/46 (Dec 5).
HW-7-5531 SRDB 31571	#102 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 12/18/46(Dec 18).
HW-7-5553 SRDB 31573	#103 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 12/25/46(Dec 27).

300 Area–December

Description	No.
Special work permits processed	5
Routine and special surveys	4
Air monitoring samples	9

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
1947	
HM-11 (Sent)	An Introduction to Plutonium provided in internal General Electric Memorandum (Aug 29). The oxalate precipitate as formed in purification is a flocculent precipitate somewhat similar to aluminum hydroxide. It settles quite rapidly and forms a rather dense cake. It is a rich green color and can be readily transferred as a slurry. This oxalate after drying and oxidizing has a light brown color and after fluorination to the tetrafluoride, it is a light pink, having the color and consistency of face powder. Plutonium is far more dangerous internally than it is externally due to the fact that plutonium is not easily eliminated from the body but concentrates in the bone marrow where its alpha radiation stops the production of the white cells in blood. One microgram of plutonium in a human body is considered the life time tolerance. The quickest way of obtaining this tolerance is by allowing plutonium to enter the body through a break in the skin. The other paths of entry, the mouth and nose make necessary the careful monitoring of air, and hands, as well as general checks for surface contaminations….It is desired to run all operations wherever possible without the spread of any plutonium, preventing the contamination of personnel.
HW-7-5595 SRDB 31503	#88 H. I. Report for the 100 Areas and 300 Area for Week Ending January 6, 1947
HW-7-5633 SRDB 31574	#105 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 1/8/47(Jan 10).
HW-7-5680 SRDB 31504	#90 H. I. Report for the 100 Areas and 300 Area for Week Ending January 20, 1947
HW-7-5688 SRDB 31575	#107 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 1/22/47(Jan 23).
HW-7-5706 SRDB 31521	#91 H. I. Report for the 100 Areas and 300 Area for Week Ending January 27, 1947
HW-7-5760 SRDB 37499	H. I. Section Report for January 1947
HW-7-5757 SRDB 31522	#92 H. I. Report for the 100 Areas and 300 Area for Week Ending February 3, 1947
HW-7-5882 SRDB 50787	H. I. Section Report for February 1947.
HW-7-6025 SRDB 31523	#100 H. I. Report for the 100 Areas and 300 Area for Week Ending March 31, 1947
HW-7-6140 SRDB 31524	#104 H. I. Report for the 100 Areas and 300 Area for Week Ending April 28, 1947
HW-7-6284 SRDB 31525	#108 H. I. Report for the 100 Areas and 300 Area for Week Ending May 26, 1947
HW-7-6409 SRDB 31526	#111 H. I. Report for the 100 Areas and 300 Area for Week Ending June 16, 1947
HW-7-6450 SRDB 31527	#112 H. I. Report for the 100 Areas and 300 Area for Week Ending June 23, 1947
HW-7184-PT2 SRDB 24119	H.I. Lecture Series -- Part 11 -- Introductory Lecture Series in Health Instrumentation (Lectures 16-21) (Jul 1). Lectures used as part of the regular technical training for personnel assigned to radiation protection duties. This reference describes the Hanford operating facilities and processes, and the hazards.
HW-7795-DEL SRDB 37568	Hanford Works Monthly Report September 1947
HW-7997-DEL SRDB 37569	Hanford Works Monthly Report October 1947

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-8267-DEL
SRDB 37571</td><td>Hanford Works Monthly Report November, 1947</td></tr>
<tr><td>HW-7-5633
SRDB 31574</td><td>#105 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 1/8/47(Jan 10).</td></tr>
<tr><td>HW-7-5688
SRDB 31575</td><td>#107 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 1/22/47(Jan 23).</td></tr>
<tr><td>HW-7-5734
SRDB 31581</td><td>#108 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 1/29/47(Jan 30).</td></tr>
<tr><td>HW-7-5784
SRDB 31583</td><td>#109 H.I. Report on the 200 Areas and Associated Laboratories for the Week Ending 2/5/47(Feb 7).</td></tr>
<tr><td>HW-8438-DEL
SRDB 37580</td><td>Hanford Works Monthly Report December, 1947</td></tr>
<tr><td></td><td>Personnel Meters Monthly Report December 1947.
<table>
<tr><th>Description</th><th>100-B/D</th><th>100-F</th><th>200E&N</th><th>200-W</th><th>300</th><th>Total</th></tr>
<tr><td>Total pencils read</td><td>11,918</td><td>13,514</td><td>32,143</td><td>34,964</td><td>31,098</td><td>123,637</td></tr>
<tr><td>No. of single readings (100 to 280 mr)</td><td>53</td><td>64</td><td>86</td><td>65</td><td>83</td><td>351</td></tr>
<tr><td>No. of Paired readings (100 to 280 mr)</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>No. of single readings: >280 mr</td><td>166</td><td>148</td><td>272</td><td>71</td><td>201</td><td>858</td></tr>
<tr><td>No. of paired readings: 280 mr</td><td>0</td><td>1</td><td>4</td><td>2</td><td>3</td><td>10</td></tr>
<tr><td colspan="7">Badge results by areas</td></tr>
<tr><td>Total badges processed</td><td>7,166</td><td>4,829</td><td>4,986</td><td>6,072</td><td>5,469</td><td>28,522</td></tr>
<tr><td>No. of readings (100 to 500 mrep)</td><td>2</td><td>1</td><td>14</td><td>0</td><td>80</td><td>98</td></tr>
<tr><td>No. of readings (> 500 mrep)</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>No. of film packets lost in processing</td><td>2</td><td>1</td><td>16</td><td>2</td><td>1</td><td>22</td></tr>
</table>
</td></tr>
<tr><td colspan="2">1948</td></tr>
<tr><td>HW-8931-DEL
SRDB 37582</td><td>Hanford Works Monthly Report January 1948</td></tr>
<tr><td>HW-9191-DEL,
HAN-13586
SRDB 36762</td><td>Hanford Works Monthly Report February 1948</td></tr>
<tr><td>HW-9595-DEL
SRDB 37587</td><td>Hanford Works Monthly Report March 1948</td></tr>
<tr><td>HW-8547
SRDB 38397</td><td>Slow Neutron Survey Method (Jan 5). A comparison of surveys made with slow neutron pencils and the BF_3 Counter at the 100-F instrument cubicles in the -9’ Level and the “B” Test Hole Assembly show fairly close correlation for fluxes below 10 mrem/hr. Accordingly it is concluded that pencils should be quite satisfactory for direct survey and personnel monitoring.</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
	Bldg 234-5 construction begun (June) originally to build the Remote Mechanical (RM) design but changed to the Rubber Glove (RG) design because of time constraints. The RG design was a simpler method whereby operators would operate the process manually through rubber gloves.
HW-9922-DEL SRDB 37591	Hanford Works Monthly Report April 1948
HW-8973 SRDB 34747	Proposed Revisions of H.I. Procedures: Routine Film Badge Program (Feb 25). This report describes elements of the existing administration of the Hanford personnel dosimetry program and potential changes. The report describes that all workers (site and contractor) are issued dosimeters upon entry into a radiological controlled area (i.e., 100, 200 and 300 Areas).
HW-9585 SRDB 37891	A Portable Fast Neutron Survey Meter–Preliminary Report (Apr 20). A portable fast neutron survey meter called “Neut” with a useful neutron survey range from 0.5 mrem/hr to 10 rem/hr, approximately, has been developed. It uses argon and methane chambers separately with a modified Zeuto measuring circuit. Gamma ionization current is cancelled with a slide-back arrangement. Preliminary reports from the Survey Group indicate satisfactory performance.
HW-10166-DEL SRDB 37256	Hanford Works Monthly Report May 1948
HW-10378-DEL SRDB 37261	Hanford Works Monthly Report June 1948
HW-10714-DEL SRDB 37265	Hanford Works Monthly Report July 1948
DUN-6888 SRDB 333	B Reactor returns to operation
HW-10993-DEL, HAN-18766-DEL SRDB 37270	Hanford Works Monthly Report August 1948
HW-11226-DEL SRDB 37271	Hanford Works Monthly Report September 1948
HW-11499, HAN-20213 SRDB 37274	Hanford Works Monthly Report October 1948
HW-11835-DEL, HAN-20858 SRDB 33265	Hanford Works Monthly Report November 1948
HM-206 SRDB 37866	Instrument Requirements for Health Monitoring in the 234-5 Building (June 14). Portable alpha, photon and neutron (BF_3) instrument needs are identified for the 234-5 Building work areas.
HW-10522 SRDB 4909	Bioassay at Hanford (July 20). Document describes methods of analysis for plutonium and states that tolerance at Hanford is 0.5 microgram. Bioassay is conducted for three groups of identified workers as every three, six and 12 months depending on the potential for exposure.
HW-12107 SRDB 37112	#179 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of December 1948 (Dec 31).
HW-12086-DEL SRDB 37280	Hanford Works Monthly Report December 1948

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
SRDB File 5/26/09 06114	Personnel Meters Monthly Reports December 1948

	December 1948						1948
Description	**100-B**	**100-D**	**100-F**	**200E&N**	**200-W**	**300**	**Total**
Total pencils read	12,788	12,897	14,646	32,002	47,395	42,897	1,692,224
No. of single readings (100 to 200 mr)	25	33	20	45	79	73	4,894
No. of paired readings (100 to 200 mr)	0	0	0	0	1	2	38
No. of single readings: 200 mr	20	28	34	55	98	105	9,761
No. of paired readings: 200 mr	0	0	0	0	2	4	142
Badge results by areas							
Total badges processed	2,793	2,160	2,068	2,955	3.570	8,435	268,112
No. of readings (100 to 500 mrep)	1	0	0	10	9	215	3,277
No. of readings (>500 mrep)	0	1	0	1	3	0	49
No. of film packets lost in processing	0	0	0	14	1	15	230

Reference	Description
1949	
HW-12390 SRDB 37200	#180 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of January 1949 (Jan 31).
HW-12733 SRDB 37207	#181 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of February 1949 (Feb 28).
HW-12391-DEL SRDB 37281	Hanford Works Monthly Report January 1949
HW-12666-DEL SRDB 37282	Hanford Works Monthly Report February 1949

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-12710 SRDB 7756	General (Hanford) Operating Tolerances (Mar 11). The permissible tolerances used at Hanford Works are as follows: External Radiation Limits Whole Body– 0.3 rem per week or whatever the National Committee on Radiation Protection recommends. Hands Only– 1.0 rem per week or whatever the National Committee on Radiation Protection recommend. Internal Emitter Limits 0.3 rem per week to the significant organ or whatever the National Committee on Radiation Protection recommends. Drinking Water Uranium–100 μg/liter–believe this is high. Plutonium**–0.01 μg/liter–intend to revise to not more than 0.001 μg/liter. Mixed fission products–0.1 μg/liter–to be changed when new figure provided by K. Z. Morgan's Subcommittee (more limits in reference)
HW-12937-DEL SRDB 37297	Hanford Works Monthly Report March 1949
HW-13190-DEL SRDB 37306	Hanford Works Monthly Report April 1949
HW-12959 SRDB 37209	#182 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of March 1949 (Mar 31).
HW-13329 SRDB 37219	#183 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of April 1949 (Apr 29).
DOE/RL-97-1047 SRDB 27666	234-5 RG line began "hot" processing (i.e., using plutonium feed) (Jul 5).

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-35745
SRDB 32559</td><td>
<p>Three Memos: Neutron Measurements in the 234-5 Process (Aug 8). The first memo concerns fast neutron measurements at Hood 9 in the 234-5 process with a hydrogen recoil proton counter and also with BF_3 counters. Monitoring results are presented in the report as fast neutron flux densities in $n/sec/cm^2$. Comparison between the recoil counter and the BF_3 counter showed 14.3 ± 8.7 counts per minute with the moderated BF_3 counter to one neutron per second per cm^2 as measured with the recoil counter.</p>
<p>The second memo concerned similar measurements at Hood 8. The recoil counter was calibrated with a Po-Be neutron source and the moderated BF3 counter with a Ra-Be source. The factor used to convert flux density to dose rate was 0.16 mrem/hr per 1 $neutron/sec/cm^2$. The evolution of this factor is described in the memo. The results for three positions follows:</p>
<table>
<tr><th rowspan="2">Position</th><th colspan="3">$n/sec/cm^2$</th><th rowspan="2">Dose rate limits (mrem/hr)</th></tr>
<tr><th>Recoil counter</th><th>Mod. BF_3</th><th>Flux limits</th></tr>
<tr><td>A</td><td>8±4</td><td>16±2</td><td>8–16</td><td>1.3–2.6</td></tr>
<tr><td>B</td><td>15±5</td><td>12±2</td><td>10–20</td><td>1.6–3.2</td></tr>
<tr><td>C</td><td>123±18</td><td>55±3</td><td>50–150</td><td>8.0–24</td></tr>
</table>
<p>The third memo concerned source specific differences in the response of the 234-5 standard BF_3 counter. Interchanging various components of two calibrated BF3 counters introduced only small errors in the counting rate, less than 4%. Allowance was made for the sensitivity of the tubes and the correct operating voltage.</p>
<table>
<tr><th>Source</th><th>Average neutron energy (MeV)</th><th>Ratio $C/M/n/cm^2/sec$</th></tr>
<tr><td>PoBe</td><td>4.6</td><td>10.5±0.2</td></tr>
<tr><td>RaBe</td><td>>4.6</td><td>10.3±0.3</td></tr>
<tr><td>PoB</td><td>2.3</td><td>13.0±0.4</td></tr>
</table>
</td></tr>
<tr><td>HW-14403
SRDB 34823</td><td>432 Project–Needed Modification of the RM Line (Sep 7). This document summarizes several requested design modifications to the RM line and the basic reasons for these changes.</td></tr>
<tr><td>HW-13190-DEL
SRDB 37306</td><td>Hanford Works Monthly Report April 1949</td></tr>
<tr><td>HW-13561-DEL
SRDB 40705</td><td>Hanford Works Monthly Report May 1949</td></tr>
<tr><td>HW-13793-DEL
SRDB 37311</td><td>Hanford Works Monthly Report June 1949</td></tr>
<tr><td>HW-14043-DEL
SRDB 37323</td><td>Hanford Works Monthly Report, July 1949</td></tr>
<tr><td>HW-14440
SRDB 355</td><td>Fast Neutron Measurements–234-5 Building (Sep 15)
Measurements performed 5 days during Jul-Sep using: 1) proton recoil proportional counter to measure PoBe equivalent neutron flux and 2) BF_3 with moderator to measure counts per minute. Results shown on drawings for selected hoods.</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-14579 SRDB 34824	A Screening Review and Classification of Modifications needed on the RM Line (Sep 21). This is a reply to HW-14403 regarding 24 design modifications. Items were assigned to one of three classifications as follows: 1. Essential items requiring a cost estimate to determine magnitude of change or addition before final request. 2. Needed items on which a cost estimate is required to determine if the expense is tolerable. 3. Items in the Schenectady design in which operating difficulties are anticipated based on current experience in the RG line and on present design for the RM Line.
SRDB 26049	Memorandum dated October 27, 1949 to L.W. Finch, P.C. Jerman, P. R. McMurray and J. G. Myers, entitled “Intermediate Neutrons.” Letter stated that with present instrumentation, they were unable to determine the flux for neutrons in the intermediate energy range. Proposed the following procedure for determining intermediate neutron dosage rates. 1. Using a moderated BF3 tube, determine the count and convert to N/cm2/second on the basis of the slow neutron calibration. 2. Convert this flux to mrem/hour assuming that 300 N/cm2/second is equivalent to 6.25 mrem/hour.
HW-15011 SRDB 37223	#189 H.I. Divisions Report on the 200 Areas and Associated Laboratories for the Month for October 1949 (Nov 8).
HW-14338-DEL SRDB 37229	Hanford Works Monthly Report August 1949
HW-14596-DEL SRDB 37234	Hanford Works Monthly Report September 1949
HW-14916-DEL, HAN-28917 SRDB 33220	Hanford Works Monthly Report October 1949
DUN-6888 SSRDB 333	H Reactor startup (October 29, 1949)
HW-15267-DEL SRDB 37334	Hanford Works Monthly Report November 1949
HW-46104 SRDB 68858	Manual of Standard Procedures for 100, 200 and 300 Area Survey Work dated December 1, 1949. This is a comparatively large manual containing radiation exposure limits, contamination limits, Special Work Permits, protective clothing, Special Hazards Bulletins, descriptions of the monitoring equipment and general monitoring information regarding radiation types, selections of instruments, etc.
HW-15658 SRDB 37230	#191 H.I. Divisions Report on the 200 Areas and Associated Laboratories for the Month for December 1949 (Jan 11, 1950).

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-15550-DEL
SRDB 37341</td><td>Hanford Works Monthly Report December 1949. Report provides the annual status of several monitoring activities as follows
<table>
<tr><th>Description</th><th>100 Areas</th><th>200 Areas</th><th>300 Areas</th><th>Total</th></tr>
<tr><td>Special Work Permits (SWPs)</td><td>25,762</td><td>10,169</td><td>2,344</td><td>38,275</td></tr>
<tr><td>Routine and special surveys</td><td>19,511</td><td>17,953</td><td>2,146</td><td>39,610</td></tr>
<tr><td>107 Effluent surveys</td><td>3,656</td><td></td><td></td><td>3,656</td></tr>
<tr><td>Air monitoring samples</td><td>4,952</td><td>28,706</td><td>1,774</td><td>28,706</td></tr>
<tr><td>Thyroid checks</td><td></td><td>2,599</td><td></td><td>2,599</td></tr>
<tr><td>Pocket ionization chambers</td><td></td><td></td><td></td><td>1,708,976</td></tr>
<tr><td>Construction, beta/photon badges</td><td></td><td></td><td></td><td>63,388</td></tr>
<tr><td>Routine, beta/photon badges</td><td></td><td></td><td></td><td>240,805</td></tr>
<tr><td>Bioassays</td><td></td><td></td><td></td><td>15,746</td></tr>
</table></td></tr>
<tr><td colspan="2">1950</td></tr>
<tr><td>DOE/RL-97-1047
SRDB 27666</td><td>“Skull Recovery Project.” Skulls are thin shells of metallic plutonium that cling to the molds when plutonium is cast into specific weapons pieces. Project begun to recover plutonium from contaminated scrap. Laboratory work directed at developing recovery methods for various other types of Pu-bearing scrap such as powders, sludges, shavings, metallic chips, fines, etc.</td></tr>
<tr><td>HW-15843-DEL
SRDB 37346</td><td>Hanford Works Monthly Report January 1950</td></tr>
<tr><td>HW-15937
SRDB 72210</td><td>Technical Report entitled “Comparative Neutron Absorption of Asphalt and Paraffin,” dated January 20, 1950, “describing a study conducted to determine the relative neutron absorption of asphalt and paraffin for use as moderators of intermediate and fast neutrons emitted from the “T” seams on No. 1 Experimental level of the 100-H pile.”</td></tr>
<tr><td>HW-17056-DEL
SRDB 37239</td><td>Hanford Works Monthly Report February 1950</td></tr>
<tr><td>HW-17410-DEL
SRDB 37244</td><td>Hanford Works Monthly Report March 1950</td></tr>
<tr><td>HW-17660-DEL
SRDB 37246</td><td>Hanford Works Monthly Report April 1950</td></tr>
<tr><td>HW-15871
SRDB 37232</td><td>#192 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of January 1950 (Feb 2).</td></tr>
<tr><td>HW-16038
SRDB 34804</td><td>Americium Separation from Plant Solutions (Feb 15). Report describes analysis and tests to separate americium from aged plutonium solutions. The first reported separations of americium from plutonium was accomplished by successive LaF_3 precipitations from oxidized plutonium (VI) solutions. The report evaluates methods that could be used in 231 or 234 facilities.</td></tr>
<tr><td>HW-17191
SRDB 37236</td><td>#193 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of February 1950 (Mar 13).</td></tr>
<tr><td>HW-17472
SRDB 37238</td><td>#194 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of March 1950 (Apr 11).</td></tr>
<tr><td>HW-17766
SRDB 37241</td><td>#195 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of April 1950 (May 10).</td></tr>
<tr><td>HW-17971-DEL
SRDB 36754</td><td>Hanford Works Monthly Report May 1950</td></tr>
<tr><td>HW-18221-DEL
SRDB 36757</td><td>Hanford Works Monthly Report June 1950</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-18473-DEL
SRDB 36794</td><td>Hanford Works Monthly Report July 1950</td></tr>
<tr><td>HW-18740-DEL
SRDB 33271</td><td>Hanford Works Monthly Report August 1950</td></tr>
<tr><td>DDTS-Generated-426
SRDB 50783</td><td>Information concerning radiation exposure of personnel was requested by AEC representatives and this letter provides some information for Hanford workers as follows:
Table I.
<table>
<tr><th>Description</th><th>1947</th><th>1948</th><th>1949</th></tr>
<tr><td>Total pencils used</td><td>1,236,686</td><td>1,692,224</td><td>1,708,976</td></tr>
<tr><td>Pencils reading between 100 and 280 mr</td><td>1 in 7,700</td><td>1 in 22,000</td><td>1 in 39,000</td></tr>
<tr><td>Pencils reading over 280 mr</td><td>1 in 5,900</td><td>1 in 6,000</td><td>1 in 26,000</td></tr>
<tr><td>Pencils lost</td><td>1 in 10,300</td><td>1 in 11,500</td><td>1 in 13,500</td></tr>
</table>
Table II. Number in which both pencils read
<table>
<tr><th>Reading between (mr)</th><th>1947</th><th>1948</th><th>1949</th></tr>
<tr><td>0–30</td><td>585,535</td><td>829,411</td><td>836,685</td></tr>
<tr><td>35–60</td><td>855</td><td>697</td><td>238</td></tr>
<tr><td>65–120</td><td>88</td><td>68</td><td>13</td></tr>
<tr><td>125–280</td><td>12</td><td>15</td><td>6</td></tr>
<tr><td>Off scale</td><td>84</td><td>134</td><td>31</td></tr>
</table>
</td></tr>
<tr><td>HW-18043
SRDB 37243</td><td>#195 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of April 1950 (May 10).</td></tr>
<tr><td>HW-18561
SRDB 37091</td><td>#196 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of May 1950 (Jun 9).</td></tr>
<tr><td>SRDB 31743</td><td>Letter (Oct 19) Keene to Money, Film Badge Readings 234-5 Building, concerning maintaining accurate list of 234-5 workers to allow appropriate film badge dose interpretation.</td></tr>
<tr><td>HW-19690
SRDB 37141</td><td>#202 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of November 1950 (Dec 12).</td></tr>
<tr><td>HW-19910
SRDB 37143</td><td>#203 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of December 1950 (Jan 10, 1951).</td></tr>
<tr><td>SRDB 67675</td><td>Health Instrument Operational Division, Manual of Standard Procedures, Personnel Meters (Aug 18, 1950). This is a form manual that describes procedures used with the radiation instruments and dosimeters.</td></tr>
<tr><td>HW-19021-DEL
SRDB 36802</td><td>Hanford Works Monthly Report September 1950</td></tr>
<tr><td>DUN-6888
SRDB 333</td><td>DR reactor startup (October 3, 1950)</td></tr>
<tr><td>HW-19325-DEL
SRDB 36804</td><td>Hanford Works Monthly Report October 1950</td></tr>
<tr><td>HW-19622-DEL,
HAN-35248
SRDB 36812</td><td>Hanford Works Monthly Report November 1950</td></tr>
</table>

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-19842-DEL,
HAN-35587
SRDB 33226</td><td>Hanford Works Monthly Report December 1950. This routine monthly report provides the annual status of several monitoring activities as follow:
<table>
<tr><th>Description</th><th>100 Areas</th><th>200 Areas</th><th>300 Areas</th><th>Total</th></tr>
<tr><td>Special Work Permits (SWPs)</td><td>33,633</td><td>11,387</td><td>1,437</td><td>46,457</td></tr>
<tr><td>Routine and special surveys</td><td>23,403</td><td>23,555</td><td>2,205</td><td>49,163</td></tr>
<tr><td>Retention basin surveys</td><td>5,035</td><td></td><td></td><td>5,035</td></tr>
<tr><td>Air monitoring samples</td><td>7,268</td><td>38,874</td><td>1,857</td><td>47,999</td></tr>
<tr><td>Thyroid checks</td><td></td><td>1,705</td><td></td><td>1,705</td></tr>
<tr><td>Pocket ionization chambers</td><td></td><td></td><td></td><td>1,596,323</td></tr>
<tr><td>Construction, beta/photon badges</td><td></td><td></td><td></td><td>33,322</td></tr>
<tr><td>Routine, beta/photon badges</td><td></td><td></td><td></td><td>270,203</td></tr>
<tr><td>Neutron NTA film</td><td></td><td></td><td></td><td>3,808</td></tr>
<tr><td>Bioassays</td><td></td><td></td><td></td><td>29,515</td></tr>
</table></td></tr>
<tr><td>HW-19910
SRDB 37143</td><td>#203 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of December 1950 (Jan 10, 1951).</td></tr>
<tr><td colspan="2">1951</td></tr>
<tr><td>HW-20249
SRDB 37145</td><td>#204 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of January 1951(Feb 12).</td></tr>
<tr><td>HW-20161-DEL
SRDB 36831</td><td>Hanford Works Monthly Report January 1951</td></tr>
<tr><td>HW-20438-DEL
SRDB 36834</td><td>Hanford Works Monthly Report February 1951</td></tr>
<tr><td>HW-20671-DEL
SRDB 36837</td><td>Hanford Works Monthly Report March 1951</td></tr>
<tr><td>HW-20991-DEL,
HAN-37490
SRDB 36856</td><td>Hanford Works Monthly Report April 1951</td></tr>
<tr><td>HW-20511
SRDB 37147</td><td>#205 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of February 1951(Mar 9).</td></tr>
<tr><td>HW-20785
SRDB 32556</td><td>Radiation Studies 234-5 (I) (Apr 17). Report concluded that chief source of neutron radiation in 234-5 Bldg is the alpha-neutron reaction in fluorine. Although some neutron radiation is detected along the line, it is of significance only with the fluorination step and nearly zero once the plutonium is converted to metal. Chief sources of photon radiation are X-rays associated with alpha decay, passage of alpha radiation through material, gamma rays from plutonium and in the scattering of alpha radiation by fluorine. Predominate photon energies are approximately 17, 40 and 200 or higher keV.</td></tr>
<tr><td>HW-22490
SRDB 37291</td><td>Monthly Report–September 1951 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-22763
SRDB 37292</td><td>Monthly Report–October 1951 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-22939
SRDB 37294</td><td>Monthly Report–November 1951 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-23235
SRDB 37296</td><td>Monthly Report–December 1951 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-21260-DEL
SRDB 36864</td><td>Hanford Works Monthly Report May 1951</td></tr>
<tr><td>HW-21506-DEL
SRDB 36871</td><td>Hanford Works Monthly Report June 1951</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-21802-DEL SRDB 36889	Hanford Works Monthly Report July 1951
HW-22075-DEL SRDB 36895	Hanford Works Monthly Report August 1951
HW-20802 SRDB 37148	#206 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of March 1951(Apr 11).
HW-21040 SRDB 37149	#207 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of April 1951(May 8).
HW-21127 SRDB 73704	RMA Line Nomenclature (May 18). This document was prepared to identify terms, locations and processes, that were not classified, to enable preparations for RMA startup. The document presents a coding of RMA Line equipment in terms of Task number and process operations and the associated Instruction book volume number.
HW-21328 SRDB 31601	#208 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of May, 1951(Jun 11).
HW-21552 SRDB 31711	Fast Neutron Monitoring of Personnel (Aug 1). This document describes the routine Hanford procedures of monitoring personnel for fast neutron radiation using NTA nuclear Track Emulsions. Effects of energy, angular response, fading, calibration, training, etc. are described. The report describes the Hanford practice of using “control badges” which contain two NTA film; one is blank (i.e., no exposure) and the other is exposed to a known level of exposure. Hanford control and calibration dosimeters are exposed prior to assigning these dosimeters so that the assigned dose is maximized to compensate for fading. The document describes the extensive training necessary for technicians to effectively read the NTA film and that films are routinely read by more than one technician to detect significant differences in evaluation. The is also the practice to routinely submit audit dosimeters with known neutron exposures for evaluation.
HW-21508 SRDB 36888	RMA Startup Plans, 234-5 Bldg. (Jul 2). This report describes a list of actions to be done as prepared by the RMA Startup Committee and signed by each of the several participating Division representatives.
HW-21699 SRDB 37025	Annual Report of the Health Instrument Divisions (Jul 20). This report describes radiological exposure events during 1950 in each all of the major Hanford areas and facilities. The report describes changes in radiation exposure guidelines resulting from the 1949 TriPartite meeting at Chalk River, Canada.
HW-21905 SRDB 37153	#210 H.I. Divisions Monthly Report on the 200 Areas and Associated Laboratories for the Month of July, 1951(Aug 13).
HW-22020 SRDB 26043	Radiation Studies 234-5 Building (III) Nuclear Track Film (Aug 21). Report describes neutron spectra difference between 234-5 workplace and Po-B calibration source and the issue of the relative energy sensitivity of NTA film and the signal fading expected to occur. Recommended that a factor of 5/3 be used to increase the reported neutron doses.
HW-22021 SRDB 32557	Radiation Studies 234-5 (IV) Moderated BF_3 Calibration (Aug 23). Report describes calibration and dose interpretation using BF_3 counters and sources of calibration. Using a BF_3 whose slow neutron calibration is 8.47 cpm per nv both Ra-Be and Po-B sources give 7 c/m per neutron/sec. Since no difference is found for these two sources that differ considerable in average energy, it was assumed that the same factor can be used for Pu-F neutrons. The report also describes the dose per unit flux from Pu-F as a value of 0.011 mrem/hr per neutron/cm^2/sec.
HW-17398 SRDB 38354	Hanford Works, Separations Section, Operating Standards (Oct 15) • Part I. Bismuth Phosphate and Isolation • Part II. REDOX • Part III. Metal Recovery

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-24327
SRDB 26044</td><td>Technical report concerning on November 16, 1951 accidentally achieving prompt critical condition for a partially full spherical reactor using plutonium nitrate fuel in the 300 Area Hanford Homogenous Reactor.</td></tr>
<tr><td>HW-22902
SRDB 58612</td><td>The 120 Bldg Critical Mass Laboratory reactor, during a critical mass study on November 16, 1951, suddenly went out of control. The primary and secondary safety systems automatically shut down the reactor promptly. However, all six workers in the P-11 area at the time were overexposed to gamma and neutron radiation as noted in the following:
<table>
<tr><th rowspan="2">Worker</th><th rowspan="2">Location</th><th colspan="3">Estimated exposure (mrems)</th></tr>
<tr><th>Fast neutron</th><th>Gamma</th><th>Total</th></tr>
<tr><td>1</td><td>Control Building</td><td>400</td><td>200</td><td>600</td></tr>
<tr><td>2</td><td>Control Building</td><td>400</td><td>200</td><td>600</td></tr>
<tr><td>3</td><td>Control Building</td><td>400</td><td>200</td><td>600</td></tr>
<tr><td>4</td><td>Control Building</td><td>400</td><td>140</td><td>540</td></tr>
<tr><td>5</td><td>Gate House</td><td>225</td><td>85</td><td>310</td></tr>
<tr><td>6</td><td>Gate House</td><td>225</td><td>75</td><td>300</td></tr>
</table></td></tr>
<tr><td>HW-22304-DEL
SRDB 36926</td><td>Hanford Works Monthly Report September 1951</td></tr>
<tr><td>HW-22610-DEL,
HAN-41950
SRDB 36935</td><td>Hanford Works Monthly Report October 1951</td></tr>
<tr><td>HW-22875-DEL,
HAN-42327
SRDB 36943</td><td>Hanford Works Monthly Report November 1951</td></tr>
<tr><td>HW-22976
SRDB 36971</td><td>Radiation Studies 234-5 Building (V) (Dec 11). This report describes examination of the “blackening” of the film badge open window and the derivation of a correction factor (0.19) to estimate the X-ray dose from a radium calibration. An example is shown in the report in which an interpreted 7500 mR of radium “open window” dose based on the film response actually corresponds to 1400 mR of X-ray dose (i.e., 7500 * 0.19).</td></tr>
</table>

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-23140-DEL
SRDB 35862</td><td>Radiological Sciences Report December 1951. This project wide report contains a summary of annual activities as shown in the following:
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Special Work Permits</td><td>6,643</td></tr>
<tr><td>Routine and special surveys</td><td>11,998</td></tr>
<tr><td>Air samples</td><td>6,995</td></tr>
<tr><td>Skin contamination</td><td>372</td></tr>
</table>
Dosimeter Annual summaries as follows:
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Pencils</td><td>1,954,787</td></tr>
<tr><td>Film badges</td><td>319,530</td></tr>
<tr><td>Construction film badges</td><td>104,601</td></tr>
<tr><td>Slow neutron pencils</td><td>4,472</td></tr>
<tr><td>NTA neutron film</td><td>3,895</td></tr>
</table>
For the year there were 12 lost pencil readings and 19 lost badge readings which were investigated to assign a dose.
Radiological Calibrations as follows:
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Fixed instruments (gamma)</td><td>2,958</td></tr>
<tr><td colspan="2">Portable instruments</td></tr>
<tr><td>Alpha</td><td>3,285</td></tr>
<tr><td>Beta</td><td>6,782</td></tr>
<tr><td>Gamma (radium)</td><td>13,297</td></tr>
<tr><td>X-ray scanning</td><td>67</td></tr>
<tr><td>Special X-Ray</td><td>8</td></tr>
<tr><td>Neutron</td><td>47</td></tr>
<tr><td colspan="2">Personal meters</td></tr>
<tr><td>Beta</td><td>9,803</td></tr>
<tr><td>Gamma (radium)</td><td>77,181</td></tr>
<tr><td>X-ray</td><td>58,492</td></tr>
<tr><td>Neutron</td><td>1,583</td></tr>
</table>
</td></tr>
<tr><td colspan="2">1952</td></tr>
<tr><td>HW-23437-DEL
SRDB 37353</td><td>Hanford Works Monthly Report January 1952</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>REDOX Plant begins (January 9) operation</td></tr>
<tr><td>HW-23698-DEL
SRDB 36737</td><td>Hanford Works Monthly Report for February 1952</td></tr>
<tr><td>HW-23982-DEL
SRDB 36740</td><td>Hanford Works Monthly Report for March 1952</td></tr>
<tr><td>HW-24337-DEL
SRDB 36744</td><td>Hanford Works Monthly Report for April 1952</td></tr>
<tr><td>SRDB 74153</td><td>R. S. Bell, Manager, Separations Section to R. B. Richards, Manager, Separations Technology, entitled “Critical Mass Specifications for the 234-5 Building,” dated Feb. 19, 1952. This letter describes the conduct of a review of the critical mass history of 234-5 operations and includes a bibliography of documentation.</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
DOE/RL-97-1047 SRDB 27666	Hanford's RMA (Remote Mechanical A) line begins hot processing (March 18)
HW-23862 SRDB 38334	Preliminary investigation of DuPont Film Types (Apr 21). Document describes results of tests of DuPont 508 and 560 films in comparison with the DuPont 502 film used at Hanford since 1944. The 508 and 560 films are more sensitive than the 502 but do not exhibit the 502 film linear response to 1000 mR.
HW-24605-DEL, HAN-45180-DEL SRDB 33232	Hanford Works Monthly Report for May 1952
HW-24697-DEL SRDB 73707	Proposed Procedures in 234-5 Processes (Jun 6). This document describes a critical mass review and provides mass specifications for 234-5 processes.
HW-24928, HAN-45659 SRDB 37364	Hanford Works Monthly Report June 1952
HW-25227-DEL SRDB 36746	Hanford Works Monthly Report for July 1952
HW-25533-DEL SRDB 36749	Hanford Works Monthly Report for August 1952
HW-23472 SRDB 37299	Monthly Report–January 1952 Radiation Monitoring Services Unit
HW-23655 SRDB 37302	Monthly Report–February 1952 Radiation Monitoring Services Unit
HW-23933 SRDB 37303	Monthly Report–March 1952 Radiation Monitoring Services Unit
HW-24595 SRDB 37308	Monthly Report–May 1952 Radiation Monitoring Services Unit
HW-24859 SRDB 37313	Monthly Report–June 1952 Radiation Monitoring Services Unit
HW-25185 SRDB 37314	Monthly Report–July 1952 Radiation Monitoring Services Unit
HW-25483 SRDB 37316	Monthly Report–August 1952 Radiation Monitoring Services Unit
HW-25728 SRDB 73678	Remote Mechanical Operation Methods Vs. Rubber Glove Operating Methods for the 234-5 Process (Sept 23, 1952). Analysis of RMA Line operation in comparison with RG Line operation. Some historical information concerning RG line operation.
HW-25763 SRDB 37320	Monthly Report–September 1952 Radiation Monitoring Services Unit
HW-26086 SRDB 37321	Monthly Report–October 1952 Radiation Monitoring Services Unit
HW-26396 SRDB 37324	Monthly Report–November 1952 Radiation Monitoring Services Unit
DUN-6888 SRDB 333	C Reactor begins operation (November 18, 1952)

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-23180 SRDB 36891	Neutron Measurements in the 234-5 Process (draft). On July 7, fast neutron measurements were made on the product in the 234 process with both a recoil proton counter and a moderated boron trifluoride counter. Measurements were made in three situations as follows: 1. Two boats in a scow lying in furnace No. 1; top half of the furnace open, product had been fluorinated and was cooling at the time. Counters were placed on the Hood No. 8 window as close to the oven as possible. 2. Same as above, except that counters were placed in the glove port in line with the oven axis. The counter end was about 12 inches from the near end of the oven. 3. Two boats in a scow on the transport belt, parallel to the front face of the hood. Counters placed in a glove port directly opposite the side of one boat. End of the recoil counter and of the moderator about 2 inches from the near side of the scow. The recoil proton counter was calibrated with a PoBe neutron source, and the moderated BF_3 counter with a RaBe neutron source. The factor used to convert flux density to dose rate is 0.16 mrem/hr per 1 neutron/sec/cm^2. The evolution of this factor is described in the report (Note: This study appears to be included in HW-35745 that appears to summarize three studies done during 1949).
HW-23535 SRDB 73705	Additional Shielding in Hood 8 (Feb 13). Shielding of three waste jars in RG line hood 8 with six inches paraffin lined with cadmium is proposed to reduce the exposure rate. The shielding is planned to fit the curve surface of the jars and the jar bottom. A factor of 10 reduction in exposure rate is expected. From the perspective of criticality hazards, the configuration with 640 grams of sweepings in each jar is considered to be safe.
HW-23639 SRDB 73706	Reduction of Neutron Flux, Hood 8–RG Line (Feb 26). A study was initiated at the request of operating personnel to examine options to reduce the neutron flux at Hood 8. In normal practice the total radiation intensity at the face of Hood 8 opposite the weighing station is not infrequently in the range of 20 to 30 mrem/hr and at times even higher. Customary practice is for the radiation monitor to inform the operator when the measured exposure rate exceeds 25 mrem/hr. The operator can move waste jars that contain sweepings further back from the face of the hood or to pass the contents of the jars to Hood 9 for recovery processing. It is convenient to have the waste jars near the weighing station. Some options for installing shielding for these jars was also examined.
PNNL-13524 SRDB 12856	RMB construction was begun (May)
HW-25709 SRDB 34255	Annual Report of the Radiological Sciences Department, 1951 (Sep 22). The Health Instrument Divisions was reorganized under the Radiological Sciences Department. This report provides highlights of Hanford Site radiological activities during 1951 for all operating areas.
HW-24915 SRDB 73708	Calibration Procedure for the Victoreen Integron (Jun 30). The integron consists of two main parts: 1. A cylindrical unit, the inner side of which is coated with aquadag, is used as the outer wall of an ionization chamber. ho
HW-25781-DEL SRDB 37248	Hanford Works Monthly Report September 1952
HW-26047-DEL SRDB 36751	Hanford Works Monthly Report for October 1952

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-26376-DEL,
HAN-48244-DEL
SRDB 34267</td><td>Hanford Works Monthly Report for November 1952</td></tr>
<tr><td>HW-26720-DEL,
HAN-48706,
SRDB 35863</td><td>
<p>Radiological Sciences Report December 1952. This project wide report contains a summary of annual activities as shown in the following:</p>
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Special Work Permits</td><td>8,279</td></tr>
<tr><td>Routine and special surveys</td><td>14,267</td></tr>
<tr><td>Air samples</td><td>20,225</td></tr>
<tr><td>Skin contamination cases</td><td>690</td></tr>
</table>
<p>Dosimeter Annual summaries as follows:</p>
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Pencils</td><td>2,630,386</td></tr>
<tr><td>Film badges</td><td>524,469</td></tr>
<tr><td>Construction film badges</td><td></td></tr>
<tr><td>Slow neutron pencils</td><td>11,942</td></tr>
<tr><td>NTA neutron film</td><td>5,241</td></tr>
</table>
<p>For the year there were a total of 459 lost readings which were investigated to assign a dose.</p>
<p>Radiological calibrations as follows:</p>
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Fixed instruments (gamma)</td><td>2,338</td></tr>
<tr><td>Portable instruments:</td><td>24,794</td></tr>
<tr><td>Personal meters:</td><td>157,083</td></tr>
</table>
</td></tr>
<tr><td colspan="2">1953</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>Explosion (Sep) in RMA Line Task III hood requiring 2 week switch to RG Line</td></tr>
<tr><td>HW-26958
SRDB 37326</td><td>Monthly Report–January 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-26946-DEL,
SRDB 52681</td><td>Hanford Works Monthly Report for January 1953</td></tr>
<tr><td>HW-27236
SRDB 37327</td><td>Monthly Report–February 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-27288-DEL
SRDB 35864</td><td>Hanford Works Monthly Report for February 1953</td></tr>
<tr><td>HW-27564
SRDB 37328</td><td>Monthly Report–March 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-27889
SRDB 37348</td><td>Monthly Report–April 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-28190
SRDB 37350</td><td>Monthly Report–May 1953 Radiation Monitoring Services Unit</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-28532
SRDB 51479</td><td>Document entitled “Exposure Study of the Calibration Unit Operations,” describing an analysis of calibration staff radiation exposures. Radium gamma and neutron source dose rates are provided to allow calculation of dose based on the time involved in making the irradiation. On facet of this study involved evaluation of personnel film badge data for the first fifteen weeks of 1953 with the following observations:
1. A maximum exposure of 165 mr/week occurred on swing shift.
2. A maximum exposure of 100 mr/week occurred on day shift.
3. The average exposure for straight day employees was 12 mr/week.
4. The average exposure for shift employees on day shift was 40 mr/week.
5. The average exposure for shift employees on swing shift was 60 mr/week.
This study identified expected exposures from each of several identified radiation calibration tasks.</td></tr>
<tr><td>HW-28545
SRDB 37352</td><td>Monthly Report–June 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-28875
SRDB 37355</td><td>Monthly Report–July 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-29150
SRDB 37358</td><td>Monthly Report–August 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-29471
SRDB 37360</td><td>Monthly Report–September 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-29781
SRDB 37362</td><td>Monthly Report–October 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-30107
SRDB 37366</td><td>Monthly Report–November 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-30409
SRDB 37368</td><td>Monthly Report–December 1953 Radiation Monitoring Services Unit</td></tr>
<tr><td>HW-27194
SRDB 36973</td><td>Radiation Studies 234-5 Building (VI) Plutonium Surface Dose Rate (Jan 20). Report describes review of surface dose rate of 200 mrep/hr from plutonium metal based on unpublished measurement by Whipple and Jacobs in 1949. The 1949 measurement was apparently made on a coated piece. The dose rate for uncoated pieces would be significantly greater. This reports conclusions are:
Table I. Plutonium surface dose rates.
<table>
<tr><th rowspan="2">Absorber</th><th colspan="2">Dose rate (mrep/hr)</th></tr>
<tr><th>Coated</th><th>Uncoated</th></tr>
<tr><td>Skin (7 mg/cm^2)</td><td>246</td><td>(2,700)</td></tr>
<tr><td>Polyethylene glove (7 + 38 mg/cm^2)</td><td>185</td><td>916</td></tr>
<tr><td>Rubber glove (7 + 113 mg/cm^2)</td><td>173</td><td>795</td></tr>
</table>
</td></tr>
<tr><td>HW-27754
SRDB 36976</td><td>Radiation Survey of Task II & III–RMA (Mar 30). This report describes a need for surveys of the levels of radiation encountered in Task II and III of the RMA Line and the contemplated reduction of allowable body dosage rates. The report specifies measurements to assess:
1. Requirements and shielding properties of hood walls.
2. Shielding requirements of the vessels and containers handling the product, and
3. Location of equipment which requires routine manual operation in the Zone III.</td></tr>
<tr><td>HW-27486
SRDB 367</td><td>Gamma Dose Measurement with Hanford Film Badges (Mar 23). This report describes using the film response characteristic response curves for the open window and shielded areas of the film to evaluate the dose received.</td></tr>
</table>

Reference	Description
HW-27554 SRDB 36976	Radiation Survey of Task II & III–RMA Line (Mar 30). This report identifies a need for using measurements of the existing RMA Line processes to establish a design bases for shielding new Task III RM Line equipment. Information concerning (1) the characteristics, level, and the rate of build-up of radiation due to contaminated materials collecting on the hood interiors; (2) nature and level of radiation due to the Plutonium Charge itself; (3) how both of the above are affected by batch size; and, (4) the effectiveness as a radiation shield of typical materials used in hood construction.
HW-27570 SRDB 37810	Radiation Exposure Rates in the 222-S Process Control Laboratory (Apr 1). The 222-S laboratory prime role is to conduct radiochemical analysis of samples. This report provides a review and tabulation of potential worker exposures from handling the types of samples.
HW-27814 SRDB 34259	Annual Report of the Radiological Sciences Department, 1952 (Apr 23). This report provides a site-wide annual radiological status report as well as for each major operating facility.
HW-28116 SRDB 36982	Approximation of Energy of Radiation from 240-S-151 Diversion Box (May 13). This report describes an investigation into the reasons for high film dosimeter measured beta dose not confirmed with portable instrument measurements. The reason appears to be associated with a lower energy photon component in association with typically significant beta radiation fields. Measurements were made with a so-called Trent (modified Tracerlab CP using a T.P. probe as the ionization chamber) instrument.
HW-28655 SRDB 73709	The Evaluation of the RMA Line Reduction Yield Basis and the Reduction Process (Jul 2). This document describes a study of Task III reduction efficiency in the 234-5 Bldg.
HW-28918 SRDB 36984	Radiation Studies for Task III Design (Aug 26). This report describes BF_3 proportional counter measurements of PuF_4 powder neutron doses using selected thicknesses of water, Plexiglas and masonite shielding. The work is apparently focused on Task III (i.e., fluorination hood) design options.

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-29378
SRDB 36986</td><td>Radiation Measurements for Task I Design (Sep 18). This report describes actual measurements of a PR Can from 231-Z with 336 grams of plutonium for comparison with Operations personnel photon dosage rate measurements of 150 mr/hr on the side and 250 mr/hr on the bottom. The Trent (modified Tracerlab CP using a T.P. probe as the ionization chamber)
All measurements made with Trent
<table>
<tr><th colspan="2">Center of probe distance (in.) to:</th><th rowspan="2">Dosage rate (mr/hr)</th></tr>
<tr><th>Edge of can</th><th>Center</th></tr>
<tr><td>1</td><td>10.25</td><td>101.9</td></tr>
<tr><td>2</td><td>11.25</td><td>76.5</td></tr>
<tr><td>3</td><td>12.25</td><td>54.8</td></tr>
<tr><td>3.94</td><td>13.19</td><td>45.0</td></tr>
<tr><td>5.38</td><td>14.63</td><td>33.5</td></tr>
<tr><td>9.25</td><td>18.50</td><td>18.7</td></tr>
<tr><td>14.44</td><td>23.81</td><td>10.0</td></tr>
<tr><td>18.63</td><td>27.88</td><td>6.5</td></tr>
</table>
</td></tr>
<tr><td>HW-29443
SRDB 32558</td><td>Radiation Studies 234-5 Building (VII) Sensitivity of Nuclear Track Film to PoB and Pu-F Neutron sources (Sep 24). This report describes results of measurements of NTA sensitivity and fading to evaluate the theoretical conclusions of HW-22020. The NTA emulsion exhibits a sensitivity for Pu-F neutrons of 2.9 ± 0.5 tracks per 10^4 neutrons in good agreement with HW-22020. The extent of the fading for Pu-F amounts to 40% in one week and 60% in two weeks. Fading for Po-B amounts to about 10-15% in two weeks. The sensitivity and the fading are affected by the age of the film. The neutron fluence was determined using a BF_3 long counter in a Hanson Moderator which is stated to have a uniform sensitivity to neutrons from Pu-F.</td></tr>
</table>

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Reference	Description
1954	
HW-25457 SRDB 34200	"Manual of Radiation Protection Standards," December 15, 1954 (HW 1954). This manual contains the latest policies for control of radioactive materials and radiation hazards at HAPO. These Hanford standards have been formulated from national policies on radiation protection, AEC requirements for control of radioactive materials, and working limits which have been adopted over a period of years. A series of safety factors were introduced as summarized in the following table.

Class of exposure		Recommended safety factor[a]
Source of radiation	**Body region**	
External penetrating radiation	Whole body	5
	Hands and forearms	~2
	Feet and ankles	~2
External beta radiation	Whole body	2
	Hands and forearms	~2
	Feet and ankles	~2
	Head and neck	~2
	eyes	5
Mixed radiation	any	Not less than 5

a. *Factors relative to the appropriate maximum permissible limit.

The application of these safety factors were used to define recommended annual dose working limits as follows:

Type of radiation	Dose
X-Rays and gamma rays	3 R/year
Neutrons	3 rem/year
Beta particle emitters	15 rad/year
Any ionizing radiation to hands & forearms, feet and ankles, or head and neck (except eyes)	37.5 rem/year
Eyes	3 rem/year

Reference	Description
HW-29047 SRDB 36988	Surface Dosage Rate Studies of Task III Feed Material (Jan 15). This report describes results of an investigation to evaluate the accuracy of estimates of the surface hand exposure from handling Task III plutonium fluoride powder concerning photon and neutron radiation. The report concludes that the best estimate for the surface dosage from 450 grams of pink colored plutonium fluoride powder contained in a Plexiglas jar with one-fourth inch thick walls is 4.5 rem/hr, of which 3.0 rem/hr is due to fast neutrons from the $^{19}F(alpha,neutron)^{22}Na$ interaction with an average energy of 0.75 MeV. Surface dose rates with the blue colored Pu-F powder are 3.5 rem/hr (2.0 rem/hr due to fast neutrons). The 1.5 R/hr photon radiation was determined to have effective energies of: a) 680 keV–50%, b) 50 keV–8%, and c) 17 keV–42%.
HW-30685 SRDB 37370	Monthly Report–January 1954 Radiation Monitoring Services Unit
HW-30942 SRDB 37377	Monthly Report–February 1954 Radiation Monitoring Services Unit
HW-31255 SRDB 37429	Monthly Report–March 1954 Radiological Sciences Department Radiation Monitoring Unit
HW-31669 SRDB 37430	Monthly Report–April 1954 Radiation Monitoring Unit Radiological Sciences Department
HW-31976 SRDB 37432	Monthly Report–May 1954 Radiation Monitoring Unit Radiological Sciences Department

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Reference	Description
HW-32238 SRDB 37379	Monthly Report–June 1954 Radiation Monitoring Unit Radiological Sciences Department
HW-32571 SRDB 34314	Monthly Report–July 1954, Radiation Monitoring Unit, Radiological Sciences Department
HW-32955 SRDB 37434	Monthly Report–August 1954 Radiation Monitoring Unit Radiological Sciences Department
HW-33241 SRDB 37436	Monthly Report–September 30, 1954 Radiation Monitoring Unit Radiological Sciences Department
HW-33562 SRDB 37437	Monthly Report–October 1954 Radiation Monitoring Unit Radiological Sciences Department
HW-33936 SRDB 37442	Monthly Report–November 1954 Radiation Monitoring Unit Radiological Sciences Department
HW-34262 SRDB 37445	Monthly Report–December 1954 Radiation Monitoring Unit Radiological Sciences Department
HW-30464 SRDB 34271	Annual Report of the Radiological Sciences Department, 1953 (Jan 7, 1954). This report provides a site-wide annual radiological status report as well as for each major operating facility.
HW-30185 SRDB 73711	A Mathematical Approach to Surface Dosage Rate Problems (Jan 13). This document describes an approach to estimating the exposure rate for handling radioactive sources in intimate contact with the hands or other portions of the body. Often it is difficult to determine the exposure rates involved due to geometrical considerations of the source and receptor.
HW-31522 SRDB 36996	Surface Dosage Rate Studies of Task III Feed Material (Apr 20). In an early study, the dosage rate from plutonium fluoride powder was questioned as being too low. This document reports on a follow-up evaluation. The best value for the surface dosage rate from 450 grams of pink colored plutonium fluoride powder contained in a Plexiglas jar with one-fourth inch thick walls is 4.5 rem/hr, of which 3.0 rem/hr is due to fast neutrons from the reaction ^{19}F(alpha, neuron)^{22}Na with an average energy of 0.75 MeV. The surface dosage rate from 450 grams of blue colored plutonium fluoride powder contained in a Plexiglas jar with one-fourth inch thick walls appears to be 3.5 rem/hr of which 2.0 rem/hr is due to fast neutrons from the above reaction.
HW-32476 SRDB 26045	Neutron Measurements (I) (Jul 26). This report clarifies the primary Hanford calibration sources and emission rate. Dose rates are specified as follows: RaBe: 1.6×10^{-2} mrad/hr per n/cm^2-sec PoB: 1.3×10^{-2} mrad/hr per n/cm^2-sec

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<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-32571
SRDB 34314</td><td>Radiation Monitoring Unit, Radiological Sciences Department, Monthly Report, July 1954 (Jul 30). Neutron film badge for the week ending 6-20-1954 indicated a definite high neutron exposure for an individual working in room 24. A total exposure of 405 was estimated which included 270 mrem of fast and intermediate neutrons, 45 mrem of slow neutrons and 90 mR of gamma radiation. High slow neutron pencil readings were detected during the week in question and recommendations were made that no other radiation work should be done for the rest of the week. This incident was formally investigated (Class II, No. 77)
<p>300 Area General Statistics</p>
<table>
<tr><th>Description</th><th>June</th><th>July</th><th>1954 to date</th></tr>
<tr><td>Special Work Permits</td><td>218</td><td>224</td><td>1,553</td></tr>
<tr><td>Routine and special surveys</td><td>569</td><td>455</td><td>3,602</td></tr>
<tr><td>Air samples</td><td>366</td><td>256</td><td>2,140</td></tr>
<tr><td>Skin contamination</td><td>5</td><td>5</td><td>25</td></tr>
</table>
<p>July Statistics–300 Area</p>
<table>
<tr><th>Description</th><th>SWPs</th><th>Surveys</th><th>Air sampling</th></tr>
<tr><td>304, 314, 3730, 3732 Bldgs., fuel tech</td><td>7</td><td>9</td><td>1</td></tr>
<tr><td>321 Bldg., Cold Semiworks</td><td>0</td><td>10</td><td>7</td></tr>
<tr><td>325 Bldg., Radiochemistry</td><td>19</td><td>98</td><td>8</td></tr>
<tr><td>326 and 3741 Bldgs., Pile Tech.</td><td>35</td><td>83</td><td>0</td></tr>
<tr><td>327 Bldg., Radiometallurgy</td><td>117</td><td>102</td><td>147</td></tr>
<tr><td>329 Bldg., Biophysics</td><td>6</td><td>53</td><td>91</td></tr>
<tr><td>3745, 3745-A, 3745-B Bldgs., calibrations</td><td>0</td><td>1</td><td>2</td></tr>
<tr><td>Miscellaneous bldgs., 300 Area</td><td>4</td><td>68</td><td>0</td></tr>
<tr><td>Construction</td><td>26</td><td>30</td><td>0</td></tr>
</table>
</td></tr>
<tr><td>HW-35282
SRDB 36990</td><td>Some Notes on the Surface Dosage Rate of Plutonium Metal (Apr 13). This report summarizes studies made on the surface dosage rate on plutonium metal during the previous year. It states that the assumption is made that a dosage rate of 800 mr/hr is assumed for buttons and for uncoated pieces.</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>Violent chemical reaction and fire in PFP Metallurgical Laboratory (May)</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>Metal turnings fire stopped Tasks IV and V for three weeks (July).</td></tr>
<tr><td>HW-32516
SRDB 378</td><td>Gamma Dose Measurement with Hanford Film Badges (Jul 21). This document describes dose algorithms used to determine nonpenetrating and penetrating dose with the Hanford film dosimeter.</td></tr>
<tr><td>HW-32492
SRDB 36999</td><td>Gamma Surface Dosage Rates From Task II Feed Material (Aug 2). This report describes results of an investigation to evaluate the surface dosage rate involving Task II feed material. A best estimate of the gamma surface dosage rate from a full boat of plutonium oxalate is 732 ± 54* mr/hr. The best estimate for an empty filter boat is 459 ± 133* mr/hr. For routine exposure calculations a dosage rate of 800 mr/hr is recommended in the report for both materials.
* one standard deviation.</td></tr>
</table>

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-32493
SRDB 37005</td><td>Hand Exposures During Routine Operation of the RMA Line (Aug 3). This report describes a summary of potential exposure to workers involved with manual manipulation of plutonium in several chemical states along the RMA Line. All primary jobs on the RMA Line are stated to have been evaluated and the upper limit (90% confidence level) of potential exposure for each job is tabulated.
<table>
<tr><th>Task II</th><th>Dose (mrem)</th></tr>
<tr><td>1. Process one boat through the line</td><td>32</td></tr>
<tr><td colspan="2">Task III</td></tr>
<tr><td>1. Weigh chemicals and prepare can pack</td><td></td></tr>
<tr><td>a. with no addition of turnings</td><td>~0</td></tr>
<tr><td>b. with addition of turnings</td><td>60</td></tr>
<tr><td>2. Charge the furnace</td><td>26</td></tr>
<tr><td>3. Break out the button and mark</td><td>40</td></tr>
<tr><td>4. Pickling</td><td>40</td></tr>
<tr><td>5. Stripping (chemical)</td><td></td></tr>
<tr><td colspan="2">Task IV</td></tr>
<tr><td>1. Charge the furnace</td><td>16</td></tr>
<tr><td>2. Break out casting and skull disposal (note)</td><td>16</td></tr>
<tr><td colspan="2">Note: If crucible fragments adhere to the casting and filing is required involving hand exposure, calculate exposure based on a surface dosage rate of 800 mrem/hr (13.3 mrem per minute)</td></tr>
<tr><td colspan="2">Task V</td></tr>
<tr><td>1. Machining (does not include turning cleanup)</td><td>125</td></tr>
<tr><td>2. Turning recovery (cleanup)</td><td></td></tr>
<tr><td>a. with turnings going to storage</td><td>55</td></tr>
<tr><td>b. with turnings going to briquetting</td><td>45</td></tr>
<tr><td>3. Briquetting</td><td>35</td></tr>
<tr><td colspan="2">Task VII</td></tr>
<tr><td>1. Coating hood operation (when using remote tool)</td><td>~0</td></tr>
<tr><td>2. Cleaning and polishing, testing (room 242)</td><td></td></tr>
<tr><td>a. excellent quality</td><td>30</td></tr>
<tr><td>b. good quality</td><td>55</td></tr>
<tr><td>c. poor quality</td><td>~200</td></tr>
<tr><td>3. Mating</td><td>35</td></tr>
<tr><td>4. Final polish</td><td>10</td></tr>
<tr><td colspan="2">Miscellaneous Operations</td></tr>
<tr><td>1. Canning normal buttons for off-plant shipment</td><td>60</td></tr>
<tr><td>2. Sealing out plutonium fluoride powder (including hood sweepings from TASKS II and III)
a. **to be determined at time of job</td><td>a</td></tr>
</table>
</td></tr>
<tr><td>HW-32494
SRDB 37002</td><td>RMA Hand Exposure (Aug 3). This is a supplement to HW-32493 with the measurement data provided in a series of appendices.</td></tr>
<tr><td>HW-32526
SRDB 378</td><td>Gamma Dose Measurement with Hanford Film Badges</td></tr>
</table>

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<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>Hydrogen explosion in RMA Line Task II Hood.</td></tr>
<tr><td>WHC-MR-0512
SRDB 474</td><td>RMA Line expansion and improvements (especially Tasks I–oxalate precipitation, II–fluorination, and III–reduction)</td></tr>
<tr><td>HW-33533
SRDB 32278</td><td>Achievements in HAPO Radiation Monitoring, 1944 to 1954 (Sep 15). This is a review of radiation monitoring challenges and successes during the period of 1944-54.</td></tr>
<tr><td>HW-34365
SRDB 393</td><td>Radiation Protection in the Atomic Energy Industry–A Ten Year Review (Nov 26). This is a general review of personnel exposure and monitoring.</td></tr>
<tr><td>HW-25457
SRDB 27679</td><td>Manual of Radiation Protection Standards, Compiled by Radiological Sciences Department (Dec 15). This manual contains updates to some previously issued and some new procedures (see revision log at the bottom of each procedure).</td></tr>
<tr><td>HW-34147-E
SRDB 34312</td><td>Radiological Sciences Department Report for Month of December, 1954. This routine monthly report provides the annual status of several monitoring activities as follow:
<table>
<tr><th>Description</th><th></th><th>Total</th></tr>
<tr><td>Special Work Permits (SWPs)</td><td></td><td>6,425</td></tr>
<tr><td>Routine and special surveys</td><td></td><td>19,342</td></tr>
<tr><td>Air samples</td><td></td><td>18,357</td></tr>
<tr><td>Skin contamination</td><td></td><td>182</td></tr>
<tr><td>Gamma PIC</td><td></td><td>2,766,976</td></tr>
<tr><td>Slow neutron PIC</td><td></td><td>15,526</td></tr>
<tr><td>Beta/photon film badges</td><td></td><td>461,600</td></tr>
<tr><td>Neutron NTA badges</td><td></td><td>6,349</td></tr>
<tr><td>Bioassays:</td><td></td><td></td></tr>
<tr><td>Plutonium</td><td>9,063</td><td></td></tr>
<tr><td>Fission product</td><td>9,754</td><td></td></tr>
<tr><td>Uranium</td><td>3,811</td><td>22,628</td></tr>
</table>
</td></tr>
<tr><td colspan="2">1955</td></tr>
<tr><td>DUN-6888
SRDB 333</td><td>KW initial startup (January 4, 1955)</td></tr>
<tr><td>WHC-MR-0521
SRDB 474</td><td>RG Line shuts down during January and February while Task I equipment is installed</td></tr>
</table>

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<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-35905
SRDB 34301</td><td>Annual Report of the Radiological Sciences Department, 1954 (Feb 4). This report provided summary statistics as follows:
Table I. Radiation incidents reported.
<table>
<tr><th>Year</th><th>Informal</th><th>Class I</th><th>Class II</th><th>Total</th></tr>
<tr><td>1944</td><td>5</td><td>0</td><td>3</td><td>8</td></tr>
<tr><td>1945</td><td>88</td><td>35</td><td>6</td><td>129</td></tr>
<tr><td>1946</td><td>85</td><td>39</td><td>4</td><td>128</td></tr>
<tr><td>1947</td><td>99</td><td>27</td><td>2</td><td>128</td></tr>
<tr><td>1948</td><td>126</td><td>38</td><td>2</td><td>166</td></tr>
<tr><td>1949</td><td>121</td><td>36</td><td>0</td><td>157</td></tr>
<tr><td>1950</td><td>124</td><td>20</td><td>5</td><td>149</td></tr>
<tr><td>1951</td><td>77</td><td>25</td><td>13</td><td>115</td></tr>
<tr><td>1952</td><td>130</td><td>71</td><td>12</td><td>213</td></tr>
<tr><td>1953</td><td>239</td><td>69</td><td>26</td><td>334</td></tr>
<tr><td>1954</td><td>287</td><td>76</td><td>20</td><td>383</td></tr>
</table>
Table II. Whole body gamma exposure summary.
<table>
<tr><th>Year</th><th>>1 r</th><th>>2 r</th><th>>3 r</th><th>>4 r</th><th>>5 r</th></tr>
<tr><td>1944</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1945</td><td>8</td><td>1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1946</td><td>8</td><td>2</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1947</td><td>13</td><td>2</td><td>1</td><td>1</td><td>1 (6.4 r)</td></tr>
<tr><td>1948</td><td>10</td><td>2</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1949</td><td>4</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1950</td><td>3</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1951</td><td>23</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1952</td><td>179</td><td>22</td><td>1</td><td>0</td><td>0</td></tr>
<tr><td>1953</td><td>323</td><td>42</td><td>4</td><td>0</td><td>0</td></tr>
<tr><td>1954</td><td>372</td><td>68</td><td>16</td><td>3</td><td>1 (14.4 r)</td></tr>
</table>
</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>RECUPLEX begins operation (July 1)</td></tr>
<tr><td>HW-34810
SRDB 34359</td><td>Monthly Report–January 1955, Radiation Monitoring Unit, Radiological Sciences Department</td></tr>
<tr><td>HW-35499
SRDB 37447</td><td>Monthly Report–February 1955 Radiation Monitoring Unit Radiological Sciences Department</td></tr>
<tr><td>HW-35979
SRDB 34283</td><td>Monthly Report–March 1955, Radiation Monitoring Unit, Radiological Sciences Department</td></tr>
<tr><td>HW-36424
SRDB 37448</td><td>Monthly Report–April 1955 Radiation Monitoring Unit Radiological Sciences Department</td></tr>
<tr><td>DUN-6888
SRDB 333</td><td>KE initial startup (April 17, 1955)</td></tr>
<tr><td>HW-36929
SRDB 37450</td><td>Monthly Report–May 1955 Radiation Monitoring Unit Radiological Sciences Department</td></tr>
<tr><td>HW-37651
SRDB 34280</td><td>Monthly Report–June 1955, Radiation Monitoring Unit, Radiological Sciences Department</td></tr>
<tr><td>HW-38333
SRDB 34364</td><td>Monthly Report–July 1955, Radiation Monitoring Unit, Radiological Sciences Department</td></tr>
<tr><td>HW-38846
SRDB 34354</td><td>Monthly Report–August 1955, Radiation Monitoring Unit, Radiological Sciences Department</td></tr>
</table>

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-39674
SRDB 37453</td><td>Monthly Report–October 1955 Radiation Monitoring Unit Radiological Sciences Department</td></tr>
<tr><td>HW-40185
SRDB 34288</td><td>Monthly Report–November 1955, Radiation Monitoring Unit, Radiological Sciences Department</td></tr>
<tr><td>HW-40696
SRDB 34356</td><td>Monthly Report–December 1955, Radiation Monitoring Unit, Radiological Sciences Department</td></tr>
<tr><td>HW-39558
SRDB 37079</td><td>Annual Report of the Radiological Sciences Department, Fiscal Year 1955 (Sep 23, 1955). This report provides a site-wide annual radiological status report as well as for each major operating facility.</td></tr>
<tr><td>HW-40448
SRDB 34825</td><td>Dosimetry of 234-5 Manufacturing Processes–A summary of current problems (Nov 21). The purpose of this document is stated to be a summary of day-to-day operating problems of the Z Plant Radiation Monitoring Subsection. Apparently, with the new equipment, the HW-32493 dosage rates need to be updated. Several monitoring “rules of thumb” are provided as follows:
<table>
<tr><th colspan="3">Full filter boats</th></tr>
<tr><th>CP reading on carrier</th><th colspan="2">Exposure rate in boat (mrem/hr)</th></tr>
<tr><td><40 mr/hr</td><td colspan="2">800</td></tr>
<tr><td>>40 mr/hr but <120 m/hr</td><td colspan="2">1,500</td></tr>
<tr><td>>120 mr/hr but <200 mr/hr</td><td colspan="2">3,000</td></tr>
<tr><td>>200 mr/hr</td><td colspan="2">To be determined</td></tr>
<tr><th colspan="3">Fluoride powder</th></tr>
<tr><td><3 inches of powder</td><td colspan="2">4,500</td></tr>
<tr><td><12 in. but >3 in</td><td colspan="2">800</td></tr>
<tr><td><3 inches of a full can pack</td><td colspan="2">1,500</td></tr>
<tr><th colspan="3">Uncoated metal</th></tr>
<tr><th rowspan="2">CP meter reading (window closed)</th><th colspan="2">Exposure rate on metal (mrem/hr)</th></tr>
<tr><th><3 in.</th><th>3–12 in</th></tr>
<tr><td><100 mr/hr</td><td>800</td><td>200</td></tr>
<tr><td>>100 mr/hr, <250 mr/hr</td><td>1,500</td><td>?</td></tr>
<tr><td>>250 mr/hr, <350 mr/hr</td><td>3,000</td><td>800</td></tr>
<tr><td>>350 mr/hr</td><td colspan="2">To be determined</td></tr>
<tr><th colspan="3">Coated metal</th></tr>
<tr><td><12 in.</td><td colspan="2">250</td></tr>
</table></td></tr>
<tr><td>HW-39774
SRDB 34248</td><td>Radiological Sciences Department, Monthly Section Reports, October 1955 (Nov 4)</td></tr>
<tr><td>HW-40188
SRDB 37082</td><td>Radiological Sciences Department, Monthly Section Reports, November 1955 (Dec 5)</td></tr>
<tr><td>HW-40468
SRDB 34826</td><td>Preliminary Notes on Dosimetry Problems, Room 242, 234-5 (Dec 15).
The report describes hand and extremity exposure evaluations of an activity involving soot removal and rough polishing. Based on 4 studies on uncoated metal, the surface dosage rate on coated metal was estimated to be 400 ± 40 mr/hr based on the assumption the high energy photon emission will penetrate the nickel coat and the low energy photon components (17 keV) will not. Concern was expressed that these doses are about a factor of 2 higher than noted in HW-27194.</td></tr>
</table>

Reference	Description
1956	
HW-40977 SRDB 51503	Comparison of Estimated Radiation Exposure and Film Badge Results (Jan 10). This document describes Hanford penetrating and beta dose limits and the practice of estimating the exposure to workers while waiting for the official film dosimeter result. A nine month study from January 1 through September 30, 1955 was conducted to compare estimated and recorded film badge doses for several maintenance (e.g., millwrights and pipefitters) and radiation monitoring staff. For all groups of workers the film badge measured dose was less than the estimated exposure based on workplace survey measurements and time-keeping.
PNNL-13524 SRDB 12856	Startup (January 12) of PUREX high product output drives production at PFP to higher levels
HW-41167 SRDB 73748	N-1 Tank Neutron Studies, 231 Building (Jan 27). This report concerns data collected with a enriched BF_3 tube enclosed in a standard moderator mounted as close as practicable to the bottom of the N-1 Tank, cell 4, 231 Bldg. This was done because of a suspicion of buildup of plutonium on a filter in the tank. Meaningful measurements for this purpose were collected when the tank was empty because otherwise the tank contents tended to shield the neutrons.
HW-41209 SRDB 34296	Monthly Report–January 1956, Radiation Monitoring Unit, Radiological Sciences Department
HW-41704 SRDB 37455	Monthly Report–February 1956 Radiation Monitoring Unit Radiological Sciences Department
HW-42297 SRDB 37457	Monthly Report–March 1956 Radiation Monitoring Unit Radiological Sciences Department
HW-42710 SRDB 58383	Monthly Report–April 1956 Radiation Monitoring Unit Radiological Sciences Department
HW-43438 SRDB 37459	Monthly Report–May 1956 Radiation Monitoring Unit Radiological Sciences Department
HW-44009 SRDB 37461	Monthly Report–June 1956 Radiation Monitoring Unit Radiological Sciences Department
HW-44588 SRDB 37463	Monthly Report–July 1956 Radiation Monitoring Unit Radiological Sciences Department
HW-45153 SRDB 37465	Monthly Report–August 1956 Radiation Monitoring Unit Radiological Sciences Department
HW-45736 SRDB 37382	Monthly Report–September 1956 Radiation Monitoring Operation Hanford Laboratories Operation
HW-46368 SRDB 37385	Monthly Report–October 1956 Radiation Monitoring Operation Hanford Laboratories Operation
HW-47107 SRDB 37388	Monthly Report–November 1956 Radiation Monitoring Operation Hanford Laboratories Operation

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<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>05-26-09
File 006001-1
SRDB 67521</td><td>Exposure Evaluation and Records Monthly Report, November 1956. Routine report regarding site-side status. A summary of 18 incidents is provided. The effort to replace the two-element personnel dosimeter with the multielement badge was apparently underway. The report identifies an unresolved issue concerning the interpretation of dose for 234-5 staff compared with the Chemical Processing Department staff. This is anticipated to involve issues associated with primarily a primarily low and higher energy photon radiation field (234-5) with issues of mixed beta and photon fields (processing facilities). There is a reference to a new program to remove PICs from workers who do not normally work or enter radiation zones. The number of pencils assigned during November 1956 was about 18% less than assigned during October 1956 and 8% less than the 1956 monthly average to date. This report also describes an effort to prepare computer input cards that contain the total beta and gamma exposure from 1944 through the first nine months of 1956 for all operational with current active clearance and construction employees for input to the new IBM database. This effort was being made so that the IBM database system could maintain a total accumulated dose for each Hanford worker on a current basis.</td></tr>
<tr><td>05-26-09
File 006001-2
SRDB 67522</td><td>Exposure Evaluation and Records Monthly Report, December 1956. Routine report regarding site-side status. This report provides a summary of year-end 1956 dosimetry processing totals as follows:
<table>
<tr><th colspan="5">Pencils</th></tr>
<tr><th>1956 total</th><th>100-280 mr</th><th></th><th>>280 mr</th><th>Lost readings</th></tr>
<tr><td>3,615,432</td><td>233</td><td></td><td>231</td><td>164</td></tr>
<tr><th colspan="5">Beta/gamma film[a]</th></tr>
<tr><th>1956 total</th><th>100-300 mr</th><th>300-500 mr</th><th>>500 mr</th><th>Lost readings</th></tr>
<tr><td>668,863</td><td>10,532</td><td>330</td><td>172</td><td>634</td></tr>
<tr><th colspan="5">Slow neutron pencils</th></tr>
<tr><th>1956 total</th><th>4-12 mrem</th><th></th><th>>12 mrem</th><th>Lost readings</th></tr>
<tr><td>12,586</td><td>460</td><td></td><td>63</td><td>30</td></tr>
<tr><th colspan="5">Fast neutron film (NTA) badges</th></tr>
<tr><th>1956 total</th><th></th><th></th><th>>12 mrem</th><th>Lost readings</th></tr>
<tr><td>10,025</td><td></td><td></td><td>11</td><td>25</td></tr>
</table>
a. It was also noted that for 1956 total films (668,863) that the average open window dose was 3.39 mrad while the average shielded dose was 3.29 mr. (This implies are comparatively penetrating photon energy on average).</td></tr>
<tr><td>HW-47657
SRDB 37389</td><td>Monthly Report–December 1956 Radiation Monitoring Operation Hanford Laboratories Operation</td></tr>
<tr><td>HW-41233
SRDB 37090</td><td>Radiological Sciences Department Section Reports for January 1956</td></tr>
<tr><td>HW-41702
SRDB 53072</td><td>Radiological Sciences Department Report for Month of February 1956 (Mar 5)</td></tr>
<tr><td>HW-42219
SRDB 53073</td><td>Radiological Sciences Department Report for Month of March 1956 (Apr 6)</td></tr>
<tr><td>HW-41369
SRDB 34828</td><td>Further Notes on the Surface Dosage Rate of Plutonium Metal (Feb 20). This report describes the history of Hanford surface dosage rate measurements on plutonium metal and the range in measurement results. The author describes an estimate of the average dosage rate of uncoated plutonium metal as between 1066 and 1322 mr/hr based on 400 CP readings that show wide variations in the measured dosage rate. This dosage rate is through 110 mg/cm^2 of tissue equivalent absorber.</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-41439 SRDB 34830	Surface Dosimetry and Effective Energy Calculations, (Sep 8). This report provides a more detailed examination of the surface dosage rate from plutonium metal with several attenuation curves provided in the report, estimation of workplace energy spectra and account in the dosage rate for instrument energy response. The estimated “true’ dosage rate is 817 mr/hr. Tables of reference data are provided at the end of the report to be used in examining 4 typical workplace exposure scenarios.
HW-42195 SRDB 58385	Technical Document entitled “Beta and Gamma radiations from PUREX Produced Plutonium,” identifying the presence of significant beta emitting nuclides in plutonium product. (May 28, 1956)
PNNL-13524 SRDB 12856	Uncontrolled chemical reaction occurred (May) in RMA TASK I.
HW-42626 SRDB 34290	Radiological Sciences Department Report for Month of April 1956 (May 4)
HW-43345 SRDB 34831	Exposures in 234-5, Room 242 (May 23). Report provides brief summary of radiation exposures received by personnel performing normal operations in room 242, 234-5 building as follows: <table><tr><th>Operations</th><th>Exposure per piece (mrem)[a]</th></tr><tr><td>1. Spot removal, whisker removal, cleaning and preliminary testing.</td><td>24</td></tr><tr><td>2. Polishing, cutting to weight, gauging and marking</td><td>13</td></tr><tr><td>3. Electrolytic testing</td><td>8</td></tr><tr><td>4. Final polishing.</td><td>8</td></tr></table>a. Value is the upper 95% level in that 95% of the time the long-term average exposure will be this value or less.
HW-43448 SRDB 37006	Surface Dose Rates from plutonium Metal (Jun 1). This report is one of a series concerning surface dosage rate studies on fabricated and unfabricated plutonium metal. Values are valid for REDOX produced plutonium (and might not be appropriate for PUREX, please see HW-42195) as follows: <table><tr><td>Metal from Task III</td><td>Probability is that the surface dosage rate from this form of metal is between 1,246 and 2,154 mr/hr with a most likely value of 1,638 mr/hr. In addition, the probability is 95% that 90% or more of the time the surface dosage rate on an individual item will be below 4,923 mr/hr.</td></tr><tr><td>Metal from Tasks IV and V</td><td>Probability is 95% that the surface dosage rate from this form of metal lies between 1,027 mr/hr and 1,224 mr/hr with a most likely value of 1,121 mr/hr. In addition, the probability is 95% that 90% or more of the time the surface dosage rate on an individual item will be below 1,540 mr/hr.</td></tr><tr><td>Metal from Task VII</td><td>Probability is 95% that the surface dosage rate from this form of metal lies between 311 mr/hr and 405 mr/hr with a most likely value of 355 mr/hr. In addition, the probability is 95% that 90% or more of the time the surface dosage rate on an individual item will be below 622 mr/hr.</td></tr></table>
HW-43137 SRDB 34309	Radiological Sciences Department Report for Month of May–1956 (Jun 4)

Reference	Description
HW-43784 SRDB 37009	Past Exposure Problems in 234-5 Room 242 (Jun 20). Report one of a series to complete the record of exposure problems in room 242, 234-5 Building. The studies in this report were made during production. This report is a supplement to HW-32493, HW-32494, HW-40468 and HW-43345. Exposures per operation are presented in report for each operation in this room. It was noted that substantially less exposure is received by an experienced technician as compared to an inexperienced technician. All exposures in report were based on the latest best estimate of a surface dosage rate from coated plutonium, 355 mr/hr (see HW-43448).
HW-43938 SRDB 34305	Radiological Sciences Department Report for Month of June–1956 (Jul 6). This report provides site wide radiation monitoring statistics, incident descriptions, etc.
HW-43979 SRDB 34307	Radiological Sciences Department Section Reports for June–1956 (Jul 6). This report provides site wide radiation monitoring statistics, incident descriptions, etc.
HW-43811 SRDB 37013	Effective Energies of Radiations from Pu Metal (Jun 22). Report provides a brief summary of the effective energies from fabricated and unfabricated plutonium metal. Energies are valid for REDOX produced plutonium but at the time of the report could not be interpreted as valid for PUREX produced plutonium (Report is a supplement to HW-41369 and HW-43448).

Unfabricated Metal

Effective energy				Surface dosage rate		
Average	95% confidence limits			Average	95% confidence limits	
keV	Upper	Lower	Task	mr/hr	Upper	Lower
18.1	18.6	17.6	III	745	786	708
			IV	745	786	708
59.2	63.1	55.3	III	152	297	78
			IV	119	168	84
616	658	575	III	568	769	336
			IV	259	317	211

Fabricated Metal (from Task VII)

Effective energy				Surface dosage rate		
Average	95% confidence limits			Average	95% confidence limits	
kev	Upper	Lower		mr/hr	Upper	Lower
62	65	59		83	108	63
500	540	460		243	254	232

Reference	Description
PNNL-13524 SRDB 12856	T-Plant separation operation terminated (Aug)
HW-44580 SRDB 34303	Radiological Sciences Department Report for Month of July–1956 (Aug 6). This report provides site wide radiation monitoring statistics, incident descriptions, etc.
HW-44706 SRDB 34304	Radiological Sciences Department Section Reports for July–1956 (Aug 6). This report provides site wide radiation monitoring statistics, incident descriptions, etc.
HW-44836 SRDB 34833	234-5 Exposures in Task V, Hoods 200A&B (Aug 9). Report provides a summary of radiation exposures received by personnel performing machining operation at Hoods 200 A & B. Using standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2, an exposure of 60 mrem per piece should be used for routine exposure accountability purposes. Note: This exposure does not include the sanding operation. Exposure received for the sanding operation is received at an average rate of 20 mrem/minute, and should be determined by clock or stop watch each time this occurs. Using lead impregnated gloves reduces the exposures.

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-44934 SRDB 37016	Exposures in Task V, Part II (Aug 17). Report provides a summary of radiation exposures received by personnel performing cleanup and briquetting operation at Hoods 200 A & B and the briquetting hood, 234-5 Building. Using standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2, an exposure of 35 mrem per operation should be used for routine exposure accountability purposes for the cleanup and briquetting operation. Note: This exposure does not included exposure received while placing burned turnings into a bottle. Exposure for this step is received at an average of 20 mrem/minute, and should be determined by clock or stop watch each time this occurs. When Edmont Glove Company lead impregnated plastic gloves are installed in all glove ports the exposure rate is reduced to 12 mrem per operation.
HW-45142 SRDB 34788	Exposures in Task IV 234-5 Building, Part I (Aug 31). Dosimetry of Plutonium Fabrication–Interim Report (Oct 2). Report provides a summary of radiation exposures received by personnel performing 1) the Task IV furnace loading and 2) the Task IV furnace unloading. Using standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2, an exposure of 35 mrem per operation should be used for routine exposure accountability purposes for the Task IV furnace loading operation when crucibles are double stacked. An exposure of 35 mrem per operation should be used for routine exposure accountability purposes for the Task IV furnace unloading each casting. This does not include sealing out skulls.
HW-45114 SRDB 34293	Radiological Sciences Department Section Reports for August 1956 (Sep 7).
HW-45115 SRDB 34292	Radiological Sciences Department Report for Month of August–1956 (Sep 7). This is stated to be the last routine monthly report by the Radiological Sciences Department. These responsibilities are apparently assumed by the Radiation Protection Operation under the Hanford Laboratory.
HW-45472 SRDB 37879	The Feasibility of Processing Pocket Ionization Chambers on a Weekly Basis (Sep 10). This report describes a study involving 83 pairs of pencils issued in three groups as follows: 1) 55 pairs to 303 area workers, 2) 13 pairs to 3705 Bldg workers and 3) 15 pairs set aside as controls. Pencils were charged and issued for weekly periods and read about 7.5 days later. More than 50% of the paired readings were zero while the highest was 35 mr. Only 4 pencils read more than 100 mr and three of these were off scale. The program of weekly processing is concluded to be feasible.
HW-45674 SRDB 36496	Hanford Irradiation Processing Department issued “Radiation Control Standards and Procedures” manual dated December 14, 1956. This manual describes numerous routine radiation safety functions pertaining to workplace controls, measuring and recording exposures to workers, and applicable exposure limits.

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-45600
SRDB 34789</td><td>Dosimetry of Plutonium Fabrication–An Interim Report (Oct 2). Report provides a summary of radiation exposures authorized for routine exposure accountability on portions of the RMA Line.
<table>
<tr><th>Location and operation</th><th colspan="2">Exposure (mrem)</th></tr>
<tr><td>Room 242</td><td colspan="2"></td></tr>
<tr><td>1. Soot removal, whisker removal cleaning and preliminary testing</td><td>27</td><td>142</td></tr>
<tr><td>2. Polishing, cutting to weight, gauging, and marking</td><td>14</td><td>—</td></tr>
<tr><td>3. Electrolytic testing</td><td>8</td><td>10</td></tr>
<tr><td>4. Mating</td><td>—</td><td>43</td></tr>
<tr><td>5. Final polishing</td><td>8</td><td>27</td></tr>
<tr><td>Task V</td><td colspan="2"></td></tr>
<tr><td>1. Machining, without leaded gloves</td><td>63</td><td></td></tr>
<tr><td>Machining, with leaded gloves</td><td>43</td><td></td></tr>
<tr><td>2. Sanding</td><td colspan="2">20 mrem per minute</td></tr>
<tr><td>3. Cleanup and briquetting</td><td>35</td><td></td></tr>
<tr><td>Task IV</td><td></td><td></td></tr>
<tr><td>1. Loading furnaces</td><td>35</td><td></td></tr>
<tr><td>2. Unloading furnaces</td><td colspan="2">35 mrem per casting</td></tr>
</table>
</td></tr>
<tr><td>HW-46522
SRDB 34366</td><td>Radiological Protection Operation Report for Month of October 1956 (Nov 9). This report provides site wide radiation monitoring statistics, incident descriptions, etc.</td></tr>
<tr><td>HW-46023
SRDB 34790</td><td>Exposures in Task VII, 234-5 Building (Oct 12). Report provides a summary of radiation exposures received by personnel performing 1) the Task VII coating hood loading, and 2) the Task VII coating hood unloading operations. Using standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2, an exposure of 5 mrem per piece should be used for routine exposure accountability purposes for loading the coating hoods. Using a minimum of surgical gloves with an average density thickness of 15 mg/cm^2, an exposure of 4 mrem per piece should be used for routine exposure accountability purposes for loading the coating hoods.</td></tr>
<tr><td>HW-46068
SRDB 34791</td><td>Exposures in Task V, Part III-190 (Oct 15). This report evaluates radiation exposures received by personnel performing machining operation. Using standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2, an exposure of 77 mrem per operation should be used for routine exposure accountability purposes. Please note this exposure does not include the sanding and cavity cleaning operation. Exposures for sanding and cleaning cavities are received at a rate of 20 mrem/minute and should be determined by clock or stop watch each time this occurs. When lead impregnated plastic gloves equivalent to those manufactured by the Edmont Glove Company are used at the glove ports for planar surface machining, exposure of 50 mrem/piece should be used.</td></tr>
</table>

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-46383
SRDB 34792</td><td>Exposures in Task III, Part I (Oct 31). Report provides a summary of radiation exposures received by personnel performing the button knockout and pickling operation, Task III. Using standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2, an exposure of 16 mrem per button should be used for routine exposure accountability purposes for knocking out and pickling one button. Please Note: This does not include removal of the button from the pickling solution, inspection, weighing and storage. This data will be included in a second report to be issued as soon as the data are compiled.

For purposes of definition, the steps involved in knocking out and pickling one button are:
1. Remove crucible and button from hopper
2. Hold button and remove fragments with hammer
3. Pick up fragments and put into hopper.
4. Transfer button to pickling hood.</td></tr>
<tr><td>HW-46401
SRDB 34793</td><td>Surface Dosage Rate Problems From Task III and Task IV Wastes (Nov 1).

Report describes the most recent Surface Dosage Rate (SDR) problems from Task III and IV crucible fragment cans with the goal to prepare for RECUPLEX Operations. The report provides a description of estimating the gamma and neutron dose rates from single CP or BF_3 measurements, respectively. The gamma dosage rate in mr/hr on cans of waste materials from Tasks III and IV can be estimated from the equation

Gamma SDR = 8 (CPR),

Where the CP reading is the window open dial reading. The neutron surface dosage rate in mrem/hr on cans of waste material from Tasks III and IV can be estimated from the equation

Neutron SDR = (16) (mrem/hr at contact)

There apparently is no correlation with the CP reading. The gamma activity on Task IV fragments appears to have a half-life of approximately 157 days.</td></tr>
<tr><td>HW-46449
SRDB 34794</td><td>Exposure Studies, 234-5 Building, Book II (Nov 5). Document contains many pages of original measurement data that is difficult to interpret.</td></tr>
<tr><td>HW-46507
SRDB 34795</td><td>Exposure in Task II (Nov 9). This report describes measurements of exposures received by personnel performing all phases of routine Task II operations. Using standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2, an exposure of 35 mrem per boat should be used for routine exposure accountability purposes for all routine operations in Task II. Details were provided as follows:

Exposure per boat per job step, Task II
<table>
<tr><th rowspan="2">Step</th><th rowspan="2">Mean (mrem)</th><th colspan="2">95% C.I., interval (mrem)</th><th rowspan="2">Variance (log)</th></tr>
<tr><th>Upper</th><th>Lower</th></tr>
<tr><td>1. Stir fluoride powder</td><td>1.2</td><td>1.9</td><td>0.8</td><td>0.10173</td></tr>
<tr><td>2. Stir oxalate</td><td>8.4</td><td>13.5</td><td>5.2</td><td>0.11970</td></tr>
<tr><td>3. Put empty boat in bathtub</td><td>5.0</td><td>7.4</td><td>3.3</td><td>0.08043</td></tr>
<tr><td>4. Place boat on door</td><td>5.2</td><td>7.3</td><td>3.8</td><td>0.06270</td></tr>
<tr><td>5. Change o-ring or inspect as required</td><td>9.6</td><td>27.0</td><td>3.5</td><td>0.33564</td></tr>
</table>
</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-46508
SRDB 34796</td><td>Exposure in Task III, Part II, Exposures in Task IV, Part II, Waste Material (Nov 12). This report describes measurements of exposures received by personnel performing the seal-out operations for Task III and Task IV crucible fragments. Using standard 30 gauge neoprene hood gloves with an average density thickness of 100 mg/cm^2, an exposure of 7 mrem per can should be used for routine exposure accountability purposes for sealing one can of crucible fragments in Tasks III or IV. For purposes of definition, the steps involved in sealing out one can of crucible fragments are:
1. Place lid on can and tape
2. Place can in plastic bag
3. Seal out and number
4. Survey
5. Transfer to storage box.</td></tr>
<tr><td>HW-46688
SRDB 49315</td><td>A New Neutron Dosimeter–Its Calibration and Use in Shield Evaluation (Dec 18). This report describes a neutron dosimeter consisting of a paraffin-moderated enriched BF$_3$ proportional counter that has been developed by the Hanford Physics and Instruments Operation. Calibration has been made for all available neutron energies and approximates the dose response quite well except for intermediate energy neutrons. Modifications for field use are described as well as the program for shield evaluation tests using this instrument. The instrument appears to be satisfactory for neutron dose measurements of all types except for small beams.</td></tr>
<tr><td>HW-46697
SRDB 5156</td><td>Penetration of Gamma Ray Secondaries (Sep 28). Technical report of radiation penetration in media used to examine response of X-ray film response to photons of different energies.</td></tr>
<tr><td>HW-46774
SRDB 34797</td><td>Exposure in Task III, Part III (Nov 20). This report describes radiation exposures received by personnel performing the last part of the pickling operation, Task III. Using standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2, an exposure of 12 mrem per button should be used for routine exposure accountability purposes for completing the pickling operation and transfer to storage, Tasks III.</td></tr>
<tr><td>HW-46775
SRDB 37018</td><td>Exposures in Task IV, Part III (Nov 20). This report provides a summary of radiation exposures received by personnel while removing buttons from cans and preparing the metal for firing, Task IV. Using standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2, the following exposures should be used for routine exposure accountability purposes.
<table>
<tr><td>1.</td><td>Place cans in hood</td><td>9 mrem per operation, regardless of the number of cans</td></tr>
<tr><td>2.</td><td>Open can, remove button from plastic</td><td>10 mrem per button</td></tr>
<tr><td>3.</td><td>Transfer to train, pick up briquettes, transfer and weigh</td><td>7 mrem per weighing, regardless of the number of buttons weighed at one time.</td></tr>
</table></td></tr>
<tr><td>HW-46776
SRDB 34798</td><td>Summary for HW-48000, Dosimetry of Plutonium Fabrication (Nov 20). This report contains only the table shown under HW-48000.</td></tr>
<tr><td>HW-47230
SRDB 34310</td><td>Radiological Protection Operation Report for Month of November 1956 (Dec 11). This report provides site wide radiation monitoring statistics, incident descriptions, etc. Weekly assignment of pencil dosimeters was initiated.</td></tr>
</table>

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-48000 SRDB 34799	The Dosimetry of Plutonium Fabrication–Terminal Report (Nov 27). This report reviews the history of plutonium surface dosage rates from the earliest available information through the present. The method for the determination of the surface dosage rate on plutonium is given, as well as tests to detect significant changes in exposure rates. The tests are based on simple measurements with the CP radiation monitoring instrument. The exposure received for performing a given operation is presented for every operation which involves significant radiation. The following Table presents the recommended values for routine exposure calculations.

Activity	Description	Dose
Task I		
1.	All operations	Based on total time and average background.
Task II		
1.	Complete processing for one boat	35 mrem per boat
Task III		
1.	Charge furnace	No significant exposure
2.	….	16 mrem per button
3.	…, Monitor, inspect, store	12 mrem per button
Task IV		
1.	Charge double stacked furnace	35 mrem per furnace
2.	Unload double stacked furnace	35 mrem per casting
3.	Unload triple stacked furnace	57 mrem per furnace
4.	Remove overflow plutonium (use stopwatch)	20 mrem per minute
5.	Uncan. buttons charging to furnace	
	a. Place cans in hood	9 mrem per operation
	b. Open can, remove button from plastic	10 mrem per button
	c. Transfer to train, …, weigh	7 mrem per weighing
Tasks III and IV		
1.	Seal out…..fragments	7 mrem per can
Task V		
1.	Machining, no leaded gloves	60 mrem per piece
2.	Machining, leaded gloves only	40 mrem per piece
3.	Machining, … no leaded gloves	77 mrem per piece
4.	Sanding (use stop watch)	20 mrem per minute
5.	Cleanup and briquetting	35 mrem per briquette
	a. Cleanup only	16 mrem per operation
	b. Briquetting only	20 mrem per briquette
Task VII		
1.	Charging a coating hood…	5 mrem per piece
2.	Unloading a coating hood, transport to Room 242	4 mrem per piece
3.	All other hood work not involving plutonium metal	No significant exposure
Room 242		
1.	Soot removal, experienced operator	12 mrem per piece
2.	Soot removal, average, inexperienced operator	24 mrem per piece
3.	Polishing, experienced operator	11 mrem per piece
4.	Polishing, experienced operator	14 mrem per piece

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td></td><td>
<table>
<tr><th>Activity</th><th>Description</th><th>Dose</th></tr>
<tr><td>5.</td><td>Polishing, inexperienced operator</td><td>14 mrem per piece</td></tr>
<tr><td>6.</td><td>Lapping</td><td>2 mrem per piece</td></tr>
<tr><td>7.</td><td>Electrolytic testing</td><td>8 mrem per piece</td></tr>
<tr><td>8.</td><td>Final polishing</td><td>8 mrem per piece</td></tr>
<tr><td colspan="3">Room 192, final Inspection (See HW-46443 and HW-46449)</td></tr>
<tr><td>1.</td><td>Preliminary screening</td><td>15 mrem per piece</td></tr>
<tr><td>2.</td><td>Initial and final alpha count..</td><td>0.6 mrem per piece per operation</td></tr>
<tr><td>3.</td><td>Electrolytic testing</td><td>9 mrem per piece</td></tr>
<tr><td>4.</td><td>Gauging</td><td>12 mrem per piece</td></tr>
<tr><td>5.</td><td>Magna gauging</td><td>3 mrem per piece</td></tr>
<tr><td>6.</td><td>Radioaudiography</td><td>5 mrem per piece</td></tr>
<tr><td>7.</td><td>Neutron counting</td><td>0.9 mrem per piece</td></tr>
<tr><td>8.</td><td>Final numbering</td><td>10 mrem per piece</td></tr>
<tr><td>9.</td><td>Final packaging</td><td>0.5 mrem per piece</td></tr>
<tr><td>10.</td><td>Radiography</td><td>0.7 mrem per piece</td></tr>
<tr><td colspan="3">RECUPLEX</td></tr>
<tr><td>1.</td><td>Remove material from storage and charge dissolver (HW-4650 F)</td><td>19 mrem per charge</td></tr>
</table>
</td></tr>
<tr><td>HW-64716 RD
SRDB</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–September 1956 Through June 1957.</td></tr>
<tr><td colspan="2">1957</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>231-Z Building ends it original “isolation” plutonium processing mission (Jan)</td></tr>
<tr><td>HW-47655
SRDB 73750</td><td>RMC Line Flowsheet–Tasks I, II and III (Jan 2). This report provides a flowsheet to be used in scoping Tasks I, II, and III of the new RMC Line. For Tasks I and II, the flow rates and concentrations are the same as specified for the continuous Tasks I and II. For Task III, the flowsheet is essentially the same as the one now in use on the RMA Line and reflects only minor changes in chemical additions and waste losses.</td></tr>
<tr><td>WHC-MR-0521
SRDB 474</td><td>Project GC-691 Continuous Tasks I-II equipment installed in RMA Line achieving a continuous calcination/hydrofluorination process that essentially combined the flow of Tasks I and II.</td></tr>
<tr><td>HW-48045
SRDB 37391</td><td>Monthly Report–January 1957 Radiation Monitoring Operation Hanford Laboratories Operation</td></tr>
<tr><td>HW-48817
SRDB 37393</td><td>Monthly Report–February 1957 Radiation Monitoring Operation Hanford Laboratories Operation</td></tr>
<tr><td>SRDB 15396</td><td>Letter “Exposure Problem 234-5 Building,” (Feb 12). History of using factor of 20% of the open window to increase assigned deep dose from low-energy photon fields characteristic of plutonium. Letter from AR Keene to GE Backman.</td></tr>
<tr><td>HW-49437
SRDB 37394</td><td>Monthly Report–March 1957 Radiation Monitoring Operation Hanford Laboratories Operation</td></tr>
<tr><td>HW-50586
SRDB 37395</td><td>Monthly Report–May 1957 Radiation Monitoring Operation Hanford Laboratories Operation</td></tr>
<tr><td>HW-51753
SRDB 37397</td><td>Monthly Report–July 1957 Radiation Monitoring Operation Hanford Laboratories Operation</td></tr>
<tr><td>HW-52849
SRDB 37398</td><td>Monthly Report–September 1957 Radiation Monitoring Operation Hanford Laboratories Operation</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-48741 SRDB 34604	Radiological Protection Operation Report for Month of February 1957 (Mar 8). This report provides site wide radiation monitoring statistics, incident descriptions, etc. Report describes process of converting film badge data to electronic data processing and the practice of checking master records for any errors. The report also states that a program of placing multiple dosimeters at selected locations on the body was started with a group of Radiation Monitoring Operation staff to evaluate the distribution of exposure over the body.
HW-48751 SRDB 15402	Weekly Processing of Pencil Dosimeters (Apr 15). This report provides results of a study of 450 workers who wore pocket ionization chambers (pencils) on a weekly basis. The study was conducted in the 300 Area. Pencil results are compared with results of daily processed pencils from another group of randomly selected employees. Comparisons with both daily pencil results and corresponding badge films showed that weekly processing of pencil results in a program of near equal reliability with a better dose measurement than does daily processing.
HW-49854 SRDB 34607	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–April 1957 (Apr 30). This report provides site wide radiation monitoring statistics, etc.
HW-50298 SRDB 73751	Design Scope of the RMC Button Line (May 24). The purpose of this document is to detail the design scope of the RMC Button Line. The proposed installation consists of installing Task I, II and III equipment in the RG area of the 234-5 Building. The process equipment is planned to be installed behind an operational barrier constructed of Plexiglas and steel. Equipment is planned to generally be operated remotely from the Zone I area.
HW-50339 SRDB 34368	Radiation Protection Operation Report for Month of May 1957 (Jun 10). This report provides site wide radiation monitoring statistics, incident descriptions, etc.
HW-51189 SRDB 34608	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–June 1957 (Jun 28). This report provides site wide radiation monitoring statistics, etc.
HW-51317 SRDB 26046	Surface Dose From Plutonium (Jul 10). The technical report describes an examination of the surface dose rate from plutonium metal for variations in reactor exposure and provides a technical basis for estimating the dose for any relative isotopic composition.
HW-51783 SRDB 37881	A Scintillation Fast Neutron Exposure Rate Meter (Jan 8). A scintillation fast neutron exposure rate meter has been developed to give a flat response from 1.0 MeV to at least 5.2 MeV fast neutrons with a reading error over this range of ± 10 per cent.
HW-51934 SRDB 15409	Reproducibility of Personnel Monitoring Film Densities (Jul 25). This document reports on an examination of personnel and calibration film processed during the previous 13 years (beginning in 1944). No indications of any immediate problems in film density fading were apparently observed. Variations between the original and reread optical densities were considered reasonable for all calibration levels. Generally fluctuations were 10% or less with occasional differences of 30 to 40%. More variation was noted in readings for personnel film with some errors detected as a result of misreads of the film density originally or in posting results; however, all obvious errors detected occurred prior to 1950.
HW-52325 SRDB 5166	Energy Discrimination in Gamma Dose Evaluation (Nov 18). This report describes a study of dose evaluation for film packets given controlled doses of X- and Gamma-ray exposures from 16.1 to 170 keV, and 1,000 keV, respectively.
HW-53465 SRDB 34610	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–October 1957 (Oct 31). This report provides site wide radiation monitoring statistics, etc.

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-53515
SRDB 61205</td><td>A Study of Zinc Impregnated Rubber Overlay Hood Gloves for Shielding Effectiveness (Nov 7). A study was done which showed an approximate 50% reduction in the surface dose rate using a hood glove with a 10 ml zinc impregnated rubber overlay compared to the standard 30 gauge neoprene hood gloves with an average density thickness of 110 mg/cm^2.</td></tr>
<tr><td>HW-54027
SRDB 34614</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–November 1957 (Nov 27). This report provides site wide radiation monitoring statistics, etc.</td></tr>
<tr><td>HW-54242
SRDB 53752</td><td>Shielding Requirements for the RMC Button Line Process Technology Study Report (Dec 3). Shielding in the RMC Button Line to be constructed has a design requirement of < 1 mrem/hr in the Zone 1 Operating Gallery, and from 8 to 10 mrem/hr in Zone 3. Shielding requirements for the RMC Button Line were evaluated using improved radiation measuring instruments on existing comparable process hoods in 234-5. These measurements showed that neutron exposure is approximately equal to that of gamma exposure. The radiation levels from process hoods under maximum operating conditions which result in some build up of radioactive materials within the hoods will require additional shielding to achieve a radiation exposure level of < 1 mrem/hr in Zone 1. The measured dose data are shown in the following table.
<table>
<tr><th rowspan="2">RMC hood</th><th rowspan="2">Equivalent RMA hood</th><th colspan="3">Doses at hood walls from RMA and 691 hood readings (mrem/hr)</th></tr>
<tr><th>Neutron</th><th>Gamma</th><th>Total</th></tr>
<tr><td>HC 6</td><td>H-5</td><td>1</td><td>5</td><td>6</td></tr>
<tr><td>HC 7</td><td>H-5</td><td>3</td><td>10</td><td>13</td></tr>
<tr><td>HC 9 (top)</td><td rowspan="3">HC-9B</td><td>15</td><td>50</td><td>65</td></tr>
<tr><td>HC 9 (center)</td><td>25</td><td>40</td><td>65</td></tr>
<tr><td>HC 9 (bottom)</td><td>20</td><td>25</td><td>45</td></tr>
<tr><td>HC 10</td><td>H-9W</td><td>50</td><td>10</td><td>60</td></tr>
<tr><td>HC 11</td><td>16 CS</td><td>60</td><td>15</td><td>75</td></tr>
<tr><td>HC 12 S</td><td>H-11</td><td>15</td><td>8</td><td>23</td></tr>
<tr><td>HC 13 MD</td><td>H-13 MD</td><td>20</td><td>8</td><td>28</td></tr>
<tr><td>HC 15 (A, B C)</td><td>H-13</td><td>10</td><td>8</td><td>18</td></tr>
<tr><td>HC 16 CC</td><td>14 CC</td><td>10*</td><td>10</td><td>20</td></tr>
<tr><td>HC 17 DC</td><td>14 DC</td><td>40*</td><td>10</td><td>50</td></tr>
<tr><td>HC 17 P</td><td>14 P</td><td>25*</td><td>10</td><td>35</td></tr>
<tr><td>HC 17 B</td><td>15 B</td><td>10*</td><td>5</td><td>15</td></tr>
<tr><td>HC 18 BS</td><td>16 BS</td><td>25*</td><td>10</td><td>35</td></tr>
<tr><td>HC 42</td><td>H-41</td><td>0</td><td>2</td><td>2</td></tr>
<tr><td>Maint hood</td><td>Rm 170 hood</td><td>0.3</td><td>3</td><td>3.3</td></tr>
<tr><td colspan="5">* Higher than would exist on RMC hoods if movement of powder into these hoods is prohibited.</td></tr>
</table>
</td></tr>
<tr><td>HW-54408
SRDB 34617</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–December 1957 (Dec 31). This report provides site wide radiation monitoring statistics, etc.</td></tr>
<tr><td>HW-55384
SRDB 34801</td><td>Z-Plant Radiation Study Interim Report on Special Process Sampling Program (Mar 20)</td></tr>
<tr><td>HW-55463
SRDB 34802</td><td>Z-Plant Radiation Study Special Sampling Program Interim Report #2 (Mar 27)</td></tr>
<tr><td>HW-56102
SRDB 34803</td><td>Z-Plant Radiation Study Special Sampling Program Interim Report #3 (May 21).</td></tr>
</table>

HW-57358 SRDB 34805	Z-Plant Radiation Study Special Sampling Program Interim Report #4 (Sep 5)

Reference	Description
PNNL-13524 SRDB 12856	RMA Hood 9B placed into operation (Aug)
HW-64718-RD SRDB 64561	Radiological Engineering Management Report, December 13, 1957. Report contains information stating "Effective January 1, 1958, IPD's method for issuing pocket dosimeters (pencils) will change. Pencil meter post boxes will be set up at strategic locations in the 105 buildings and personnel will only be required to wear pencils while in radiation zones. Pencils will continue to be read on a daily basis, thus retaining the purpose they serve of flagging a high daily dose which is not otherwise known. The number of dosimeters issued and processed will be appreciably reduced."
HW-54408 SRDB 34617	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–December 1957 (Dec 31). This report provides site wide radiation monitoring statistics, etc. The removal of contaminated equipment from the main floor of the Plutonium Metallurgy Facility Expansion was completed and installation of new equipment is underway. Year to date statistics provided as follows: **Description** / **Year-to-date** Special Work Permits: 31,191 Routine and special surveys: 26,231 Air samples: 27,933 Skin contamination: 207 Year to date exposure investigations were summarized as follows: **Description** / **Year-to-date** Radiation occurrences: 132 Potential overexposures: 12 Technical overexposures: 2
PNNL-13524 SRDB 12856	Near criticality in RMA Hood 9B (Nov)
1958	
HW-51783 SRDB 37881	A Scintillation Fast Neutron Exposure-Rate Meter (Jan 8)
HW-54844 SRDB 34618	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–January 1958 (Jan 31).
HW-55169 SRDB 34619	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–February 1958 (Feb 28).
HW-55537 SRDB 34620	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–March 1958 (Mar 31).
HW-55907 SRDB 34621	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–April 1958 (Apr 30).

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Reference	Description
HW-54997 SRDB 50842	Preliminary Project Proposal, Reduction of Radiation Exposure, RMA Line 234-5 Building. (May 15). This document contains an analysis of current exposure conditions associated with proposal to improve shielding between Zone I and III process areas along Tasks I through IV hoods. The current combined neutron and gamma exposure levels of 1 to 5 mrem per hour along Tasks I through IV in the RMA Zone 1 (lowest level radiation area) operating aisle makes it possible for personnel to exceed the exposure limit of 5 rem per year without leaving the Zone I area, so corrective action is necessary. At that time, essentially all the neutron radiation is due to alpha-neutron reaction of the plutonium compound contained in the Task II and III operation. A second source of neutrons is from spontaneous fission of the several isotopes of plutonium which will become a more troublesome neutron contributor with the highly exposed power reactor fuels. Higher fuel exposures will also increase the quantity of gamma contributors in the plutonium product. Radiation exposures will increase with higher plutonium throughput as a result of increases in reactor power level.
HW-56205 SRDB 34622	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–May 1958 (May 29).
HW-56550 SRDB 34623	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–June 1958 (Jun 30). This report describes routine radiation monitoring statistics and includes results of a neutron survey of 231.
HW-56211 SRDB 52241	Hood 9B Nitrate Feed Tank Monitoring Studies (Jun 2). This document describes gamma measurements of unusual feed material with abnormally high fission product zirconium and ruthenium contamination.
HW-58054 SRDB 37401	Monthly Report–October 1958 Radiation Monitoring Operation Hanford Laboratories Operation
PNNL-13524 SRDB 12856	RMA Hood 9A placed into operation (Jul)
HW-57293 SRDB 49324	Double Moderator Neutron Dosimeter (Jul 15). This document describes the J. DePangher developed dosimetry method that became widely used. A history of previous neutron dosimetry methods is provided. The Double Moderator Neutron Dosimeter uses a moderated BF3 detector and used for measuring fast neutron dose, flux and average energy. The instrument consists of a “fluxmeter” and a “dosimeter” was calibrated with monoenergetic neutrons from accelerator and nuclide sources. The ratio of the fluxmeter and dosimeter responses provides a measure of the average energy of the neutron spectrum. The system was being used in Hanford workplaces.
HW-56378 SRDB 37885	Slow and Fast Neutron Scintillation Count-Rate and Dose-Rate Meter (Aug 1)
HW-57283 SRDB 69972	Technical report entitled “Revised Fission Product Specification for Z-Plant Feed from Purex,” (August 29, 1958) describing a revised fission product specification for plutonium nitrate feed received at Z-Plant from PUREX to limit the amount of fission product gamma (due mainly to ^{95}Zr and $^{103\text{-}106}$Ru) exposure to PFP workers.
HW-57716 SRDB 33188	Shielding Basis for high exposure Pu Button Line–Part I Gamma (Oct 20)
HW-58093 SRDB 32560	Shielding Basis for high exposure Pu Button Line–Part II Neutron (Nov 10)
DOE/RL-97-1047 SRDB 27666	Additional shielding installed around RMA Line to reduce personnel exposures
DOE/RL-97-1047 SRDB 27666	Design of Plutonium Reclamation Facility 232-Z Incinerator construction begun
HW-64714 SRDB 36861	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–October 1958 to June 1959 (Oct 31). This is a collection of several monthly reports from Oct 1958 through June 1959.

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td colspan="2">1959</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>PFP RMC Line construction completed (Jul)</td></tr>
<tr><td>HW-56827
SRDB 26047</td><td>Technical document entitled “A Personnel Film Badge Neutron Dosimeter,” issued that describes features of the Hanford personnel neutron dosimeter (May 15, 1959). This dosimeter has thermal neutron capability using Sn and Cd filters and also a fast neutron dose capability using NTA film.</td></tr>
<tr><td>HW-60620
SRDB 73753</td><td>Technical document entitled “Gamma Energy Analysis of the RMA Line and RECUPLEX,” dated June 15, 1959. Measurement results were consistent with theoretical expectations. Gamma energies were measured at 7 levels ranging from 17 (Pu) keV to 750 (Zr) keV. Energy levels of 17, 60, 100, 200 and 380 keV associated with Pu were prevalent at all RMA measurement locations.</td></tr>
<tr><td>HW-60699
SRDB 58403</td><td>Technical document entitled “Estimate of Gamma Dose Rates from 1000 MWD/T and 2000 MWD/T Plutonium,” dated June 22, 1959.</td></tr>
<tr><td>HW-60905
SRDB 60597</td><td>Technical report dated June 30, 1959 concerning accuracy of extremity dose from plutonium. Report notes that the dose is being under-estimated and suggest use of a correction factor of 5.8.</td></tr>
<tr><td>DDTS-GENERATED-933
SRDB 36552</td><td>Monthly Report–June 1959 Radiological Engineering Unit</td></tr>
<tr><td>HW-60225
SRDB 37403</td><td>Monthly Report–April 1959 Radiation Monitoring Operation Hanford Laboratories Operation</td></tr>
<tr><td>SRDB 31747</td><td>Measured NP dose ratios included in attachment to October 19, 1962 letter from P. E. Bramson to C. M. Unruh regarding NP ratios for identified specific 234-5 locations included in May 13, 1959 letter from V. P. Madsen to L. M. Knights.</td></tr>
<tr><td>HW-61041
SRDB 51252</td><td>Neutron Emission Rate Measurements on the Plutonium Compounds Common to 234-5 Building (Jul 13). Document presents measured neutron emission rate from plutonium compounds of nitrate, oxalate, and oxide, and metal present at 234-5.</td></tr>
<tr><td>HW-64713 RD
SRDB 64502</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–July 1959 Through June 1960 (Jul 1959).</td></tr>
<tr><td>HW-61140
SRDB 51173</td><td>Review of Radiation Shielding Requirements and Exposure to Operators, RMC Button Line, Project COC-734 (Jul 15). This report provides an overall analysis of potential PFP worker exposure for handling the higher irradiated reactor fuel. There is an analysis of measured gamma doses and also the application of NP dose ratios hood by hood.
Total Zone IIII Gamma Exposure (r/yr)
<table>
<tr><th rowspan="2">Hood</th><th colspan="3">650 MWD/T</th><th colspan="3">2000 MWD/T</th></tr>
<tr><th>None</th><th>¼” X-ray</th><th>1” HD</th><th>None</th><th>¼” X-ray</th><th>1” HD</th></tr>
<tr><td>HC-6</td><td>14</td><td>6.3</td><td>2.2</td><td>18.4</td><td>7.0</td><td>2.4</td></tr>
<tr><td>HC-7</td><td>4</td><td>0.8</td><td>0.2</td><td>7.0</td><td>1.4</td><td>0.3</td></tr>
<tr><td>HC-9B</td><td>32</td><td>3.6</td><td>0.7</td><td>46.2</td><td>6.1</td><td>1.1</td></tr>
<tr><td>HC-12S/16CC</td><td>1</td><td>0.1</td><td>—</td><td>1.8</td><td>0.2</td><td>—</td></tr>
<tr><td>HC-17DC</td><td>6.5</td><td>0.5</td><td>0.1</td><td>11.2</td><td>1.1</td><td>0.1</td></tr>
<tr><td>HC-17P/18RS</td><td>2.5</td><td>0.5</td><td>0.1</td><td>3.7</td><td>0.9</td><td>0.2</td></tr>
<tr><td>Total</td><td>60.0</td><td>11.9</td><td>3.3</td><td>88.3</td><td>16.7</td><td>4.1</td></tr>
</table>
</td></tr>
<tr><td>HW-61358
SRDB 51253</td><td>Estimated Effects of Variations in Plutonium Isotopic Concentrations on HAPO Personnel Exposures as Measured by Film Badges. (Sep 24). This document provides several formulas to calculate surface and penetrating dose from plutonium isotopes. The document uses this information to forecast future doses to workers from blends of higher exposed plutonium fuel in reference to 1958 film measured doses.</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-61755, Part I
SRDB 34845</td><td>Z-Plant Radiation Study Interim Report #5–
Part I Possibilities for Reducing NPR Gamma Dose Rate, Pt 1 (Oct 22). This document contains substantial information concerning neutron and photon dose rates. The report states “plutonium fluoride which has a high neutron flux from alpha-neutron reaction was found to be by far the most difficult process material in Z-Plant to shield for gamma radiation. Measurements of dose rates with routine survey instruments showed twice as much lead to be required to reduce gamma radiation from fluorides than was required for any other plutonium compounds including the metal. An explanation of this behavior is presented in Figure IF. It shows that with fluorides gamma reduction is governed by attenuation of 1.27 MeV and the 2.1 MeV components of the fluoride gamma energy spectrum. These two high gamma energies were observed in all fluoride, but in no other samples.” The 1.27 MeV gamma is produced by Na-22 when it decays to Neon-22. The Na-22 is formed from the fluorine atom when it absorbs an alpha particle and produces a neutron. The 2.1 MeV gamma is attributable to neutron captures by hydrogen to form deuterium.</td></tr>
<tr><td>HW-61755 Part II
SRDB 34846</td><td>Z-Plant Radiation Study Interim Report #5–
Part II, Data on Gamma Shielding of Special Plutonium Samples (Oct 22)</td></tr>
<tr><td>HW-62589
SRDB 34669</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–October 1959 (Oct 30).</td></tr>
<tr><td>HW-62873
SRDB 34670</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–November 1959 (Nov 30).</td></tr>
<tr><td>HW-63308
SRDB 34671</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–December 1959 (Dec 31). Year to date statistics were provided as follows:
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Special Work Permits</td><td>23,995</td></tr>
<tr><td>Routine and special surveys</td><td>20,546</td></tr>
<tr><td>Air samples</td><td>30,069</td></tr>
<tr><td>Skin contamination</td><td>106</td></tr>
</table>
Year to date 1959 exposure investigations were summarized as follows:
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Radiation occurrences</td><td>23</td></tr>
<tr><td>Potential overexposures</td><td>15</td></tr>
<tr><td>Technical overexposures</td><td>4</td></tr>
</table>
</td></tr>
<tr><td colspan="2">1960</td></tr>
<tr><td>HW-63710
SRDB 34672</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–January 1960 (Jan 29).</td></tr>
<tr><td>SRDB 26050</td><td>Letter report dated June 10, 1960 to file containing results of Intersite Personnel Dosimeter Intercomparison Study for workplace plutonium radiation fields (photon only) among Hanford, SRS, LANL and RFP.</td></tr>
<tr><td>HW-64086
SRDB 34673</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–February 1960 (Feb 29).</td></tr>
<tr><td>HW-64156
SRDB 74648</td><td>Design Study Interim Report: RMA Button Line Radiation Reduction (Apr 1)
The purpose of this design study was to develop new design concepts for handling and processing high exposure plutonium from the nitrate through the button stage and to prepare design criteria to form the basis for design and construction of a new facility. A detailed discussion and description of each process function is provided in Appendix I of the report.</td></tr>
</table>

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-65047 SRDB 73755	Technical report entitled “Interim Product Specification for Z Plant Feed from Purex,” May 9, 1960) regarding Z Plant radiation control consideration for radiation levels near the button processing equipment.
HW-66675 SRDB 34848	Technical report entitled “Predicted Z Plant Radiation Exposure Levels vs. Plutonium Isotopic Concentration of Products,” regarding relationship between WB exposure levels encountered in Z Plant versus the plutonium isotopic concentration of the product.
HW-25457, Rev 2 SRDB 27679	Manual of Radiation Protection Standards, Hanford Atomic Products Operation, General Electric Company, March 1, 1960. This manual contains updates to some previously issued procedures (see revision log at bottom of procedures) and also some new procedures. Appears to be major revision of HW-25457 issued December 15, 1954. Occupational External Exposure Standard Occupational exposure as a result of ionizing radiation from a source external to the body shall not exceed: 1. 5 rems multiplied by the number of years between the person’s age and age 18, including not more than 3 rems in any 13 consecutive weeks, to the whole body, head and trunk, blood-forming organs, eyes or gonads due to radiation of sufficient penetrating power to affect a significant fraction of the critical organ; 2. 10 rems multiplied by the number of years between the person’s age and age 18, including not more than 8 rems in any 13 consecutive weeks, to the skin of a major portion of the body, due to radiation of very low penetrating power (half value less than 1 mm of soft tissue); 3. 75 rems per year, including not more than 25 rem in any 13 consecutive weeks, to the hands, forearms, feet and ankles. Hanford Operational External Exposure Control The control of external exposure is primarily achieved at HAPO through the personnel meter program. Therefore, the following exposure limitations are to be applied by facility management to assure that HAPO Radiation Protection Standards are met: 1. The “whole-body dose”, evaluated through the personnel meter program shall not be permitted to exceed 1 rem in any regular four-week badge period, or 5 rems including 3 r in any calendar year. 2. The “skin dose”, evaluated through the personnel meter program shall not be permitted to exceed 2 rems in any regular four-week badge period, or 10 rems in any calendar year. 3. The “extremity dose”, evaluated through the personnel meter program shall not be permitted to exceed 8 rems in any regular four-week badge period, or 40 rems in any calendar year. Application of the four-week badge period shall be such that the Occupational External Exposure Standard limits above are not exceeded.
HW-64591 SRDB 34674	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–March 1960 (Mar 31).
HW-64979 SRDB 34675	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–April 1960 (Apr 29).
HW-65153 SRDB 34847	Scope Basis–Shielding–Plutonium Reclamation Facility Project CAC-880 (May 9).
HW-65441 SRDB 34676	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–May 1960 (May 31).

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>SRDB 26050</td><td>Wilson letter report dated June 10, 1960 regarding Inter-Site comparison to plutonium irradiations conducted at Hanford. Hanford, Savannah River, Rocky Flats and Los Alamos participated in the study. Each site evaluated their dosimeters which were simultaneously exposed at Hanford.</td></tr>
<tr><td>HW-65946
SRDB 34677</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–June 1960 (Jun 30).</td></tr>
<tr><td>HW-66675
SRDB 34848</td><td>Predicted Z Plant Radiation Exposure Levels versus plutonium isotopic concentration of Products (Aug 19)</td></tr>
<tr><td>HW-66280
SRDB 34678</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–December 1960 (Dec 30).</td></tr>
<tr><td>HW-66861
SRDB 34849</td><td>Gamma Shielding Calculations for Slag and Crucible Fragment Handling–Plutonium Reclamation Facility Project CAC-880 (Sep 27)</td></tr>
<tr><td>HW-71702
SRDB 37787</td><td>Technical report entitled “Gamma Calibration and Evaluation Techniques for Hanford Beta-Gamma Film Badge Dosimeters.” (Sep 1960). This report describes many of the operational techniques and experience in using the Hanford multielement beta/gamma dosimeter implemented during 1957. The document was apparently prepared as part of a Film Dosimeter Information Exchange held at Hanford during September 20-22, 1960 with representatives from Argonne, Oak Ridge, Los Alamos, Savannah River, Rocky Flats, Idaho Falls, University of California at Berkeley, Hanford AEC and Hanford Atomic Products Operations.</td></tr>
<tr><td>HW-66979
SRDB 34680</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–September 1960 (Sep 30).</td></tr>
<tr><td></td><td>RMC Line hot operations begun (Oct)</td></tr>
<tr><td>HW-67248
SRDB 34681</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–October 1960 (Oct 31).</td></tr>
<tr><td>HW-67642
SRDB 34682</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–November 1960 (Nov 30).</td></tr>
<tr><td>HW-SA-1933
SRDB 24381</td><td>Analysis of the Distribution of Externally Received Radiation at Hanford, 1944-59</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>PRTR begins (Nov. 21) operation in 300 Area.</td></tr>
<tr><td>HW-67982
SRDB 34683</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–December 1960 (Dec 30). Year to date statistics provided as follows:
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Special Work Permits</td><td>27,377</td></tr>
<tr><td>Routine and special surveys</td><td>19,566</td></tr>
<tr><td>Air samples</td><td>35,095</td></tr>
<tr><td>Skin contamination</td><td>112</td></tr>
</table>
Year to date exposure investigations were summarized as follows:
<table>
<tr><th>Description</th><th>Year-to-date</th></tr>
<tr><td>Type A occurrences</td><td>0</td></tr>
<tr><td>Type B occurrences</td><td>0</td></tr>
<tr><td>Type C occurrences</td><td>33</td></tr>
</table>
</td></tr>
<tr><td colspan="2">1961</td></tr>
<tr><td>HW-68352
SRDB 34684</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–January 1961 (Jan 31).</td></tr>
<tr><td>HW-68706
SRDB 34685</td><td>Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–February 1961 (Feb 28).</td></tr>
</table>

Reference	Description
HW-69039 SRDB 34686	Radiation Monitoring Operation, Hanford Laboratories Operation, Monthly Report–March 1961 (Mar 31).
HW-SA-2140 SRDB 32561	Reproducible Precision Polyethylene Long Counter For Measuring Fast Neutron Flux (Apr 3)
HW-69817 SRDB 37406	Monthly Report–May 1961 Radiation Monitoring Operation Hanford Laboratories Operation
HW-69650 SRDB 60071	Technical report entitled “Impurity Levels in Plutonium Nitrate to Yield Acceptable Metal By Direct Calcination, Hydrofluorination, and Bomb Reduction,” regarding average fission product specification for zirconium and ruthenium to preclude excessive button radiation.
HW-SA-2182 SRDB 52831	Document entitled “Radiological Development Within the Hanford Laboratories Radiation Protection Program,” presented at the annual Health Physics Society Meeting during July 13-16, 1961. Paper describes general characteristics of Hanford dosimetry capabilities as follows: “An assessment of personnel dosimeter capabilities indicates that Hanford’s personnel dosimeter utilizing a 1 mm sterling silver shield as the primary shield for interpretation of gamma dose performs well for gamma energies between 0.200 and 2 MeV. A given dose between 0.1 and 1 R at any energy or from a mixture of energies in this range can be interpreted routinely within ±10% at better than the 95% confidence interval. For similar exposure for gamma energies between 0.050 and 0.200 MeV, the interpretation is not as satisfactory. Our recent studies have shown that a tantalum shield or a tungsten shield of the appropriate thickness and when encased in plastic can give a nearly linear film density response for a given gamma dose in the energy range from 0.050 and 2 MeV. The actual deviation from a linear density response is about ±10%. For low energy about 17 to 50-keV X-ray or gamma ray doses in the range from 0.1 to 1 R, our present dose interpretation capabilities, on a routine bases, might be limited to about ±50%, and the presence of a few tenths of a rad of beta radiation further limits the accuracy of the low energy dose interpretation. The use of an iron filter and two plastic filters of appropriate thicknesses has resulted in more accurate interpretation of these low energy gamma doses and has extended the dose evaluation capabilities to low energy gamma doses in the presence of beta radiation.
HW-71353 SRDB 49327	An Automated Reader for Personnel Dosimeter Films (Nov 8). This document describes the development of the Hanford automated film reader system.

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td colspan="2">1962</td></tr>
<tr><td>HW-68023
SRDB 36923</td><td>Development of Gamma and Neutron Radiation Data for Three Alternate Design Concepts for the Plutonium Reclamation Facility (PRF), Project CAC-880 (Jan 4).

The focus of this document was to evaluate three options for design of the Plutonium Reclamation Facility. The RECUPLEX facility was considered to be the most representative of conditions anticipated in the recovery of plutonium. Photon spectra were analyzed and showed substantial photon contribution from plutonium fission product contaminants that contributed substantial photon exposure compared to plutonium photon radiation particularly for higher exposed fuel. Measurements at the 234-5 RECUPLEX Facility are summarized in Table F of the report and were used as a basis in the analysis of PRF Design Options. A selection of measurements from Table F are shown below.
<table>
<tr><th rowspan="3">Distance from hood (ft)</th><th colspan="6">Dose rate (mr/hr)[a]</th></tr>
<tr><th colspan="2">R B hood</th><th colspan="2">S E hood</th><th colspan="2">S C hood</th></tr>
<tr><th>Gamma</th><th>Neutron</th><th>Gamma[b]</th><th>Neutron</th><th>Gamma</th><th>Neutron</th></tr>
<tr><td>At hood</td><td>37</td><td>0.9</td><td>90</td><td>0.3</td><td>31</td><td>3.3</td></tr>
<tr><td>1</td><td>27</td><td></td><td>30</td><td>0.2</td><td>12</td><td>2.0</td></tr>
<tr><td>2</td><td>21</td><td></td><td>19</td><td></td><td>6</td><td></td></tr>
<tr><td>3</td><td>17</td><td></td><td></td><td>0.2</td><td>4</td><td>1.2</td></tr>
<tr><td>4</td><td>14</td><td></td><td>14</td><td></td><td>3</td><td></td></tr>
<tr><td>5</td><td>11</td><td></td><td></td><td></td><td>2</td><td></td></tr>
<tr><td>6</td><td>9</td><td></td><td></td><td></td><td>2</td><td></td></tr>
<tr><td>7</td><td>7</td><td></td><td></td><td></td><td>2</td><td></td></tr>
<tr><td>8</td><td>6</td><td></td><td></td><td></td><td>2</td><td></td></tr>
</table>
a. Measurements 3-24-60.
b. Measurements 3-2-60.</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>232-Z Incinerator begins operations (Jan 5)</td></tr>
<tr><td>HW-75546
SRDB 29140</td><td>Dosimetry Investigation of the RECUPLEX Criticality Incident.</td></tr>
<tr><td>HW-71764
SRDB 37788</td><td>Technical report entitled “A Personnel Dosimeter Filter System for Measuring Beta and Gamma Doses in Mixed Radiation Fields,” (March 1962). This report describes details of dose interpretation using the 1962 Hanford beta/photon film dosimeter system. Based on studies of mixed field beta radiation exposures from uranium and low-energy photon exposures from plutonium metal, and also k-fluorescent irradiations, interpreted doses were within ±10% of the given doses.</td></tr>
<tr><td>HW-70032
SRDB 52282</td><td>Evaluation of Fixed Radiation Monitoring Instrumentation for use in IPD (Jun 27). Evaluation of instruments used as fixed detectors in Hanford reactors.</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
HW-72315 SRDB 74143	Document entitled, "NPR Shield Review," (Jan 16). This document describes the shielding features of the N Reactor under construction according to five protective zones as follows: Zone 1 which is adjacent to the charge face, the discharge face, and the top of the reactor. No access is possible to this zone during operation. Monitored access is possible during reactor shutdown. This zone is operated at a negative pressure relative to Zone 2. Zone 2 which includes secondary radiation areas such as the inner and outer rod rooms, the gas system, the flux and rupture monitor room, the ball system, and the ventilation exhaust system from Zone 1. Normally, no access to the restricted areas of zones 2 will be required during operation but limited emergency access is possible. Zone 2 is operated at a negative pressure relative to Zone 3. Zone 3 is a normal access or buffer zone which will have free access at all times except perhaps for quite abnormal conditions. This zone includes most of the work regions and corridors around the reactor in which metal handling and other routine operations will be conducted. Zone 4 is an unlimited access area with essentially no radiation during normal operations. Zone 5 is defined as a warranted access area in which continuous access is maintained at all time including emergencies. Zone 5 is limited to the main control room and the main instrument room beneath the main control room.
HW-73212 SRDB 37425	Monthly Report–March 1962 Radiation Monitoring Operation Hanford Laboratories Operation
SRDB 31745	Letter from LM Knights to JJ Courtney entitled "Personnel Exposure to Neutrons–Button Line," dated April 6, 1962. This letter describes use of a neutron to photon dose ratio of 1:1 (i.e., NP ratio of 2) to control worker dose because of the time lapse involved in receiving neutron dose for the processed dosimeters.
HW-74811 SRDB 37426	Monthly Report–August 1962 Radiation Monitoring Operation Hanford Laboratories Operation
HW-75697 SRDB 37427	Monthly Report–November 1962 Radiation Monitoring Operation Hanford Laboratories Operation
HW-76050, HAN-84031 SRDB 446	N Reactor Department Monthly Report December 1962
HW-76944 SRDB 5230	Technical Report entitled, "The New Hanford Film Badge Dosimeter" (Mar 1, 1963). This report describes the technical features of the improved beta gamma dosimeter implemented at Hanford on August 10, 1962. This dosimeter provides for the evaluation of radiation dose from beta, gamma and X-ray radiations present independently or concurrently. Activation foils provide neutron dosimetry in the event of a criticality or similar radiation event. Two small silver phosphate glass rod dosimeters (fluoride) are included to provide measurement of high gamma dose. Indium foil is provided for prompt sorting of directly-involved personnel following a criticality event.
HW-81037 SRDB 54563	Weapon Manufacturing Operation, Radiation Control Report, 1962 and 1963
1963	
HW-SA-2904 SRDB 51219	Hanford Plutonium Fuel Development Laboratory (Feb 13). This document describes the worker exposure experience of the 308 Plutonium Fabrication Pilot Plant (PFPP) after 4 years of operation. The document provides an analysis of hazards associated with the plutonium isotopes handled at Hanford.

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-77295
SRDB 52814</td><td>Radiation Protection Aspects of the RECUPLEX Incident of April 7, 1962 (May)</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>RMC Line Fire in Room 227 Glovebox (Nov)</td></tr>
<tr><td>HW-81037
SRDB 54563</td><td>Weapon Manufacturing Operation, Radiation Control Report, 1962 and 1963
<table>
<tr><th rowspan="2">Date</th><th colspan="6">Instrument measurements</th></tr>
<tr><th>Hoods 7C-9B gamma (mR/hr)</th><th>Hoods 7C-9B neutron (mrem/hr)</th><th>Hoods 7C-9B, inst. NP ratio</th><th>Button line gamma, (mR/hr)</th><th>Button line neutron (mrem/hr)</th><th>Button, instr. NP ratio</th></tr>
<tr><td>Jan-63</td><td>3.6</td><td>24.5</td><td>6.8</td><td>1.5</td><td>4.8</td><td>3.2</td></tr>
<tr><td>Feb-63</td><td>4.6</td><td>18.6</td><td>4.0</td><td>1.9</td><td>3.6</td><td>1.9</td></tr>
<tr><td>Mar-63</td><td>5.1</td><td>21.6</td><td>4.2</td><td>1.0</td><td>4.2</td><td>4.2</td></tr>
<tr><td>Apr-63</td><td>4.8</td><td>21.6</td><td>4.5</td><td>1.5</td><td>4.2</td><td>2.8</td></tr>
<tr><td>May-63</td><td>4.6</td><td>NA</td><td></td><td>1.8</td><td>5.1</td><td>2.8</td></tr>
<tr><td>Jun-63</td><td>4.1</td><td>NA</td><td></td><td>2.0</td><td>4.2</td><td>2.1</td></tr>
<tr><td>Jul-63</td><td>5.7</td><td>NA</td><td></td><td>1.6</td><td>6.3</td><td>3.9</td></tr>
<tr><td>Aug-63</td><td>5.6</td><td>NA</td><td></td><td>1.9</td><td>3.0</td><td>1.6</td></tr>
<tr><td>Sep-63</td><td>5.0</td><td>NA</td><td></td><td>1.5</td><td>4.0</td><td>2.7</td></tr>
<tr><td>Oct-63</td><td>2.4</td><td>NA</td><td></td><td>1.1</td><td>2.7</td><td>2.5</td></tr>
<tr><td>Nov-63</td><td>5.2</td><td>NA</td><td></td><td>2.4</td><td>3.6</td><td>1.5</td></tr>
<tr><td>Dec-63</td><td>6.0</td><td>NA</td><td></td><td>1.3</td><td>4.7</td><td>3.6</td></tr>
</table></td></tr>
<tr><td>HW-77071
SRDB 52813</td><td>Preliminary Engineering Report, Replacement and Improvement of Fixed Radiation Monitoring Instrumentation. Discussion of project to upgrade fixed instrumentation in Hanford reactor facilities.</td></tr>
<tr><td>HW-77077
SRDB 73757</td><td>Document entitled, “Acceptance and Startup Testing of N Reactor Plant.. (Mar 26)). This document generally describes the anticipated testing of the N Reactor regarding physics, operation and power ascension.</td></tr>
<tr><td>HW-77093
SRDB 51210</td><td>A Method of Measuring Integrated Thermal Neutron Exposure (Mar 22). Document describes a method to measure the integrated thermal neutron exposure in a reactor core.</td></tr>
<tr><td>SRDB 4829</td><td>Hanford External Dosimetry Operations, Operating Procedures (1963). Document contains routine external dosimeter procedures to prepare, issue, process and calibrate Hanford dosimeters. Procedures 2.6 and 2.7 describe thermal and fast neutron interpretation, respectively. For example, the Hanford Neutron Film Badge Dosimeter contains two shield areas. These consist of an opposed pair of cadmium shields 0.040” thick and an opposed pair of tin shields of the same thickness. These shields have very nearly equal absorption of gamma rays over a wide energy range. However, the tin shield is essentially transparent to thermal neutrons, while the cadmium shield has a very high thermal neutron cross-section. …The difference in optical density, between these two filtered regions of the film, is directly related to the thermal neutron exposure.</td></tr>
<tr><td>HW-77335
SRDB 52815</td><td>Technical Criteria for Reactor Radiological Monitoring Systems (Apr 22). Document provides technical basis for the design of the production reactor radiological monitoring systems.</td></tr>
</table>

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-77917 PT1
SRDB 73758</td><td>Document entitled, “Startup Test N-1–Procedures, N Reactor Startup Physics Test Program, Cold Physics Tests (Nov 22).” This document describes on page 74 an evaluation of radiological hazards at several locations known to have some potential. Testing is done under conditions to maximize readings. All possible beams must be surveyed and the areas properly marked to prevent unnecessary exposure in the vicinity of the beams. Recoil reflects must be surveyed at the confinement walls.</td></tr>
<tr><td>HW-77937
SRDB 73759</td><td>RMC Button Line Radiation (Jun 7)

In 1960, the RMC Button Line was equipped with a 1) water wall shield between the front and rear side and 2) a one-inch high density (HD) glass shielded gloveboxes. Several studies were done to compare worker dose rates particularly with consideration of processing higher exposed fuel. This document presents the average personnel exposure for the button line from 1959 to 1962. The data clearly shows reduction in the photon exposure from the one-inch HD shielded gloveboxes. Measured average doses for 33 operators in 1962 are: 1,422 mR/yr photon and 1,657 mrem/yr neutron with a ratio of 1.16. For 1961, the corresponding doses are: 1,200 mR/yr photon and 1,243 mrem/yr neutron with a ratio of 1.03. These measured values are for fuel exposures of 500 MWD/ton. The paper presents analyses of extrapolated exposures for handling plutonium from 2,000 MWD/ton exposed fuel.</td></tr>
<tr><td>AECM 0524
SRDB 13037</td><td>AEC Manual 0524, “Standards for Radiation Protection,“ issued with several requirements for radiation monitoring and records. Dose limits specified for external radiation follow:

Radiation Protection Standards for External Exposure
<table>
<tr><th>Type of exposure</th><th>Condition</th><th>Dose (rem) or dose commitment (rem)</th></tr>
<tr><td>(Prospective annual limit) Whole body, head and trunk, gonads, lens of the eye, red bone marrow, blood forming organs</td><td>Year
Calendar quarter</td><td>5
3</td></tr>
<tr><td>(Retrospective annual limit) Type of exposure same as above</td><td>Accumulated dose</td><td>5 (N-18)</td></tr>
<tr><td>Unlimited areas of skin (except hands and forearms). Other organs, tissues and organ systems</td><td>Year
Calendar quarter</td><td>15
5</td></tr>
<tr><td>Forearms</td><td>Year
Calendar quarter</td><td>30
10</td></tr>
<tr><td>Hands</td><td>Year
Calendar quarter</td><td>75
25</td></tr>
</table>
</td></tr>
<tr><td>WHC-SP-0297
SRDB 64586</td><td>N Reactor begins initial fuel loading on December 16 and achieves initial criticality on December 31, 1963.</td></tr>
</table>

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
1964	
HW-78500 SRDB 38343	N Reactor Radiation Protection and Procedures (January 1). This document states the Hanford exposure standards dose limits and the operational controls as follows: **HAPO Exposure Standards** Occupational exposure as a result of ionizing radiation from a source external to the human body shall not exceed: 1. 5 rem multiplied by the number of years between the person’s age and age 18, including not more than 3 rem in any 13 consecutive weeks to the whole body, head and trunk, active blood-forming organs, lens of the eyes, or gonads, due to radiation of sufficient penetrating power to affect a significant fraction of the critical tissue; 2. 10 rem multiplied by the number of years between the person’s age and age 18, including not more than 6 rem in any 13 consecutive weeks to the skin of the major portion of the body, due to radiation of very low penetrating power (half-value less than 1 mm of soft tissue); 3. 75 rem/year, including not more than 25 rem in any 13 consecutive weeks to the hands, forearms, feet or ankles. **Operational Controls** The following exposure limitations will normally be applied throughout NRD to assure that JAPO Radiation Protection Standards are met: 1. The WB penetrating dose should not be permitted to exceed 1 rem in any regular four-week badge period, or 5 rem including 3 r in any calendar year. 2. The WB skin dose should not be permitted to exceed 2 rem in any regular four week badge period, or 10 rem in any calendar year. 3. The extremity dose should not be permitted to exceed 8 rem in any regular four week badge period, or 40 rem in any calendar year. 4. Application of the four-week badge period shall be such that the basic HAPO exposure standards above are not exceeded. If planned work will cause personnel to exceed an exposure check point(s), the responsible supervisor shall, before work begins: 1. Complete all sections of the appropriate “Personnel Exposure Request” form. These forms are required for: • Exposure over 300 mrem, but less than 500 mrem in 7 days (A-5000-832). • Exposure over 500 mrem in 7 days (A-5000-830). • Exposure over 3 rems per year (A-5000-830). 2. Submit the completed form to Radiation Monitoring for review (if required on the form). Acquire from Environmental Engineering, the current radiation exposure status for each individual listed on the form.
ORAUT-TKBS-0006-2	234-5Z RMA Line shutdown in 1964. Glovebox reactivated in 1967. Tasks I-III were cleaned out and reactivated in 1968. Line placed on standby in 1984.
DOE/RL-97-1047 SRDB 27666	Pu Reclamation Facility (PRF, 236-Z) hot processing begun (May)

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>HW-83246
SRDB 60049</td><td>Technical report entitled “<i>Button Line Process Over-All Impurity Decontamination</i> (July 29, 1964)” use of spectrographic analyses of each hood 6 plutonium nitrate feed batch to develop a new specification for button line feed solutions.</td></tr>
<tr><td>HW-79746
SRDB 73762</td><td>Document entitled, “N Reactor Start-Up Test N-2, Low Power Testing Program,” (Jan 20). This document describes on page 72, radiation survey requirements as stated “The Low Power Testing Program includes the first increases in reactor power level above 1 MW. To monitor the shielding adequacy and detect any unforeseen radiation beams, a complete building radiation survey is included in each test step calling for special data. These steps are as follows:
<table>
<tr><th>Step</th><th>Power level (MW)</th></tr>
<tr><td>4</td><td>0</td></tr>
<tr><td>11</td><td>100</td></tr>
<tr><td>13</td><td>200</td></tr>
<tr><td>17</td><td>300</td></tr>
<tr><td>19</td><td>400</td></tr>
</table>
</td></tr>
<tr><td>HW-82366
SRDB 57442</td><td>Document entitled “Measurement of the Radiation Intensity Streaming Through The NPR Steam Vent Shield Penetration and an Analysis of the Proposed Steam Vent Shielding,.” (May 24). This document describes significant dose rates of gamma and neutron radiation emerging below the steam vent penetrations. The N Reactor steam vent penetrations are located in the bottom shield of the reactor and open to the southeast and southwest corners of the ball hopper retrieval system. On April 29, Hanford Laboratories personnel were called in to instrument these penetrations to determine the gamma and neutron radiation intensities. Shielding design changes were evaluated to achieve the following:
<table>
<tr><th>Radiation</th><th>Transmitted dose (R/hr)</th></tr>
<tr><td>Gamma rays</td><td>9.5</td></tr>
<tr><td>Fast neutrons</td><td>0.2</td></tr>
<tr><td>Resonance neutrons</td><td>0.5</td></tr>
<tr><td>Thermal neutrons</td><td>1.4</td></tr>
</table>
</td></tr>
<tr><td>HW-82272
SRDB 73762</td><td>Document entitled, “Startup Test N-2 Low Power Testing Program, Preliminary Summary Report,” (May 26). This document describes status of neutron leakage found (see HW-82366) to have a higher than expected neutron level during reactor operation. The cause on investigation was neutron streaming down the steam vent piping provided at two locations to permit venting of steam from a process tube rupture. Corrective action was required for purposes of radiation protection and to reduce the possibility of neutron activation of system components in the ball recovery room. The action consisted of adding a pipe offset to achieve a labyrinth design and to provide additional shielding.</td></tr>
<tr><td>HW-82452
SRDB 36920</td><td>Critical Mass Control Specification–Recycling of Non-standard Powders–Hoods 9-A and HC-9B (Jun 1). This report identifies critical mass specifications for the recycling of nonstandard powders through the calciner and fluorinator in hoods 9-A and HC-9B. This specification sets forth supplemental conditions to HW-66936 Rev (Hood 9-B) and HW-76553 (9-A) under which powder might be recycled.</td></tr>
<tr><td>HW-81363
SRDB 50800</td><td>Radiological Control Experience with Plutonium Fuels (Mar 26). This document describes the worker exposure experience of the 308 Plutonium Fabrication Pilot Plant (PFPP) after 4 years of operation. The document provides an analysis of hazards associated with the plutonium isotopes handled at Hanford (seemingly identical to HW-SA-2904, dated 2/13/63).</td></tr>
</table>

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
PL 88-376	Public Law 88-376 passed by Congress on July 14, 1968 giving official recognition to the NCRP to provide radiation protection guidance and changed its name slightly to the National Council on Radiation Protection and Measurements.
UCRL-12199 SRDB 6180	Angular Dependence of Eastman Type A (NTA) Personnel Monitoring Film. This document recommends using a correction factor of 1.3.
DDTS-GENERATED-988 SRDB 34775	Monthly record report 01/1964 radiological engineering unit
DDTS-GENERATED-989 SRDB 34776	Monthly record report 02/1964 radiological engineering unit
DDTS-GENERATED-990 SRDB 34777	Monthly record report 03/1964 radiological engineering unit
DDTS-GENERATED-991 SRDB 34778	Monthly record report 04/1964 radiological engineering unit
DDTS-GENERATED-992 SRDB 36444	Monthly record report 05/1964 radiological engineering unit
DDTS-GENERATED-993 SRDB 34779	Monthly record report 06/1964 radiological engineering unit
DDTS-GENERATED-994 SRDB 34780	Monthly record report 07/1964 radiological engineering unit
DDTS-GENERATED-995 SRDB 34781	Monthly record report 08/1964 radiological engineering unit
DDTS-GENERATED-996 SRDB 34782	Monthly record report 09/1964 radiological engineering unit
DDTS-GENERATED-997 SRDB 34783	Monthly record report 10/1964 radiological engineering unit
DDTS-GENERATED-998 SRDB 34784	Monthly record report 11/1964 radiological engineering unit
DDTS-GENERATED-999 SRDB 34785	Monthly record report 12/1964 radiological engineering unit
RL-GEN-1768 SRDB 74140	Basic hazards information
HW-83681 SRDB 74142	N reactor status report 50 percent power
HW-NUSAR-81580 SRDB 73768	Startup test N3 N Reactor power ascension program
HW-NUSAR-81580 SRDB 73768	Startup test N3 N Reactor power ascension program

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><td>DDTS-GENERATED-988
SRDB 34775</td><td>Monthly record report 01/1964 radiological engineering unit</td></tr>
<tr><td>DDTS-GENERATED-989
SRDB 34776</td><td>Monthly record report 02/1964 radiological engineering unit</td></tr>
<tr><td>DDTS-GENERATED-990
SRDB 34777</td><td>Monthly record report 03/1964 radiological engineering unit</td></tr>
<tr><td>DOE/DP-0137
SRDB 12292</td><td>PFP produces first reactor-grade plutonium product (see Figure 1).</td></tr>
<tr><td>RL-SEP-376
SRDB 54564</td><td>Weapon Manufacturing Operation, Radiation Control Report, 1964
<table>
<tr><th>Date</th><th>Hoods 7C-9B gamma</th><th>Hoods 7C-9B neutron</th><th>Hoods 7C-9B, inst. NP ratio</th><th>Button line Gamma</th><th>Button line Neutron</th><th>Button, instr. NP ratio</th></tr>
<tr><td colspan="7">Instrument measurements</td></tr>
<tr><td>Mar-64</td><td>4.8</td><td>10.5</td><td>2.2</td><td>1.5</td><td>3.4</td><td>2.3</td></tr>
<tr><td>Jun-64</td><td>5.3</td><td>16.6</td><td>3.1</td><td>1.3</td><td>3.1</td><td>2.4</td></tr>
<tr><td>Sep-64</td><td>5.1</td><td>18.2</td><td>3.6</td><td>1.1</td><td>4.1</td><td>3.7</td></tr>
<tr><td>Dec-64</td><td>5.3</td><td>18.6</td><td>3.5</td><td>0.9</td><td>4.4</td><td>4.9</td></tr>
<tr><td colspan="7">Film dosimeter measurements</td></tr>
<tr><td>Mar-64</td><td>2.5</td><td>5.0</td><td>2.0</td><td>0.5</td><td>2.0</td><td>4.0</td></tr>
<tr><td>Jun-64</td><td>2.8</td><td>6.1</td><td>2.2</td><td>0.8</td><td>1.7</td><td>2.1</td></tr>
<tr><td>Sep-64</td><td>3.1</td><td>6.8</td><td>2.2</td><td>0.5</td><td>2.2</td><td>4.4</td></tr>
<tr><td>Dec-64</td><td>2.9</td><td>6.8</td><td>2.3</td><td>0.5</td><td>1.4</td><td>2.8</td></tr>
</table>
</td></tr>
<tr><td></td><td>PFP produces its first nondefense plutonium for EURATOM</td></tr>
<tr><td>USPHS Performance testing,
SRDB 15021</td><td>The National Sanitation Foundation initiates performance testing of “Standards of Performance for Film Badge Services” during December 1964. The types and numbers of organizations that submitted film badges for this testing included:
<table>
<tr><td>Commercial</td><td>12</td></tr>
<tr><td>Federal agencies</td><td>8</td></tr>
<tr><td>State health departments</td><td>4</td></tr>
<tr><td>Private</td><td>1</td></tr>
</table>
Approximately 2,000 film badges were irradiated with various types and energies of radiation. Exposures ranged from 0.002 to 497 Roentgens. The dosimetry services did not know which badges were exposed to what type, energy, or dose of radiation.</td></tr>
<tr><td>HW-SA-4000
SRDB 50809</td><td>The Administration of Radiation Safety at Hanford (Dec 28). Broad discussion of Hanford Radiation Protection Program. Annual doses controlled to 5 rem including 3 R photon dose. Establishment of workplace Zones 1 to 4. Monitoring conducted for all workers and visitors entering radiological controlled areas.</td></tr>
<tr><td>HW-84600
SRDB 36446</td><td>Document entitled “Hanford Periodic and Serial Reports 1943-1964, A Book Catalog,” issued (December 1964). This 300 page document lists numerous report series by general category.</td></tr>
<tr><td>WHC-SP-0297
SRDB 64586</td><td>N Reactor achieves 4000 MWt design operating level on December 9, 1964 following approximately one year of system testing.</td></tr>
<tr><td>DUN-6888
SRDB 333</td><td>DR Reactor was shut down for deactivation (December 30, 1964)</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
1965	
DOE/RL-97-1047 SRDB 27666	Battelle memorial Institute assumes Pacific Northwest Laboratory contract effective 1/1/1965 to technically direct Hanford personnel dosimetry services such as WB counter, personnel dosimetry, radiological calibrations, etc., in addition to general research and development.
HW-82536 SRDB 73765	Document entitled, “Final Report, startup test N-2, Low Power Testing Program Steps 13 and 18,” (Jan 15). This document presents an example of the extensive tests conducted and includes references to numerous test results.
DOE/RL-97-1047 SRDB 27666	US Testing assumes Hanford contract to provide radiochemical analyses and personnel dosimeter processing services.
DOE/RL-97-1047 SRDB 27666	Douglas United Nuclear (DUN), November 1965 to August 1967 assumes responsibility for Hanford reactor operations and fuel fabrication.
BNWC-8-1 SRDB 64808	Battelle-Northwest Monthly Activities Report, January 1965 (Feb 15). Report describes Battelle-Northwest assumption of Hanford Site personnel dosimetry and environmental surveillance responsibilities from General Electric effective January 4, 1965. Report also describes role of U.S. Testing Company to conduct personnel dosimetry processing, bioassays and environmental radiochemical analyses effective January 1, 1965.
BNWC-8-2 SRDB 64810	Battelle-Northwest Monthly Activities Report, February 1965 (Mar 15). Report describes highlights of Hanford Site dosimetry support. As noted in this report a new 1000 gram plutonium fluoride neutron source was obtained. The new source is doubly contained with an inner can of monel material and an outer can of aluminum. The monel inner container was chosen to provide maximum inertness to fluorine. The air space of approximately 1/8 inch is provided between the two containers so that X-ray examination can be used to detect any possible source swelling of the inner container. The higher density monel metal has significantly reduced the gamma radiation dose rate from this source. Also, the recent purification of the plutonium used has resulted in a source with a minimum of ^{241}Am. Gamma radiation rates from this source will increase as the ^{241}Am increases.
DUN-6888 SRDB 333	H Reactor was shut down for deactivation (April 21, 1965)
Letter Report SRDB 73677	Field Evaluation of Badge, Pencil Dosimeter, and CP Response. This report dated April 1, 1965 compares 3 film dosimeters, 3 Victoreen pencils, 3 Bendix pencils, and 6 Stephens pencils under three different field conditions. The pencils indicated an average exposure about 25% higher than the film dosimeter dose.
PNNL-13524 SRDB 12856	Am-241 recovery begun at 242-Z facility (May)
DUN-6888 SRDB 333	F Reactor was shut down for deactivation (June 25, 1965)
RL-REA-2247 SRDB 73773	Historical report issued entitled, “Historical Events–Reactors and Fuels Fabrication,” (July 1, 1965). The stated purpose of this report is to document, in one place, the significant historical events pertinent to the operation of the production reactors at Hanford.
BNWC-8-9 SRDB 64813	Battelle-Northwest Monthly Activities Report, September 1965 (Oct). Report describes highlights of site-wide dosimetry support. An update to Hanford participation in the AEC Health and Mortality Study was provided. “Work on the Mancuso Project is continuing both at Hanford and Pittsburgh, Pennsylvania. At Hanford the identification of approximately 10,000 payroll numbers used during the early portion of the data processing program with the names of employees was initiated. At Pittsburgh the independent audit of approximately 20,000 personnel film was initiated. Approximately one million calibration films were shipped for use in this project.”

Reference	Description
RL-SEP-820 SRDB 34155	Thorium and N Reactor Technical Record
BNWC-8-10 SRDB 64815	Battelle-Northwest Monthly Activities Report, October 1965 (Nov). Report describes highlights of site-wide dosimetry support. There is a description of a study involving neutron dosimeters, based on foil activation and film dosimetry principles, placed on field tests at the PRTR, at production reactors, and at selected locations in the Weapons Fabrications building. Preliminary results indicate that these dosimeters which permit an evaluation of fast neutron dose by film density measurements are performing satisfactorily in the field. They can provide an intermediate step to provide an improved neutron dosimetry over that currently available with the NTA film dosimeters.
RL-REA-472 SRDB 36698	Routine report entitled “Irradiation Processing Department Monthly Report January, 1965 (Feb 15).” Report primarily addresses exposures at the single-pass reactors.
RL-REA-475 SRDB 36715	Routine report entitled “Irradiation Processing Department Monthly Report April, 1965 (May 14).” Report primarily addresses exposures at the single-pass reactors.
RL-REA-476 SRDB 36717	Routine report entitled “Irradiation Processing Department Monthly Report May, 1965 (Jun 14).” Report primarily addresses exposures at the single-pass reactors.
RL-REA-477 SRDB 36718	Routine report entitled “Irradiation Processing Department Monthly Report June, 1965 (Jul 15).” Report primarily addresses exposures at the single-pass reactors.
RL-REA-2248 SRDB 52841	Routine report entitled “Irradiation Processing Department Monthly Report July, 1965 (Aug 15).” Report primarily addresses exposures at the single-pass reactors.
RL-REA-2249 SRDB 52842	Routine report entitled “Irradiation Processing Department Monthly Report August, 1965 (Sep 15).” Report primarily addresses exposures at the single-pass reactors.
RL-REA-2250 SRDB 52850	Routine report entitled “Irradiation Processing Department Monthly Report September, 1965 (Oct 15).” Report primarily addresses exposures at the single-pass reactors.
RL-NRD-150-6-DEL SRDB 57679	N reactor dept monthly report 06/1965 □
RL-REA-2251 SRDB 36691	Routine report entitled “Irradiation Processing Department Monthly Report October, 1965 (Nov 15).” Report primarily addresses exposures at the single-pass reactors.
PNNL-13524 SRDB 12856	RMA Weapons fabrication facility shutdown (Dec 31)
RL-SEP-925 SRDB 54565	Weapon Manufacturing Operation, Radiation Control Report, 1965

Date	Hoods 7C-9B gamma	Hoods 7C-9B neutron	Hoods 7C-9B, inst. NP ratio	Button line gamma	Button line neutron	Button, instr. NP ratio
Instrument measurements						
Mar-65	3.9	16.1	4.1	1.0	3.9	3.9
Jun-65	5.6	20.2	3.6	1.0	3.6	3.6
Sep-65	5.7	18.7	3.3	1.2	3.5	2.9
Dec-65	3.3	16.4	5.0	1.0	3.7	3.7
Film dosimeter measurements						
Mar-65	2.6	3.8	1.5	0.9	1.5	1.7
Jun-65	2.4	5.7	2.4	0.6	1.2	2.0
Sep-65	2.2	3.1	1.4	0.7	0.9	1.3
Dec-65	2.0	3.3	1.7	0.5	0.5	1.0

Reference	Description
1966	
PNNL-13524 SRDB 12856	NPR fuel processed at REDOX (Mar-Apr)

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>RL-NRD-294-11
SRDB
57683</td><td>N Reactor Trends Report December 1965 (Jan 4). This is one of a report series describing many facets of N Reactor Operation. This document provides a summary of data for 1965 to include:
1. Dates and causes of all scrams or shutdowns.
2. Fuel failures, etc., along with a summary of monthly radiation dose rates (rad/hr) at selected locations.</td></tr>
<tr><td>ORAUT-TKBS-0006-2</td><td>Fabrication of pits removed from 234-5Z RMC Line in 1966. Line shut down in 1976 as a result of explosion in 242-Z. RMC Line restarted in 1985, shut down in 1989.</td></tr>
<tr><td>RL-NRD-822
SRDB 38400</td><td>Radiological Status of the N Reactor for January and February, 1966 (Mar 24). Routine report describing radiological status. Report states that the final Battelle evaluation on personnel dosimetry for 1965 at N Reactor indicated that on average all crafts except radiation monitors were well below the N Reactor operational control limit for external WB dose. This limit is 5 rem including 3 Roentgens per calendar year.
Calendar Year 1965 Radiation Dose of N Reactor Personnel
<table>
<tr><th>Critical groups</th><th>Dose (mR)</th></tr>
<tr><td>**Maintenance**</td><td></td></tr>
<tr><td>Exempt supervision–first line</td><td>1,200</td></tr>
<tr><td>Non-exempt electrical</td><td>830</td></tr>
<tr><td>Non-exempt instrument techs.</td><td>1,470</td></tr>
<tr><td>Non-exempt millwrights</td><td>1,330</td></tr>
<tr><td>Non-exempt pipefitters</td><td>2,330</td></tr>
<tr><td>**Processing**</td><td></td></tr>
<tr><td>Exempt supervisors</td><td>1,470</td></tr>
<tr><td>Non-exempt process operators</td><td>1,950</td></tr>
<tr><td>Non-exempt radiation monitors</td><td>2,740</td></tr>
<tr><td>**All other groups**</td><td></td></tr>
<tr><td>Exempt</td><td>530</td></tr>
<tr><td>Non-exempt</td><td>480</td></tr>
</table></td></tr>
<tr><td>BNWL-255
SRDB 68419</td><td>Battelle-Northwest Monthly Activities Report, April 1966 (May). Report describes under Personnel Dosimetry Section results of an evaluation of NTA measurement of neutron radiation dose from a glovebox PuF_4 source as follows:
Doses from Plutonium Fluoride Source Exposure
<table>
<tr><th></th><th colspan="2">PuF_4 source, dose, rad</th></tr>
<tr><th>Neutron energy category</th><th>Bare</th><th>½” Lucite shield</th></tr>
<tr><td>> 1.3 MeV</td><td>0.302</td><td>0.119</td></tr>
<tr><td>1.3 to 0.4 MeV</td><td>0.187</td><td>0.078</td></tr>
<tr><td>Epithermal (>0.4 eV)</td><td>0.008</td><td>0.002</td></tr>
<tr><td>Thermal (<0.4 eV)</td><td>0.000</td><td>0.000</td></tr>
<tr><td>Total dosimeter evaluated dose</td><td>0.566</td><td>0.199</td></tr>
</table>
The one-half inch Lucite shield was used to simulate a typical plutonium hood. The measurements show the Lucite reduces the neutron dose for energies above 1.3 MeV by about 40%; the total dose is reduced by about 35%. These data indicate that at least 60% of the PuF_4 neutron dose observed through a one-half inch Lucite panel can be monitored with the NTA emulsion neutron dosimeter.</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
RL-GEN-960-1 SRDB 36880	Radiological status of the N reactor for March 1966 (April 18, 1966). Routinely prepared report that provides monthly status report of survey readings in mR per hour under stated operating conditions, along with information concerning incidents, contamination levels, etc.
BNWL-275 SRDB 64821	Battelle-Northwest Monthly Activities Report, May 1966 (June 1966). Report describes under Personnel Dosimetry “The evaluation and correction of approximately 2,500 dose results for dosimeters worn during the period ending March 1966, which were reported to be questionable, is nearly complete. Approximately 700 dose results for neutron dosimeters worn during the periods ending March and April 1966 were reported to be questionable. Evaluation and correction of these results is approaching completion. Special external exposure evaluations were performed for 45 other Hanford contractor employees; however, no exposures over permissible limits were revealed.”
RL-GEN-960-2 SRDB 36885	Radiological status of the N reactor for April 1966 (May 13, 1966). Routinely prepared report that provides monthly status report of survey readings in mR per hour under stated operating conditions, along with information concerning incidents, contamination levels, etc.
BNWL-302 SRDB 64822	Pacific Northwest Laboratory Monthly Activities Report, July 1966, Division of Production and Hanford Plant Assistance Programs (August 1966).
DUN-558 SRDB 57660	Douglas United Nuclear, Inc. Monthly Report 01/1966
DUN-559 SRDB 57660	Douglas United Nuclear, Inc. Monthly Report 02/1966
DUN-560 SRDB 57661	Douglas United Nuclear, Inc. Monthly Report 03/1966
DUN-561 SRDB 57662	Douglas United Nuclear, Inc. Monthly Report 04/1966
DUN-562 SRDB 57666	Douglas United Nuclear, Inc. Monthly Report 05/1966
DUN-563-DEL SRDB 57667	Douglas United Nuclear, Inc. Monthly Report 06/1966 (Jul 1966). Report covers primarily single-pass cooling production reactors operated by DUN. However, on page 14, this report describes “The assignment of neutron badges was discontinued within the DUN reactor facilities in April, 1966, however, the present practice requires each individual to sign a Neutron Exposure Register form prior to entering a radiation zone, where a neutron dose rate has been established, and to record an estimated dose.” Radiation Practices Engineering has provided signs for each reactor area outlining the procedure to be followed for the neutron dose recording program.
DUN-1293-DEL SRDB 57599	Douglas United Nuclear, Inc., Monthly Report July, 1966.
DUN-1294 SRDB 57601	Douglas United Nuclear, Inc., Monthly Report August, 1966. Report describes settlement on August 21, 1966 of a strike by HAMTC which began on July 8, 2006.
DUN-1295 SRDB 57603	Douglas United Nuclear, Inc., Monthly Report September, 1966
DUN-1638 SRDB 57608	Douglas United Nuclear, Inc., Monthly Report October, 1966
DUN-1639 SRDB 57613	Douglas United Nuclear, Inc., Monthly Report November, 1966
ISO-611 SRDB 61207	Technical report entitled “$ZrNb^{95}$ Effect on Plutonium Button Gamma Dose Rate” regarding measurements of dose rate in plutonium buttons in association with $ZrNb^{95}$. Gamma spectra presented in graphs within the report showing substantial high energy (~750 keV) contribution from $ZrNb^{95}$.

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>ISO-694
SRDB 54566</td><td>Plutonium Finishing Section, Radiation Control Report, 1966
<table>
<tr><th>Date</th><th>Hoods 7C-9B gamma</th><th>Hoods 7C-9B neutron</th><th>Hoods 7C-9B, inst. NP ratio</th><th>Button line gamma</th><th>Button line neutron</th><th>Button, instr. NP ratio</th></tr>
<tr><td colspan="7">Instrument measurements</td></tr>
<tr><td>Mar-66</td><td>3.7</td><td>16.1</td><td>4.4</td><td>1.4</td><td>3.6</td><td>2.6</td></tr>
<tr><td>Jun-66</td><td>3.1</td><td>14.5</td><td>4.7</td><td>1.0</td><td>3.0</td><td>3.0</td></tr>
<tr><td>Sep-66</td><td>2.8</td><td>16.6</td><td>5.9</td><td>2.0</td><td>4.3</td><td>2.2</td></tr>
<tr><td>Dec-66</td><td>4.0</td><td>14.2</td><td>3.6</td><td>1.7</td><td>3.9</td><td>2.3</td></tr>
<tr><td colspan="7">Film dosimeter measurements</td></tr>
<tr><td>Mar-66</td><td>1.8</td><td>4.5</td><td>2.5</td><td>0.8</td><td>1.6</td><td>2.0</td></tr>
<tr><td>Jun-66</td><td>2.0</td><td>4.4</td><td>2.2</td><td>0.9</td><td>2.0</td><td>2.2</td></tr>
<tr><td>Sep-66</td><td>2.4</td><td>3.9</td><td>1.6</td><td>1.2</td><td>1.3</td><td>1.1</td></tr>
<tr><td>Dec-66</td><td>2.5</td><td>3.6</td><td>1.4</td><td>1.3</td><td>1.7</td><td>1.3</td></tr>
</table></td></tr>
<tr><td colspan="2">1967</td></tr>
<tr><td>BNWL-498
SRDB 64823</td><td>Pacific Northwest Laboratory Monthly Activities Report, June 1967, Division of Production and Hanford Plant Assistance Programs (July 1967). Report states, “A study is being made to prepare recommendations on the feasibility of pursuing the activation neutron dosimeter concept. Development work on a portable neutron survey instrument continued as did studies on the performance and possible uses of thermoluminescent and glass materials for dosimetry work.”</td></tr>
<tr><td>DUN-1640
SRDB 57614</td><td>Monthly Report December 1966</td></tr>
<tr><td>RL-GEN-1482
SRDB 60602</td><td>Document issued entitled “Production Program For Irradiating All Hanford-Produced Neptunium.” (March 22, 1967)</td></tr>
<tr><td>DUN-2011
SRDB 57616</td><td>Douglas United Nuclear, Inc., Monthly Report January 1967</td></tr>
<tr><td>DUN-2012-DEL
SRDB 57630</td><td>Douglas United Nuclear, Inc., Monthly Report February, 1967</td></tr>
<tr><td>DUN-2013-DEL
SRDB 57631</td><td>Douglas United Nuclear, Inc., Monthly Report March 1967</td></tr>
<tr><td>DUN-2424
SRDB 57634</td><td>Douglas United Nuclear, Inc., Monthly Report 04/1967</td></tr>
<tr><td>DUN-2425
SRDB 57635</td><td>Douglas United Nuclear, Inc., Monthly Report 05/1967</td></tr>
<tr><td>DUN-2426
SRDB 57636</td><td>Douglas United Nuclear, Inc., Monthly Report 06/1967</td></tr>
<tr><td>DUN-6888
SRDB 333</td><td>D Reactor was shut down for deactivation (June 26, 1967)</td></tr>
<tr><td>DUN 7949
SRDB 72203</td><td>Document entitled, “N Reactor Startup and Operation, 1963 to 1970 Working Papers,” (May 28, 1972). This document on page 37 includes a letter from W. Devine, Director, AEC Production Reactor Division to R.L. Dickeman, General Manager, General Electric Company, HAPO describing planned transfer of N Reactor responsibilities to DUN.</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>ARH-393
SRDB 54567</td><td>Plutonium Finishing Section, Radiation Control Report, 1967
<table>
<tr><th>Date</th><th>Hoods 7C-9B gamma</th><th>Hoods 7C-9B neutron</th><th>Hoods 7C-9B, inst. NP Ratio</th><th>Button line gamma</th><th>Button line neutron</th><th>Button, instr. NP ratio</th></tr>
<tr><td colspan="7">Instrument measurements</td></tr>
<tr><td>Mar-67</td><td>7.3</td><td>13.4</td><td>1.8</td><td>1.4</td><td>3.7</td><td>2.6</td></tr>
<tr><td>Jun-67</td><td>6.2</td><td>12.2</td><td>2.0</td><td>1.1</td><td>2.7</td><td>2.5</td></tr>
<tr><td>Sep-67</td><td>5.7</td><td>14.6</td><td>2.6</td><td>1.4</td><td>2.6</td><td>1.9</td></tr>
<tr><td>Dec-67</td><td>5.0</td><td>12.6</td><td>2.5</td><td>1.7</td><td>3.6</td><td>2.1</td></tr>
<tr><td colspan="7">Film dosimeter measurements</td></tr>
<tr><td>Mar-67</td><td>2.6</td><td>3.3</td><td>1.3</td><td>0.9</td><td>1.5</td><td>1.7</td></tr>
<tr><td>Jun-67</td><td>2.3</td><td>3.5</td><td>1.5</td><td>1.4</td><td>1.6</td><td>1.1</td></tr>
<tr><td>Sep-67</td><td>2.3</td><td>4.3</td><td>1.9</td><td>1.2</td><td>2.3</td><td>1.9</td></tr>
<tr><td>Dec-67</td><td>2.8</td><td>3.2</td><td>1.1</td><td>1.9</td><td>1.7</td><td>0.9</td></tr>
</table></td></tr>
<tr><td>DUN-2872
SRDB 37637</td><td>Douglas United Nuclear, Inc., Monthly Report July 1967 (Aug 17). Operating responsibility for the N Reactor and associated fuel and target fabrication facilities was assumed by DUN on July 1, 1967. Personnel transfers from General Electric totaled 592: 219 exempt and 373 nonexempt.</td></tr>
<tr><td>DUN-2873-DEL
SRDB 57638</td><td>Douglas United Nuclear, Inc., Monthly Report 08/1967</td></tr>
<tr><td>DUN-2874
SRDB 57639</td><td>Douglas United Nuclear, Inc., Monthly Report 09/1967</td></tr>
<tr><td>BNWL-542
SRDB 14914</td><td>Technical report entitled, “The Establishment and Utilization of Film Dosimeter Performance Criteria.” (Sep 1967). This report describes the ongoing evolution in the effort to define criteria for a national dosimeter performance testing program. Table B-1 entitled, “Bias and Variance Features for Hanford Film Badge Dosimetry Measurement Records,” provides analysis of Hanford quality control dosimeter results for beta, gamma and X-ray exposures at various exposure levels.”</td></tr>
<tr><td>DUN-3179
SRDB 57640</td><td>Douglas United Nuclear, Inc., Monthly Report 10/1967</td></tr>
<tr><td>DUN-3180
SRDB 57641</td><td>Douglas United Nuclear, Inc., Monthly Report 11/1967</td></tr>
<tr><td>DUN-3181
SRDB 57642</td><td>Douglas United Nuclear, Inc., Monthly Report December, 1967. Report includes information concerning a HAMTC strike for 103 days that started September 1, 1967 and resolved on December 12, 1967.</td></tr>
<tr><td>File: 1967-10
SRDB 33189</td><td>GR Yesberger, Richland Operations Office, Health and Safety Division, prepared historical summary of Hanford Radiation Protection Standards, Procedures, Practices, and Exposure Records (Oct 1967). This analysis was prepared in association with “On September 1, 1967, eight chemical operators employed at the 100-N Reactor were sent home by Douglas United Nuclear (DUN) management when the men refused to perform work which would increase their weekly radiation exposure above 300 mrem per week. The eight men were all members of the Hanford Atomic Metal Trades Council (HAMTC). A strike ensued that lasted at least 60 days.</td></tr>
<tr><td>DUN-3385
SRDB 57643</td><td>N Reactor Coproduct Demonstration</td></tr>
<tr><td>DUN-3180-RD
SRDB 57641</td><td>Reactor operations month end report 11/30/1967</td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
1968	
DUN-3595-DEL SRDB 37644	Douglas United Nuclear, Inc., Monthly Report 01/1968
DUN-3596-DEL SRDB 37645	Douglas United Nuclear, Inc., Monthly Report 02/1968
DUN-6888 SRDB 333	B Reactor was shut down for deactivation (February 12, 1968)
DUN-3597-DEL SRDB 57646	Douglas United Nuclear, Inc., Monthly Report 03/1968
SRDB 37796	Letter to DR Elle to file entitled: “Film Badge Dosimetry–Anomalous Results in December 1967, January, February and March 1968, Dosimeters. (Apr 23, 1968).” Letter describes a meeting involving representatives from AEC-RL, ARCHO, BNW, ITT/FSS, J. A. Jones, and U. S. Testing, Company was held to discuss the problem of anomalous film badge readings which resulted in a high dose evaluation in December 1967 and the first quarter of 1968.
SRDB 38330	Letter from KR Heid to file, dated May 2, 1958 regarding follow-up to April 22, 1968 meeting to investigate the cause of high dose reports. The estimated high dose bias was based on quality control dosimeter results which are described in the letter.
DUN-4017-DEL SRDB 57647	Douglas United Nuclear, Inc., Monthly Report 04/1968
DUN-4018-DEL SRDB 57648	Douglas United Nuclear, Inc., Monthly Report 05/1968
UNI-M-10, p 22 SRDB 59172	Radiation Exposure Usage Accountability System was established by the exposure reduction task force. This process consisted of manual recording of the daily PIC data. The original manual system was later computerized with capabilities to provide individual worker exposure for each day and in addition of the accumulated exposure for the week, month, year to date, etc.
DUN-4019-DEL SRDB 57649	Douglas United Nuclear, Inc., Monthly Report 06/1968
DUN-4450-DEL SRDB 57650	Douglas United Nuclear, Inc., Monthly Report 07/1968
DUN-4451-DEL SRDB 57651	Douglas United Nuclear, Inc., Monthly Report 08/1968
DUN-4452 SRDB 57652	Douglas United Nuclear, Inc., Monthly Report 09/1968
DUN-4811-DEL SRDB 57653	Douglas United Nuclear, Inc., Monthly Report 10/1968
DUN-4812 SRDB 57654	Douglas United Nuclear, Inc., Monthly Report 11/1968
DUN-4813-DEL SRDB 57655	Douglas United Nuclear, Inc., Monthly Report 12/1968
BNWL-CC-1762-1 SRDB 34223	Chemical Processing of Irradiated Targets From Hanford's Plutonium-238 Demonstration Program Part 1: N Reactor Neptunium-Aluminum Alloy Elements

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>ARH-1131
SRDB 54568</td><td>Plutonium Finishing Section, Radiation Control Report, 1968
<table>
<tr><th>Date</th><th>Hoods 7C-9B gamma</th><th>Hoods 7C-9B neutron</th><th>Hoods 7C-9B, inst. NP ratio</th><th>Button line gamma</th><th>Button line neutron</th><th>Button, instr. NP ratio</th></tr>
<tr><td colspan="7">Instrument measurements</td></tr>
<tr><td>Mar-68</td><td>6.0</td><td>16.5</td><td>2.8</td><td>2.2</td><td>3.0</td><td>1.4</td></tr>
<tr><td>Jun-68</td><td>5.6</td><td>14.2</td><td>2.5</td><td>2.4</td><td>3.4</td><td>1.4</td></tr>
<tr><td>Sep-68</td><td>4.5</td><td>10.0</td><td>2.2</td><td>2.7</td><td>4.7</td><td>1.7</td></tr>
<tr><td>Dec-68</td><td>4.6</td><td>14.1</td><td>3.1</td><td>4.8</td><td>2.7</td><td>0.6</td></tr>
<tr><td colspan="7">Film dosimeter measurements</td></tr>
<tr><td>Mar-68</td><td>2.9</td><td>3.8</td><td>1.3</td><td>1.1</td><td>1.3</td><td>1.2</td></tr>
<tr><td>Jun-68</td><td>3.1</td><td>5.6</td><td>1.8</td><td>1.0</td><td>2.9</td><td>2.9</td></tr>
<tr><td>Sep-68</td><td>3.0</td><td>4.4</td><td>1.5</td><td>1.6</td><td>1.9</td><td>1.2</td></tr>
<tr><td>Dec-68</td><td>3.0</td><td>4.6</td><td>1.5</td><td>1.2</td><td>1.7</td><td>1.4</td></tr>
</table>
</td></tr>
<tr><td colspan="2">1969</td></tr>
<tr><td>BNWL-1030
SRDB 64825</td><td>Pacific Northwest Laboratory Monthly Activities Report February 1969, Division of Production and Hanford Plant Assistance Programs (March 1969). Some details of construction of the new Hanford thermoluminescent dosimeter readers are presented.</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>231-Z fabricated devises for Nevada Test Program</td></tr>
<tr><td>BNWL-1340
SRDB 11096</td><td>AEC Workshop on Personnel Neutron Dosimetry (Sep 23). This report describes the first AEC workshop to discuss neutron dose issues among selected sites with a neutron dosimetry program. The report notes the potential serious under-reporting of neutron dose to workers for intermediate energy neutrons using NTA film.</td></tr>
<tr><td>DUN-5254
SRDB 57656</td><td>Douglas United Nuclear, Inc., Monthly Report 01/1969</td></tr>
<tr><td>DUN-5255
SRDB 57657</td><td>Douglas United Nuclear, Inc., Monthly Report 02/1969</td></tr>
<tr><td>DUN-5256
SRDB 57658</td><td>Douglas United Nuclear, Inc., Monthly Report 03/1969</td></tr>
<tr><td>DUN-5610
SRDB 57663</td><td>Douglas United Nuclear Monthly Report 04/1969</td></tr>
<tr><td>DUN-6888
SRDB 333</td><td>C Reactor was shut down for deactivation (April 25, 1969)</td></tr>
<tr><td>DUN-5611
SRDB 57664</td><td>Douglas United Nuclear Monthly Report 05/1969</td></tr>
<tr><td>DUN-5612
SRDB 57665</td><td>Douglas United Nuclear Monthly Report 06/1969</td></tr>
<tr><td>DUN-5965
SRDB 57605</td><td>Douglas United Nuclear Monthly Report 07/1969</td></tr>
<tr><td>DUN-5966
SRDB 57620</td><td>Douglas United Nuclear Monthly Report 08/1969</td></tr>
<tr><td>DUN-5967
SRDB 57623</td><td>Douglas United Nuclear Monthly Report 09/1969</td></tr>
<tr><td>DUN-6270
SRDB 57625</td><td>Douglas United Nuclear Monthly Report 10/1969</td></tr>
<tr><td>DUN-6271
SRDB 57626</td><td>Douglas United Nuclear Monthly Report 11/1969</td></tr>
</table>

Reference	Description
DUN-6272 SRDB 57627	Douglas United Nuclear Monthly Report 12/1969
ARH-1213 SRDB 60062	Plutonium Finishing Section, Radiation Control Report, 1969

Date	Hoods 7C-9B gamma	Hoods 7C-9B neutron	Hoods 7C-9B, inst. NP ratio	Button line gamma	Button line neutron	Button, instr. NP ratio
Instrument measurements						
Mar-69	4.0	13.2	3.3	2.5	2.6	1.0
Jun-69	5.1	17.2	3.4	4.5	3.3	0.7
Sep-69	5.2	18.0	3.5	3.2	3.6	1.1
Dec-69	5.7	19.0	3.3	3.1	3.0	1.0
Film dosimeter measurements						
Mar-69	2.5	3.6	1.4	1.0	1.8	1.8
Jun-69	3.2	3.2	1.0	2.3	2.1	0.9
Sep-69	2.7	2.6	1.0	2.5	1.4	0.6
Dec-69	4.8	5.6	1.2	2.2	3.5	1.6

Reference	Description
1970	
DUN-6888 SRDB 333	"Historical Events–Single Pass Reactors and Fuels Fabrication." (Apr 10). The stated intent of this report is to record, in one place, the significant historical events associated with the single-pass reactors from initial startup through December 1969. Significant events are listed in Section 1 of the report and specific programs are summarized in Section 2.
DUN-6888 SRDB 333	KW Reactor was shut down for deactivation (February 1, 1970)
ARH-1213-4 SRDB 54570	Plutonium Finishing Section, Radiation Control Report, 1970

Date	Hoods 7C-9B gamma	Hoods 7C-9B neutron	Hoods 7C-9B, inst. NP ratio	Button line gamma	Button line neutron	Button, instr. NP ratio
Instrument measurements						
Mar-70	5.6	13.3	2.4	2.6	2.4	0.9
Jun-70	7.6	11.2	1.5	4.0	1.7	0.4
Sep-70	7.5	11.5	1.5	5.1	1.5	0.3
Dec-70	8.3	32.1	3.9	8.6	3.5	0.4
Film dosimeter measurements						
Mar-70	2.5	3.6	1.4	1.0	1.8	1.8
Jun-70	3.2	3.2	1.0	2.3	2.1	0.9
Sep-70	2.7	2.6	1.0	2.5	1.4	0.6
Dec-70	4.8	5.6	1.2	2.2	3.5	1.6

Reference	Description
1971	
BNWL-CC-2633 SRDB 15395	Basic Hanford thermoluminescent dosimeter (TLD) implemented for nonradiological workers.
PNNL-13524 SRDB 12856	Presidential decision to close the last of Hanford single-pass reactors, KE and KW, and the Hanford N Reactor effective January 28, 1971.
DUN-6888 SRDB 333	The last single-pass cooling reactor, KE Reactor, was shut down for deactivation (January 29, 1971)

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>DUN-M-1
SRDB 59064</td><td>DUN issues Radiation Protection Manual that establishes occupational and nonoccupational exposure limits, and provides administrative check points, methods, and safeguards for use in controlling personnel exposure within limits. Section 2.6 requires the following:
“If planned work will cause personnel to exceed an exposure check point(s), the responsible supervisor shall, before work begins:
1. Complete all sections of the appropriate “Personnel Exposure Request“ form. These forms are requests for:
• Exposure over 300 mrem, but less than 500 mrem in 7 days.
• Exposure over 500 mrem in 7 days.
• Exposure over 3 rems per year.
2. Submit the completed form to Radiation monitoring for review.
Acquire from Environmental Engineering, the current radiation exposure status for each individual listed on the form.”</td></tr>
<tr><td>BNWL-SA-3955
SRDB 15397</td><td>The Hanford Thermoluminescent Multipurpose Dosimeter (May 28, 1971). This report describes the design and performance characteristics of the Hanford Multipurpose Thermoluminescent Dosimeter (TLD) implemented on January 1, 1972 for radiological workers (note: a basic Hanford one-chip TLD was implemented January 1, 1971 for nonradiological workers).

This document describes results of several laboratory studies of the dosimeter response. To include results of field testing of the dosimeter in which selected workers wore the TLD and the Hanford Neutron Film dosimeter used until December 31, 1971. Results of this field testing are summarized below.

<table>
<tr><th rowspan="2">Employee number</th><th colspan="2">Slow neutrons (mrem)</th><th colspan="2">Fast neutrons (mrem)</th></tr>
<tr><th>TLD</th><th>Film</th><th>TLD</th><th>Film</th></tr>
<tr><td>1</td><td>6</td><td>30</td><td>0</td><td>0</td></tr>
<tr><td>2</td><td>9</td><td>30</td><td>200</td><td>0</td></tr>
<tr><td>3</td><td>12</td><td>40</td><td>200</td><td>0</td></tr>
<tr><td>4</td><td>6</td><td>30</td><td>0</td><td>0</td></tr>
<tr><td>5</td><td>3</td><td>0</td><td>140</td><td>0</td></tr>
<tr><td>6</td><td>6</td><td>30</td><td>160</td><td>0</td></tr>
<tr><td>7</td><td>9</td><td>50</td><td>180</td><td>110</td></tr>
<tr><td>8</td><td>36</td><td>20</td><td>0</td><td>110</td></tr>
<tr><td>9</td><td>21</td><td>0</td><td>0</td><td>100</td></tr>
<tr><td>10</td><td>6</td><td>20</td><td>180</td><td>0</td></tr>
<tr><td>11</td><td>3</td><td>0</td><td>140</td><td>0</td></tr>
<tr><td>12</td><td>15</td><td>0</td><td>410</td><td>0</td></tr>
<tr><td>13</td><td>12</td><td>40</td><td>260</td><td>0</td></tr>
<tr><td>14</td><td>15</td><td>40</td><td>130</td><td>0</td></tr>
<tr><td>15</td><td>9</td><td>30</td><td>270</td><td>130</td></tr>
</table>

According to this report, statistical analysis of the data indicates that the TL neutron dosimeter can consistently detect 0.5 mrad of thermal neutrons and 5 mrads of fast neutrons within ±50% under ideal conditions.</td></tr>
</table>

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td>ARH-1903-DEL
SRDB 68500</td><td>200 Areas Operational Report for March 1971 (Apr 22). Routine operational monthly report that contains information as follows: “The new plutonium storage building, 2736-Z, was placed into service by the Plutonium Finishing Section. Initial survey results in the vaults indicate the installed shielding will significantly reduce the dose rates to personnel working in the vaults.”</td></tr>
<tr><td>PNNL-13524
SRDB 12856</td><td>Decision made to restart the Hanford N Reactor (August 1971).</td></tr>
<tr><td>ARH-2073
SRDB 60065, 60066, 60068</td><td>Plutonium Finishing Section, Radiation Control Report, 1971
<table>
<tr><th>Date</th><th>Hoods 7C-9B gamma</th><th>Hoods 7C-9B neutron</th><th>Hoods 7C-9B, inst. NP ratio</th><th>Button line gamma</th><th>Button line neutron</th><th>Button, instr. NP ratio</th></tr>
<tr><th colspan="7">Instrument measurements</th></tr>
<tr><td>Mar-71</td><td>9.2</td><td>12.8</td><td>1.4</td><td>9.1</td><td>1.7</td><td>0.2</td></tr>
<tr><td>Jun-71</td><td>8.3</td><td>15.0</td><td>1.8</td><td>5.3</td><td>2.6</td><td>0.5</td></tr>
<tr><td>Sep-71</td><td>7.1</td><td>19.1</td><td>2.7</td><td>3.0</td><td>2.7</td><td>0.9</td></tr>
<tr><td>Dec-71</td><td>6.8</td><td>26.2</td><td>3.9</td><td>3.6</td><td>2.6</td><td>0.7</td></tr>
<tr><th colspan="7">Film dosimeter measurements</th></tr>
<tr><td>Mar-71</td><td>4.6</td><td>3.3</td><td>0.7</td><td>3.9</td><td>1.2</td><td>0.3</td></tr>
<tr><td>Jun-71</td><td>5.6</td><td>4.8</td><td>0.9</td><td>3.0</td><td>2.8</td><td>0.9</td></tr>
<tr><td>Sep-71</td><td>4.8</td><td>5.4</td><td>1.1</td><td>2.5</td><td>2.3</td><td>0.9</td></tr>
<tr><td>Dec-71</td><td>4.4</td><td>4.8</td><td>1.1</td><td>1.9</td><td>2.2</td><td>1.2</td></tr>
</table></td></tr>
<tr><th colspan="2">1972</th></tr>
<tr><td>BNWL-SA-3955
SRDB 15397</td><td>Multipurpose Hanford thermoluminescent dosimeter (TLD) implemented for radiological workers.</td></tr>
<tr><td>BNWL-B-127
SRDB 13698</td><td>Hanford Multipurpose TL Dosimeter Field Tests and Evaluation (Aug). This report describes workplace parallel studies between the TLD nonpenetrating, penetrating and neutron dose response and the associated responses of Hanford beta/photon film and NTA film neutron dose responses. Studies involved workers wearing both types of dosimeters and also carboys placed in selected work areas with both types of dosimeters attached. These studies showed a significant under-response of the NTA neutron dose in comparison with the TLD neutron dose and resulted in a DOE/HQ technical study of Hanford neutron doses led by EJ Vallario.</td></tr>
<tr><td>ARH-2647
SRDB 4774</td><td>A Method for Estimating Neutron Exposures Received by Plutonium (draft). This report describes development of NP dose ratios to estimate an adjusted neutron dose for Hanford plutonium workers for years prior to 1972 when NTA film dosimeters were used and prior to 1950 when boron lined pencils were used along with portable instruments.</td></tr>
<tr><td>ARH-2473
SRDB 60070, 60072, 60074</td><td>Plutonium Finishing Section, Radiation Control Report, 1972
<table>
<tr><th>Date</th><th>Hoods 7C-9B gamma</th><th>Hoods 7C-9B neutron</th><th>Hoods 7C-9B, inst. NP ratio</th><th>Button line gamma</th><th>Button line neutron</th><th>Button, instr. NP ratio</th></tr>
<tr><th colspan="7">Instrument measurements</th></tr>
<tr><td>Mar-72</td><td>7.9</td><td>19.0</td><td>2.4</td><td>5.6</td><td>2.7</td><td>0.5</td></tr>
<tr><td>Jun-72</td><td>8.2</td><td>18.3</td><td>2.2</td><td>4.7</td><td>3.6</td><td>0.8</td></tr>
<tr><td>Sep-72</td><td>9.8</td><td>19.4</td><td>2.0</td><td>5.6</td><td>3.6</td><td>0.6</td></tr>
<tr><td>Dec-72</td><td>7.7</td><td>10.7</td><td>1.4</td><td>3.5</td><td>9.3</td><td>2.7</td></tr>
</table></td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th>Reference</th><th>Description</th></tr>
<tr><td colspan="2">1973</td></tr>
<tr><td>ARH-2792
SRDB 60017, 60016</td><td>Plutonium Finishing Section, Radiation Control Report, 1973
<table>
<tr><th>Date</th><th>Hoods 7C-9B gamma</th><th>Hoods 7C-9B neutron</th><th>Hoods 7C-9B, inst. NP ratio</th><th>Button line gamma</th><th>Button line neutron</th><th>Button, instr. NP ratio</th></tr>
<tr><td colspan="7">Instrument measurements</td></tr>
<tr><td>Mar-73</td><td>6.7</td><td>8.8</td><td>1.3</td><td>4.1</td><td>1.6</td><td>0.4</td></tr>
<tr><td>Jun-73</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Sep-73</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Dec-73</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
<tr><td colspan="2">1974</td></tr>
<tr><td>ARH-3082 SRDB 60076, 60077, 60079</td><td>Plutonium Finishing Section, Radiation Control Report, 1974
<table>
<tr><th>Date</th><th>Hoods 7C-9B gamma</th><th>Hoods 7C-9B neutron</th><th>Hoods 7C-9B, inst. NP ratio</th><th>Button line gamma</th><th>Button line neutron</th><th>Button, instr. NP ratio</th></tr>
<tr><td colspan="7">Instrument measurements</td></tr>
<tr><td>Mar-74</td><td>6.9</td><td>9.5</td><td>1.4</td><td>5.2</td><td>1.0</td><td>0.2</td></tr>
<tr><td>Jun-74</td><td>6.7</td><td>10.2</td><td>1.5</td><td>5.4</td><td>1.6</td><td>0.3</td></tr>
<tr><td>Sep-74</td><td>6.9</td><td>9.8</td><td>1.4</td><td>6.3</td><td>1.7</td><td>0.3</td></tr>
<tr><td>Dec-74</td><td>6.8</td><td>10.1</td><td>1.5</td><td>6.6</td><td>1.8</td><td>0.3</td></tr>
</table></td></tr>
<tr><td>UNI-174
SRDB 29156</td><td>1973 Year-End Exposure Report (May 1974). Dose components described individually to include neutron radiation as follows:

Annual dose summary as follows:
<table>
<tr><th>Type of exposure</th><th>Total exposure (mrem)</th></tr>
<tr><td colspan="2">Whole body gamma</td></tr>
<tr><td>Monthly badged employees</td><td>658,830</td></tr>
<tr><td>Quarterly badged employees</td><td>100,240</td></tr>
<tr><td>Annually badged employees</td><td>26,000</td></tr>
<tr><td>Total WB gamma</td><td>785,090</td></tr>
<tr><td>Total neutron exposure</td><td>1,330</td></tr>
<tr><td>Internal exposure WB dose</td><td>200</td></tr>
<tr><td>Total WB penetrating exposure</td><td>786,620</td></tr>
</table>
Details of neutron recorded dose as follows:
<table>
<tr><th>No. of employees</th><th>Dose/yr (mrem)</th></tr>
<tr><td>13</td><td>Less than 50</td></tr>
<tr><td>3</td><td>Between 50 and 100</td></tr>
<tr><td>5</td><td>Between 100 and 200</td></tr>
<tr><td>1</td><td>210</td></tr>
<tr><td>0</td><td>Greater-than 210</td></tr>
<tr><td>Total = 22</td><td>Total = 1330</td></tr>
</table></td></tr>
</table>

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

<table>
<tr><th colspan="2">1975</th></tr>
<tr><td>UNI-M-10
SRDB 59172</td><td>Document issued entitled, “Exposure Reduction Guide,” identifying companywide requirements (January 1, 1975)</td></tr>
<tr><td>UNI-372
SRDB 59171</td><td>1974 Year-End Exposure Report (June 1975). Dose components described individually to include neutron radiation as follows:
<table>
<tr><th>Type of exposure</th><th>Total exposure (mrem)</th></tr>
<tr><td colspan="2">Whole body gamma</td></tr>
<tr><td>Monthly badged employees</td><td>665,890</td></tr>
<tr><td>Quarterly badged employees</td><td>108,620</td></tr>
<tr><td>Annually badged employees</td><td>43,450</td></tr>
<tr><td>Total WB gamma</td><td>817,960</td></tr>
<tr><td>Total neutron exposure</td><td>2,700</td></tr>
<tr><td>Internal exposure WB dose</td><td>200</td></tr>
<tr><td>Total WB penetrating exposure</td><td>820,860</td></tr>
</table>
Details of neutron recorded dose as follows:
<table>
<tr><th>No. of employees</th><th>Dose/yr (mrem)</th></tr>
<tr><td>56</td><td>Less-than 50</td></tr>
<tr><td>5</td><td>Between 50 and 100</td></tr>
<tr><td>2</td><td>Between 100 and 200</td></tr>
<tr><td>0</td><td>Greater-than 200</td></tr>
<tr><td>Total = 63</td><td>Average = 40 mrem</td></tr>
</table>
</td></tr>
<tr><th colspan="2">1976</th></tr>
<tr><td>ORAUT-TKBS-0006-2</td><td>234-5Z RMC Line shut down in 1976 as a result of explosion in 242-Z. RMC Line restarted in 1985, shut down in 1989.</td></tr>
<tr><th colspan="2">1977</th></tr>
<tr><td>UNI-818
SRDB 59170</td><td>Document entitled “Criteria for Radiation Control Program” issued for United Nuclear Industries (July 5, 1977)</td></tr>
<tr><th colspan="2">1978</th></tr>
<tr><td>SRDB 26722</td><td>Accidental Irradiated Fuel Discharge from N Reactor Hanford Reservation Richland, Washington December 16, 1977</td></tr>
<tr><th colspan="2">1979</th></tr>
<tr><td>RHO-CD-704
SRDB 67503</td><td>The PUREX Plant receives irradiated production reactor fuels, which are processed to produce purified plutonium, uranium, and neptunium nitrates, which were shipped as liquid solutions to subsequent processing sites at Hanford. The PUREX Oxide Conversion Facility was built into the N and M Cell area (202-A Building), which is completely surrounded by the PUREX Building to provide for conversion of plutonium nitrate to plutonium oxide. The feed to the Oxide Conversion Facility is the normal PUREX product plutonium nitrate solution with 250 to 350 grams of plutonium per liter in about seven molar nitric acid. The produced plutonium oxide could then be loaded into sealed containers for shipment and storage.</td></tr>
<tr><td>UNI-M-10 Rev
SRDB 59172</td><td>UNC Nuclear Industries issues revision to “Radiation Exposure Reduction,” (June 1, 1979)</td></tr>
<tr><th colspan="2">1980</th></tr>
<tr><td>PNL-3213
SRDB 13700</td><td>Personnel Neutron Dosimetry at Department of Energy Facilities. This document describes prevalent dosimetry methods including NTA and TLD.</td></tr>
</table>

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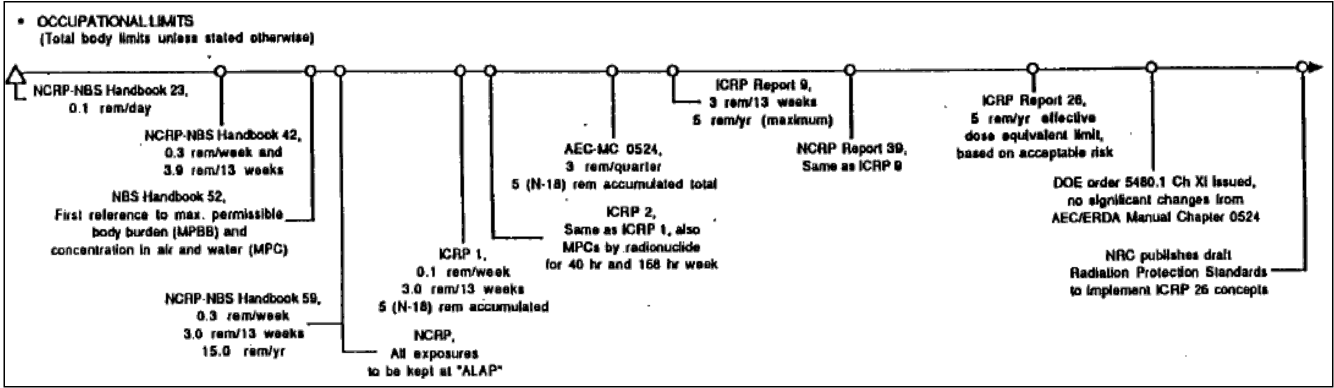
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
WHC-SP-0479 SRDB 67517	PUREX Handing Procedure for UNH Process Material, 202-A, 200-E (Jan 1, 1980). Description of some details of plutonium solution rework. Under section 4.11.2.4.1, it is stated that "Although a seemingly simple job, loading plutonium nitrate into shipping vessels requires ~70 operating steps executed in the proper sequence to minimize the potential for nuclear or radiation hazards. "
1981	
PNL-3536 SRDB 15355	Hanford Personnel Dosimeter Supporting Studies FY-1980. This document includes several studies of Hanford dosimetry system performance and some measurements in selected Hanford facilities.
1982	
PNL-3736 SRDB 15439	Hanford Personnel Dosimeter Supporting Studies FY-1981. This document includes several studies of Hanford dosimetry system performance and some measurements in selected Hanford facilities.
UNI-2137 SRDB 58670	Document issued entitled "Characterization of Surface Contamination in UNC Facilities," (August 30, 1982)
UNI-2164 SRDB 58669	Document issued entitled "Characterization of Airborne Radioactive Particles in UNC Facilities." (August 30, 1982)
1983	
PNL-3982 SRDB 13345	Response Characteristics of Selected Personnel Neutron Dosimeters (Sep).
UNI-M-10 Rev 2 SRDB 58680, 58681	UNC Nuclear Industries issues "ALARA Program and Radiation Exposure Reduction Guide," (Dec 31, 1983)
1984	
1985	
1986	
RHO-HS-ST-10-VOL1-ATT SRDB 60801	Document entitled "Historical Timelines of Hanford Operations (Aug 28, 1986)." Report provides detailed charts of Hanford operations to include a historical review of Hanford radiation protection guidelines shown below.



1987	
	N Reactor operation terminated (January).

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HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
PNL-6125 SRDB 262	Historical document entitled "Historical Review of Personnel Dosimetry Development and its Use in Radiation Protection Programs at Hanford, 1944 to the 1980s." (Feb 1987). This document describes many facets of the Hanford Radiation Protection Program. The two-element beta/gamma film dosimeter developed at the Metallurgical Laboratory (Pardue et al. 1944) and implemented at the Clinton Laboratory was used at Hanford until a new multielement beta/photon film dosimeter was implemented during April 1957. The NTA film was used in the regular Hanford beta/gamma holder from 1950 until 1957, at which time a separate "neutron dosimeter" was implemented. This neutron dosimeter consisted of the NTA film and a regular beta/gamma film packet for measurement of thermal and slow neutron exposure. Cadmium and tin shields were used to provide capabilities for slow neutron dose measurement. This dosimeter was assigned to workers with potential exposure to neutron radiation until the introduction of the thermoluminescent dosimeter (TLD) on January 1, 1972. A second multielement beta/gamma film dosimeter was implemented at Hanford during August 1962 which had improved low-energy photon and mixed beta/photon dose capabilities. This dosimeter included glass fluorods and an activation foil system to provide high-dose nuclear excursion dose capabilities. The multipurpose Hanford TLD system implemented January 1, 1972 replaced all of the beta/photon and neutron film dosimeters.
1988	
1989	
ORAUT-TKBS-0006-2	234-5Z RMC Line plutonium metal operations (May) shut down in 1989 with ongoing plutonium storage in PFP vault.
TRAC-0672 SRDB 67464	Radiological History of the PUREX Facility 1955 to 1989 (August 1, 1989). Historical review of radiological events at PUREX. On page 24, it is stated "Dose rates in the "old" N-cell hood room averaged 5 to 15 mR/hr during normal operations, but radiation measurements, on occasion, have been detected up to 300 mR/hr on the N-1 tank. Neutron radiation averaged from less than 1 to 3 mrem/hr in the N-cell glove box room." A renovated N-Cell area was constructed in 1984. On page 25, in reference to the new N-cell, it is stated "Radiation dose rate in the vicinity of the glove boxes will normally range from 2 to 20 mR/hr at the hood front while operating. Neutron radiation in the glove box rooms average 1 to 5 mrem/hr. Neutron measurements on the final product cans seldom exceed 20 mrem/hr."
PNL-6980 SRDB 27670	Historical document entitled "A Historical Review of Portable Health Physics Instruments and Their Use in Radiation Protection Programs at Hanford, 1944-1988 (Sep 1989)." This document describes the development of the various portable radiation detection instruments used at Hanford, the period of use, and the importance of these instruments to workplace radiation safety such as in the preparation of and work performance under Special Work Permits,
PNL-7439 SRDB 285	A Study of Detailed Dosimetry Records for a Selected Group of Workers Included in the Hanford Mortality Study. This document describes a review of the hard copy records in comparison with computer database records for selected workers included in the Hanford Mortality Study.
PNL-7447 SRDB 4793	Historical document entitled "Description and Evaluation of the Hanford Personnel Dosimeter Program from 1944 Through 1989 (Sep 1990)." This document describes details of the various Hanford external dosimetry system designs, algorithms, etc., along with laboratory energy response and dose measurements.

ATTACHMENT D
HISTORICAL TIMELINE OF RADIATION EXPOSURE ASSOCIATED EVENTS AT HANFORD

Reference	Description
1990	
PNL-7439 SRDB 285	A Study of Detailed Dosimetry Records for a Selected Group of Workers Included in the Hanford Mortality Study. This document describes a review of the hard copy records in comparison with computer database records for selected workers included in the Hanford Mortality Study.
1991	
PNL-7881 SRDB 13703	Response of TLD Albedo and Nuclear Track Dosimeter Exposed to Plutonium Sources
1992	
WHC-MR-0293 SRDB 470	Legend and legacy: Fifty Years of Defense Production at the Hanford Site.
1993	
WHC-MR-0440 SRDB 34730	“Multiple Missions: The 300 Area in Hanford Site History.” (Sep 1993).
1994	
PNL-10066 SRDB 305	An Assessment of Bias and Uncertainty in Recorded Dose from External Sources of Radiation for Workers at the Hanford Site.
1995	
1996	
PNL-10516 SRDB 309	Response of the Hanford Combination Neutron Dosimeter in Plutonium Environments
1997	
PNNL-11196 SRDB 5275	Historical document entitled “Retrospective Assessment of Personnel Neutron Dosimetry for Workers at the Hanford Site (Feb 1997).” This document was prepared to examine the specific issue of the potential for unrecorded neutron dose for Hanford workers with the conclusion that the neutron dose was generally underestimated prior to the implementation of the TLD on January 1, 1972.
DOE/RL-97-1047 SRDB 27666	History of the Plutonium Production Facilities at the Hanford Site Historic District, 1943-1990

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E1. EXECUTIVE SUMMARY

There is comparably low level neutron dose received by some N Reactor workers on some occasions that was not reliably measured prior to the implementation of the thermoluminescent dosimeter on January 1, 1972. The photon dose was reasonably accurately measured throughout N Reactor Operation from December 1963 through December 1986. A feasible option to reconstruct neutron dose to N Reactor workers prior to the use of the TLD is to multiply the measured photon dose by a NP dose ratio. The recommended NP lognormal distribution has a GM equal to 0.06, a GSD = 3.1 and a 95th percentile equal to 0.4. As described in this paper, relatively few positive neutron results for N Reactor workers have been measured with TLDs used since January 1, 1972. The entire annual dose history during the 1963-86 period of N Reactor operation was examined for a selected group of 592 workers. These workers were selected as persons employed at the 100-N reactor using criteria described in this paper. Only 14 of the sample of 592 workers showed a TLD-measured neutron and photon dose ≥ 30 mrem, respectively, during the 1972–1986 period. The distribution was based on a single worker with the maximum number of positive TLD-measured neutron doses consisting of 4 years (NP ratio: 1972–0.027; 1974–0.003; 1977–0.042; 1978–0.027) and for the other years had no measured neutron dose (1973, 1975, 1976, 1979, 1980, 1981, 1982, 1983, 1984, 1985 and 1986). The low-level neutron dose to workers at N Reactor is confirmed by the collective neutron dose reported during 1973 and 1974 as a fraction of 0.002 and 0.004, respectively, of the collective photon dose. The recommended NP ratio will result in significant assigned neutron dose for the period from 1964 through 1971 [i.e., measured neutron dose = 0 mrem. Assigned neutron dose = 806 mrem (50th-percentile) or = 1,612 mrem (95th percentile)]. The approach is considered to be favorable-to-claimants as illustrated in this attachment by comparing the TLD-measured neutron dose with the value that would be assigned using this approach for the period of N Reactor operation and this person's employment from 1972 through 1986 [i.e., measured neutron dose = 280 mrem. Assigned neutron dose = 934 mrem (50th percentile) or = 1,868 mrem (95th percentile)]. These neutron doses must also incorporate the ICRP Publication 60 weighting factor, which for the neutron category of 0.1 to 2 MeV is equal to 1.91 (ICRP 1991) and, thus, a further increase in assigned neutron dose of nearly a factor of 2 will occur.

E2. INTRODUCTION

The focus of this analysis concerns a technical basis for neutron dose reconstruction for Hanford 100 Area N Reactor Workers during the period of its operation from December 1963 through January 1987. A technical basis has been developed for neutron dose reconstruction at the Hanford eight single-pass cooling plutonium production reactors (B, C, D, DR, F, H, KE, and KW) constructed during the period from 1943 through 1954 that operated from 1944 through 1971 (Taulbee et al. 2008). Neutron radiation exposures to reactor workers at the Hanford 100 Area N Reactor were not reliably measured using personnel dosimeters prior to implementation of the Hanford TLD on January 1, 1972. Prior to the use of the TLD, Hanford used NTA personnel neutron film in a dedicated Hanford neutron personnel dosimeter implemented during 1958 with thermal and fast neutron dose capabilities as well as photon dose.

Hanford Radiation Protection professionals were well aware of limitations in NTA film capabilities to reliably measure intermediate energy neutron radiation dose for many years prior to startup of the N Reactor. Hanford established operational limits for WB dose in 1954 based on a safety factor of 5 to compensate for unknowns in dosimetry and risk (i.e., official guide of 15 rem WB dose per year was divided by 5). The operational limit for the photon component of the measured WB dose was established as 3 R/yr for photon and neutron radiation, respectively (GE 1954). In 1960, when the AEC adopted the NCRP radiation protection guidance for the WB external dose of 5 × (N-18) rem per year where N is the age in years, Hanford continued the practice to limit the WB photon dose to less than 3 rem/yr (GE 1960) The decision to stop assignment of NTA film personnel neutron dosimeters to N Reactor workers, along with workers at the Hanford single-pass cooling production reactors, was made effective during April 1966 (DUN 1966). For reasons explained in this attachment, the measured photon radiation dose to each worker for all years of N Reactor operation (i.e., shut down during January 1987) is considered to have been reasonably accurately measured by Hanford film and thermoluminescent dosimeters. The TLD-measured neutron dose is considered to be reasonably accurate with a significant potential to overestimate rather than underestimate the actual neutron dose (Endres et al. 1981; Scherpelz et al. 2000; Brackenbush et al. 1980). A timeline of significant events at Hanford associated with radiation protection of N Reactor workers is presented in Attachment D, Table D-2.

An option to retrospectively estimate a favorable-to-claimant neutron dose to N Reactor workers is to multiply the measured photon dose by a NP ratio. This option, assuming the distribution is properly chosen, will provide a favorable-to-claimant dose reconstruction because the vast majority of dose to N Reactor workers is the result of photon radiation exposure. It is clear from documentation in Attachment D that extensive surveys of N Reactor photon and neutron radiation exposures throughout the facility were required to comply with AEC-approved startup power accession plans. The record of TLD-measured doses confirms that neutron radiation exposure to workers was comparably low in comparison with the photon dose. The option to utilize an NP ratio to reconstruct potential neutron dose to individual workers avoids significant issues concerning:

1. During the period from December 1963 through April 1966, only selected N Reactor workers were assigned a Hanford NTA film neutron dosimeter.

2. During the period from May 1966 through December 1971, Hanford NTA film neutron dosimeters were not assigned to Hanford N Reactor workers.

3. Hanford neutron dosimeters did not reliably provide a reasonably accurate estimate of the actual neutron dose for N Reactor workers.

4. Substantial effort would be necessary to resolve unknowns regarding the completeness of the process whereby N Reactor workers signed a Neutron Exposure Register form upon access into N Reactor radiation zones where a neutron dose rate had been established (DUN 1966). The accuracy of the estimated neutron dose that was entered on the form would also need to be evaluated.

E3. SITE PROFILE NEUTRON DOSE RECONSTRUCTION RECOMMENDATIONS

The Hanford Site Profile External Radiation Technical Basis Manual prepared originally during 2003 recommends reconstruction of the neutron dose as follows:

- Use TLD-measured neutron dose from January 1972 to date along with the missed neutron dose using OCAS-IG-001 guidance (NIOSH 2007b).

- Prior to 1972, multiply the NP dose ratio times the measured and missed (using OCAS-IG-001 guidance) photon dose using ratios obtained from the following:

Process	GM	GSD	Upper 95th %
N Reactor	0.06	3.1	0.4

E4. HISTORY

Historically, several Hanford contractors were involved in N Reactor operation and maintenance and in evaluation of radiation exposure to workers (Marceau et al. 2002, p. 1.69) as follows:

- GE prior to January 1, 1965, managing all Hanford operations.

- GE through June 30, 1966, responsible for 100-N reactor operations.

- DUN, July 1, 1966 to August 1967, responsible for Hanford reactor operations and fuel fabrication.

- UNI, September 1967 to April 1973, responsible for Hanford reactor operations and fuel fabrication.

- UNI, April 1973 to June 1987, responsible for Hanford reactor operations and fuel fabrication.

- Battelle Memorial Institute as the Pacific Northwest Laboratory, contractor beginning January 1, 1965, in the capacity of assuming responsibility for technical direction of Hanford central personnel dosimetry services such as the WB counting facility, personnel dosimetry, site-wide radiological calibrations, research and development, etc.

- U.S. Testing Company beginning January 1, 1965 responsible for Hanford environmental and occupational radiochemical analyses and dosimetry services.

- JA Jones and subcontractor craftsmen were involved throughout the operation of N Reactor as noted in the various routine reports in Attachment D.

E4.1 FACILITY DESIGN

The design of the N Reactor [also commonly referred to as the 100-N or historically as the NPR (i.e., New Production Reactor)] was substantially different from the earlier eight Hanford single-pass cooling plutonium production reactors constructed during the period from 1943 through 1954. The earlier single-pass reactors, known as "piles" in the 1940s, drew cooling water from the Columbia River; the water was treated through a series of filtration and chemical processes before entering the pile; and then the water was returned to the river after holdup (~30 min to 6 hours) in retention basins to allow for short-term radioactive decay.

In contrast, the N Reactor primary coolant water was recirculated, thus releasing significantly less radioactive effluent to the Columbia River. The coolant circulated under pressure, allowing for much higher operating temperatures, and the water was demineralized so that less film was deposited inside the process channels. However, as is typical of commercial light-water reactors, substantial buildup in the coolant system of neutron activation and fission product nuclides did occur, which increased the significance of penetrating photon fields generally, and in maintenance work of reactor components of beta/photon radiation fields. The N Reactor core was surrounded by special layers of reflector graphite, water-cooled thermal shields constructed of boron steel and cast iron, and a primary shield of high-density concrete. Helium gas formed the pile atmosphere in a sealed system that prevented worker access without reactor operator knowledge while the reactor was operating. A fog spray system at both the front and rear reactor faces was provided for contamination control and cooling in case of a loss of contaminated steam from the core (WHC 1988).

The radiation environment at N Reactor was divided into zones with different shielding requirements (Bunch, 1962). Each zone had different entry requirements. N Reactor had five protective zones as follows:

- Zone 1, which is adjacent to the charge face, the discharge face, and the top of the reactor. No access is possible to this zone during operation. Monitored access is possible during reactor shutdown. This zone is operated at a negative pressure relative to Zone 2.

- Zone 2, which includes secondary radiation areas such as the inner and outer rod rooms, the gas system, the flux and rupture monitor room, the ball system, and the ventilation exhaust system from Zone 1. Normally, no access to the restricted areas of Zone 2 will be required during operation but limited emergency access is possible. Zone 2 is operated at a negative pressure relative to Zone 3.

- Zone 3 is a normal access or buffer zone with free access at all times except perhaps for quite abnormal conditions. This zone includes most of the work regions and corridors around the reactor in which metal handling and other routine operations are conducted.

- Zone 4 is an unlimited access area with essentially no elevated radiation exposure during normal operations.

- Zone 5 is defined as a warranted access area in which continuous access is maintained at all time including emergencies. Zone 5 is limited to the main control room and the main instrument room beneath the main control room.

E4.2 N REACTOR OPERATION

The Hanford low-enriched uranium, graphite-moderated, and water-cooled N Reactor achieved initial criticality on December 31, 1963. Approximately 1 year of testing was necessary for the N Reactor to achieve the design power of 4,000 MW (thermal) on December 9, 1964 (WHC 1988, Chapter 14). Throughout its history of operation, the N Reactor produced 9% ^{240}Pu reactor fuel-grade plutonium for the AEC's breeder reactor program, and 12% ^{240}Pu reactor fuel-grade fuel. In the 1980s, N Reactor produced only weapons-grade plutonium until it was shut down in January 1987. Figure E-1 presents N Reactor fuel and weapon-grade plutonium production throughout the years of operation (Lini 1993).

Throughout the years of N Reactor operation extensive administrative and technical limits were in effect such as in the form of operating safety limits and process standards. Startup of the reactor was particularly complex, involving a complete building radiation survey at stated levels of power ascension (Berrett and Hall 1964). Many operational problems were experienced in the early years of N Reactor operation with substantial downtime. As noted in Attachment D, a formal startup plan was adopted with defined tests such as the N1 physics testing, N2 testing of reactor operation just prior to providing steam for electrical power production, and N3 testing. Typically, formal documents were prepared for each step in the testing process for submittal to the AEC for its approval of advancement through the planned testing. During this process of testing, elevated photon and neutron radiation was measured (Greenborg and Berry 1964) emerging through N Reactor steam vent penetrations that are in the bottom shield of the reactor and open to the southeast and southwest corners of the ball hopper retrieval system. The corrective action consisted of adding a pipe offset to achieve a labyrinth design and providing additional shielding. This action was required for radiation protection and to reduce the possibility of neutron activation of system components in the ball recovery room (Hall 1964).

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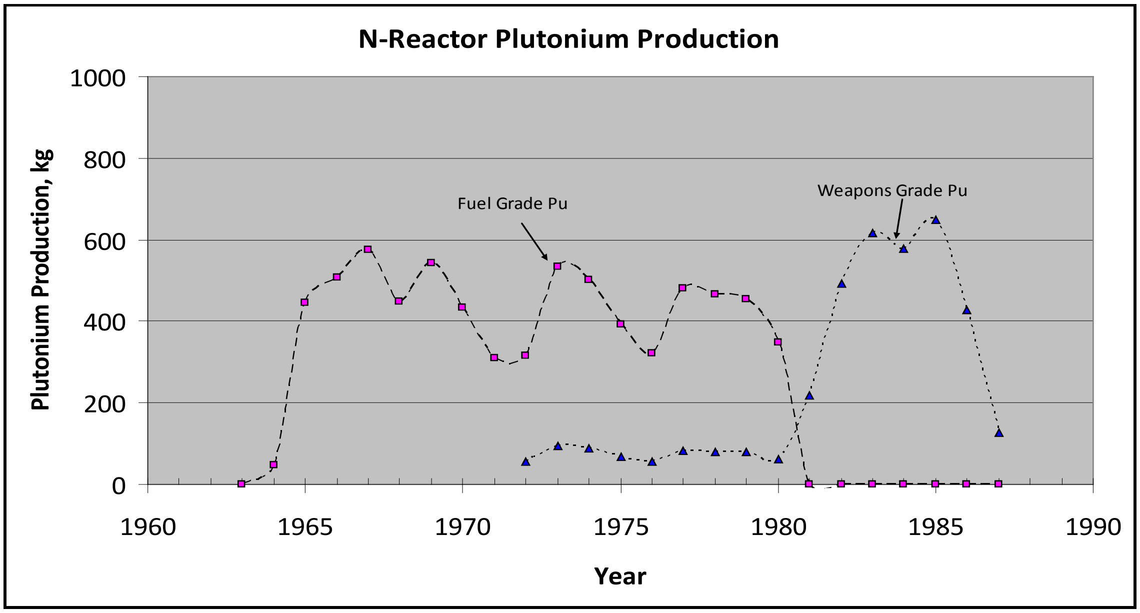

Figure E-1. Hanford N Reactor plutonium production (Lini 1993).

E5. RADIATION PROTECTION PRACTICES

The basic elements of Hanford radiation protection practices were well-defined prior to operation of the Hanford N Reactor. Pertinent Manuals of Radiation Protection specific to N Reactor Operation include:

- HW-78500, *Radiation Protection Controls & Procedures–N Reactor* (Vanderbeek 1964), published January 1, 1964.

- DUN-M-1, *Radiation Control Manual*, (DUN 1970) establishes occupational and nonoccupational exposure limits, and provides administrative check points, methods, and safeguards for use in controlling personnel exposure within limits.

Levels of beta, photon, and neutron radiation were monitored at the N Reactor during its period of operation from December 12, 1963 through 1987 by health physics staff members using personnel dosimeters, PICs, and portable radiation detection instruments. Personnel dosimeters represent the usual method to measure and record the official dose for a worker. Dosimeters assigned to workers are typically for a specified period (i.e., monthly or quarterly depending on potential for radiation exposure), and exchanged for new dosimeters according to an established monthly or quarterly schedule. The used dosimeters are typically processed and doses assigned as part of a much larger Hanford-wide group of dosimeters. Typically, the official dose based on the dosimeter is not received by the worker or their supervision until many days after a dosimeter is routinely exchanged. Until the official personnel dosimeter dose is received, administrative control of worker exposures is based on results of PICs or portable instruments and timekeeping. The portable instrument and PIC data are the methods actually used to measure and control worker radiation exposures. Basically, an administrative radiation exposure record is maintained for each worker for use in limiting exposures until the dose results from the personnel dosimeters are received. The dosimeter exchange cycle is selected based on the exposure potential for each worker and, in case of an incident, personnel dosimeters can be special-processed at any time. This process requires close attention by supervision and radiation safety personnel to the total exposure received by workers.

E6. METHODS

E6.1 SITE EXPERT INTERVIEWS

Interviews with site experts were conducted and documented regarding their assessment of the potential for significant neutron exposure of N Reactor workers, the potential work areas, and work tasks. A tour of the N Reactor was made during November 2008 with persons with expert knowledge of N Reactor design and operation. N Reactor site experts were asked to provide information concerning:

- Their knowledge of workplace radiation levels at the N Reactor, methods of measurement, exposure control practices, and particularly information concerning significant neutron exposure.

- Their knowledge concerning changes in N Reactor construction and/or operations that might undermine the applicability of applying statistical parameters from TLD-measured doses to the pre-1972 period.

- Their knowledge concerning performance of workplace surveys and particularly access to the documented surveys as well as access to the N Reactor worker measured doses, and specifically access to the N Reactor measured-TLD-measured neutron and photon doses during the period from 1972 through 1987.

- Their knowledge concerning any other information that might be relevant to the reconstruction of neutron dose to N Reactor workers prior to 1972.

E6.2 DATA CAPTURE

Data capture trips to DOE–RL with the expressed objective to obtain detailed monitoring data occurred during: October 9–15, 2007; December 2–7, 2007; June 2–6, 2008; July 7–15, 2008; September 22–26, 2008; October 13–17, 2008; and November 17–24, 2008. Keyword searches were conducted of the multiple Hanford record systems by DOE–RL and contractors and the ORAU Team using DOE–RL-provided database indexes to identify pertinent technical reports, survey forms, and correspondence. Prior to these data collection trips, record indexes were received from DOE-RL and used in the analysis of workplace photon and neutron fields. A large number of boxes and documents were identified that potentially contained relevant records. The contents of these boxes and documents were reviewed during the data collection trips. Significant documents are noted in Attachment D. Sources of data of particularly significant value include:

- Validation of photon dose measurements at the Hanford N Reactor.

- Routine operations reports that typically included some information concerning radiological information such as the annual exposure reports that summarized annual collective neutron and photon doses as shown in Attachment D.

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- Radiation Protection Procedures manuals that covered essentially the entire operating history of N Reactor.
- Query of the Hanford Radiological Record system to identify N Reactor workers and subsequently to receive the annual shallow, deep, neutron, and extremity doses during the period of N Reactor operation.
- DOE Radiation Exposure Information Record System (REIRS) routine reports.
- U.S. Nuclear Regulatory Commission (NRC) measured neutron and photon doses in commercial nuclear plants.

Interestingly, although Hanford had available portable radiation protection instrumentation to readily measure neutron exposure in the workplace (WHC 1988) and there were requirements for surveys when there was a potential for significant exposure, few of the hundreds of survey forms examined actually included results of surveys for neutron radiation exposures. There were requirements for neutron surveys during startup, and there was a documented survey that showed elevated neutron exposure rates in the 109 building incoming steam penetration with recommendations for adding additional shielding. The annual exposure reports prepared by UNC in 1973 and 1974 did include a summary of the annual photon and neutron doses.

E6.3 DOE REIRS DATA

The DOE REIRS records were examined as a potential source of information regarding WB doses for N Reactor workers considering the “reactor” category used for many years. For Hanford, prior to 1972, the reactor category also included doses received at the once-through reactors that would tend to bias the analysis towards a larger WB dose because there is greater exposure of workers, particularly to neutron radiation, in the once-through reactors.

E6.4 U.S. NUCLEAR REGULATORY COMMISSION (NRC) STUDIES OF COMMERCIAL NUCLEAR PLANTS

During the period of N Reactor operation, there were studies of neutron exposure of workers in commercial nuclear power plants. The NRC has documented extensive workplace studies of neutron spectra and dose, and was instrumental in the national adoption of the National Voluntary Laboratory Accreditation Program for testing personnel dosimeter performance and accreditation of the dosimetry service providers. Pacific Northwest National Laboratory (PNNL) was involved in many of these studies using the Hanford dosimeter along with personnel dosimeters (i.e., NTA, CR-39, TLDs) from other DOE Sites (i.e., Environmental Measurements Laboratory, Lawrence Livermore National Laboratory, SRS) and a wide variety of instruments (Snoopy, remballs, Bonner spheres, TEPCs, ^{3}He counters, etc.) to measure the neutron dose (Endres et al. 1981).

E7. RESULTS

E7.1 SITE EXPERT INTERVIEWS

Several site experts with detailed knowledge of N Reactor operation and radiological history were interviewed. Three of these experts had worked at N Reactor throughout its entire operating history.

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Site Expert 1 (Fix 2007a; Bihl 2008a). Documented interviews with Hanford Site expert who originally was hired at Hanford in 1948 and worked as a radiation monitor in the early days primarily in the 100 Area reactor areas and then as a health physicist for the last approximately 15 years of his employment. He worked at 100-N throughout all of N Reactor years of operation. There are two documented interviews. This expert stated that "The gamma exposures at 100-N with the recirculating coolant were substantially higher than the once-through reactors. Access to several high exposure areas were controlled. He was unaware of any significant facility modification that would change the general radiation field characteristics."

Site Expert 2 (Fix 2008a). Documented interview with Hanford Site expert concerning his experience at the 100 Area reactors where he performed charge, discharge, and storage and shipment of irradiated fuel elements. Site expert also performed startup, operation, and shutdown at four of the reactors as the control room console operator.

Site Expert 3 (Fix 2007b). Documented interview with Hanford Site expert who originally began employment at Hanford in June 1956. Site expert spent substantial time in research activities such as in the Building 321 Exponential Pile Physics Laboratory, and in Building 326 working with several radiation sources such as ^{238}PuBe, developing neutron spectrometer capabilities, performing work to characterize the NTA film energy response, and working to develop TLD systems. Site expert had several non-Hanford project roles including a multiyear NRC project to measure neutron spectra and dose in U.S. commercial nuclear reactors, which is described in several NUREG reports.

Site Expert 4 (Fix 2007c). Documented interview with Hanford Site expert who arrived at Hanford in about 1956 as a radiological engineer with primary responsibility for the 100-B/C reactors but who also worked at 100-D/DR and 100-F. Site expert spent entire career involved with reactor radiation safety supporting Hanford reactor operations. Interview concerned expert's recollection of radiation exposures of workers in the Hanford reactors, the significance of neutron dose, and knowledge of the AEC 1972 neutron dose Investigation.

Site Expert 5 (Scalsky 2007a). Documented interview with Hanford Site expert who began employment at Hanford plutonium facilities in 1947. Site expert worked in all Hanford areas during his career at Hanford and has written numerous technical reports including historical reviews of the Hanford radiation dosimetry program.

Site Expert 6 (Fix 2007d). Documented interview with Hanford Site expert who began employment at Hanford facilities in 1950 working primarily in the 100 Area reactor and 300 Area fuel fabrication facilities as a process engineer. Interview concerned expert's recollection of radiation exposure issues with Hanford 100 Area Reactor Facilities. Site expert did not consider himself to be a primary radiation worker but was very aware of radiation exposure limits, the use of SWPs, and general radiation safety activities (protective clothing, respirator protection, etc.).

Site Expert 7 (Fix 2008j) Documented interview with a Hanford Site Contractor Radiation Control Technologist (RCT) who arrived in 1983 at 100-N Reactor progressing to a Supervisor position. This person recalled that there were few neutron radiation fields at N Reactor accessible to workers. There might have been low-level neutron radiation fields of about 1 to 2 mrem/hr in the inner rod room. However, during reactor operation, access to the inner rod room required continuous RCT coverage. In general, the room was characterized by significant gamma radiation fields and could be accessed only while the reactor was down.

Site Expert 8 (Fix 2007e). Documented interview with Hanford Site expert who arrived at Hanford in 1950. Site expert had responsibilities for site-wide compliance with AEC/DOE Health and Safety (H&S) orders, directives, etc., as a senior health physicist. Expert stated on several occasions that all legitimate safety issues were resolved in favor of the workers. Expert provided a copy of a review of site exposure limits associated with a 1967 labor dispute at N Reactor (Hicks and Yesberger 1967).

Site Expert 8 (Fix 2008k). Documented interview with Hanford Site expert who arrived at Hanford in 1956 working at Purex and subsequently after military and other site work activities was assigned to 100-N in 1983 as a radiological engineer. This Site expert stated “The physical structure of 100-N could not be reasonably changed. Although he could not say definitively about the reactor prior to his employment there, his opinion was that neutron-to-photon ratios should have been reasonably similar throughout the operating history.”

Generally, the site experts stated there should be extensive records of radiation instrument surveys that included neutron exposure measurements even though it was generally their experience that the neutron doses were generally not on the routine survey forms. Attempts to obtain radiation surveys for the startup power ascension requirements were not successful. The experts confirmed that neutron dose could be measured in some locations but that it was comparatively insignificant in comparison to the photon dose received by workers. Locations where there was neutron radiation, such as the inner rod room, also had photon radiation and access to these areas was limited while the reactor was operating.

E7.2 DOSIMETER RECORDED PHOTON DOSE

The AEC 1972 investigation of neutron dosimetry at Hanford stated the conclusion that the measured deep dose from photon radiation with Hanford film and thermoluminescent dosimeters is reasonably accurate. Additional reasons specific to N Reactor operation to judge that the recorded photon penetrating dose is reasonably accurate include:

- Improved Hanford multielement dosimeters were used for all years of N Reactor operation (i.e., December 1963 through January 1987).
- Response characteristics of these personnel dosimeters are well documented (Kocher et al. 1972; Fix et al. 1981; Fix et al. 1982; Wilson 1987).
- Radiation Protection Procedures at N Reactor (Vanderbeek 1964; DUN 1967, 1968, 1971) required monitoring of all workers with significant potential for significant exposure.

  The Hanford dosimeter system performance at the time of N Reactor operation had been extensively reviewed in the general effort to develop and adopt a national dosimeter performance testing standard (Barber 1967; Unruh et al. 1967).

- PICs were extensively used and photon doses based on PICs were evaluated in comparison with the dosimeter measured photon dose (Valentine, 1965).

The measured photon dose for the thermoluminescent, film, and pencil dosimeters was evaluated in studies leading to the implementation of the TLD on January 1, 1972. Comparison of dose results for dosimeters worn by DUN workers during November 1970, December 1970, and January 1971 is

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shown in Figure E-2 based on data contained in BNWL-B-129 (Nichols et al. 1972). It is evident that all three types of dosimeters provide nearly identical penetrating photon radiation dose results. Concern was expressed at the time of this study regarding worker compliance to actually wear all three dosimeters at all times. The zero results for thermoluminescent, film, and pencil dosimeters (along the abscissa) are anticipated to be associated with workers not wearing one or more of these dosimeters. Field tests contained in BNWL-SA-3955 (Kocher et al. 1971) show similar good results in comparisons of penetrating photon radiation doses among the film, pencil, and thermoluminescent dosimeter systems. Unfortunately, comparison of measured neutron doses (i.e., NTA film, PIC-boron lined and thermoluminescent dosimeter systems) such as those done for many of the other Hanford work areas and included in the BNWL-B-129 document was not done. This might have simply been because N Reactor workers were not wearing NTA neutron dosimeters. However, processing the TLD involves automatically receiving all dose results (i.e., nonpenetrating, penetrating, slow and fast neutron). In BNWL-B-129, there are a couple of indications of low-level slow neutron dose for a couple of dosimeters only but generally there is no indication of any significant neutron dose. It is also possible that N Reactor was not operating during the period from November 1970 through February 1971 when these field comparison tests were being made.

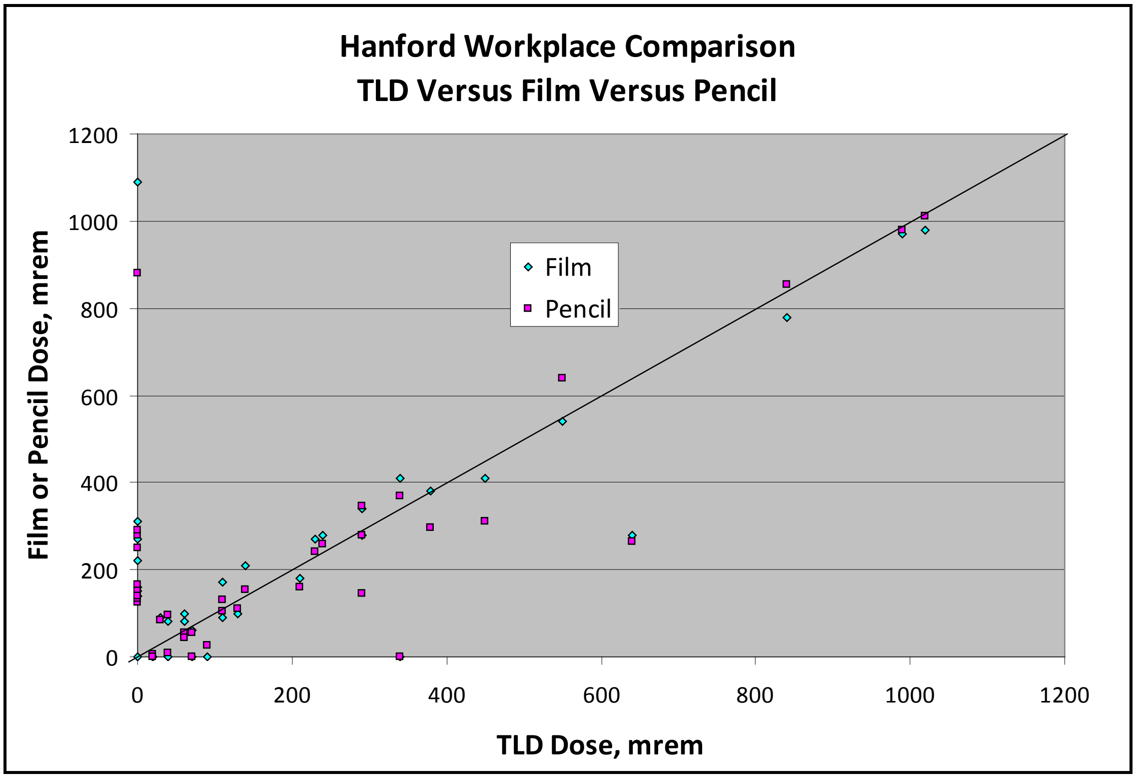

Figure E-2. Comparison of parallel field testing of thermoluminescent, film, and pencil dosimeters.

E7.3 N REACTOR REPORTS, POLICIES AND PROCEDURES

Data collections using key word searches were done to identify N Reactor routine operations reports that included:

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- Radiological information such as the annual exposure reports that summarized annual collective neutron and photon doses, as shown in Attachment D, Table D-2.

- Radiation Protection Procedures manuals and reactor power ascension startup procedures for documented workplace surveys.

- Boxes of archive Hanford N Reactor records such as for example the documents listed in Table E-1.

Table E-1. Sample of Hanford N Reactor data collection.

Box #	Year	General description	From	To
9432	RAD SURVEY RPT+MISC 65-66	RCS-Code: C2506D Custodian: Redacted Cust Addr: 1114n/100n Radiation Monitoring 105 kw. Radiation Survey Report Routine & Repetitive Surveys, Supplemental Routine Surveys, Startup Routines, Routine Neutron Survey, Building Survey Records, Shift Routine	01/01/65	12/01/66
11304	RAD SURVEY RPT+MISC 66-68	Rcs-Code: C2506d Custodian: Redacted Cust Addr: 1114n/100n Hand & Shoe Counter Background & Source Checks, Shift Log, Radiation Survey Report, Air Sample Log Sheets, Radiation Work Procedures, Neutron Survey Record, Portable Instrument & Inventory Check	06/01/66	12/01/68
11309	RADIATION SURVEY RPTS ETC 69	Rcs-Code: C2506d Custodian: Redacted Cust Addr: 1114n/100n Radiation Survey Reports, Air Sample Log, Routine Start Up Surveys, Supplemental Routine Surveys, Routine And Repetitive Surveys, Radiation Work Procedures.	01/01/69	12/01/69
13674	RADIATION SURVEY RPT ETC 1967	Rcs-Code: C2506d Custodian: Redacted Cust Addr: 1114n/100n Reactor Stack Effluent Record, Radiation Survey Report, Supplemental Routine Surveys, Startup Surveys, Routine Neutron, Portable Instrument Check & Inventory, Routine & Repetitive Surveys, Shift	01/01/67	12/01/67
18818	RADIATION SURVEY RPTS ETC 69	Rcs-Code: C2506d Custodian: Redacted Cust Addr: 1114n/100n Supplemental & Startup Routine Surveys, Building Survey Records, Routine & Repetitive Surveys, Radiation Survey Report 105b Building, Routine & Repetitive Surveys, Air Sample Log, Building Survey	01/01/69	12/01/69
26844	RADIATION SURVEY RPTS 65-8/71	Rcs-Code: C2506d Custodian: Redacted Cust Addr: 1114n/100n Routine & Repetitive Survey Reports, Air Sample Log, Reactor Stack Effluent Record	01/01/65	08/01/71
82022	RADIATION SURVEY REPORTS	Rcs-Code: C2506d Custodian: Redacted Cust Addr: 1114n/100n Radiation Survey Reports Ke & Kw Air Sample Logs Ke & Kw, Routine And Repetitive Survey Reports Ke & Kw	01/01/82	01/01/83

The documentation described in Table E-1 and in Attachment D, Table D-2 clearly states requirements for photon and neutron radiation surveys. In particular, the startup power accession plan (submitted to AEC for approval) clearly states requirements for building surveys to perform a complete building radiation survey for shielding adequacy and detect any unforeseen radiation beams, in each test step calling for special data (i.e., power levels of 0, 100, 200, 300 and 400 MW). A significant beam was detected in early 1964 (Greenborg and Berry 1964) in which significant dose rates of gamma and neutron radiation were emerging below the steam vent penetrations. The N Reactor steam vent penetrations are located in the bottom shield of the reactor and open to the southeast and southwest corners of the ball hopper retrieval system. Hanford Laboratories personnel were called in to instrument these penetrations to determine the gamma and neutron radiation intensities. As noted in Hall (1964), the cause on investigation was neutron radiation streaming down the steam vent piping provided at two locations to permit venting of steam from a process tube rupture. Corrective action was noted at the time as being required for purposes of radiation protection and to reduce the possibility of neutron activation of system components in the ball recovery room. The action consisted of adding a pipe offset to achieve a labyrinth design and to provide additional shielding.

E7.4 QUERY OF N REACTOR WORKERS DOSIMETER MEASURED NEUTRON AND PHOTON DOSE

A collaborative effort with DOE Hanford Radiological Records was conducted with the objective to select only the N Reactor workers recorded neutron and photon doses (i.e., actually shallow, deep, neutron, X-ray, eye dose categories) from 1964 through 1987 separately from doses for workers at the other single-pass reactors (i.e., which generally stopped operations prior to 1972) and other Hanford operating areas. The basic premise to select the appropriate workers was based on the observation by working with the database of a continued affiliation into 1967 of General Electric identified personnel to support operation of the N Reactor following the general termination of General Electric's role as the primary Hanford Site operations contractor which occurred approximately on January 1, 1965. Therefore, a query was made of the Hanford Radiological Record System to select only employees that met the following criteria.

- A recorded dose during 1967 (last year of GE contract role at Hanford to operate 100-N).
- A contractor code of AA (General Electric) during 1967.
- A payroll identification number less than 30000.
- Worker does not have an excreta result record for Pu-239 or U. This was necessary to distinguish between workers at N Reactor who might have transferred in earlier years from fuel fabrication or plutonium separation facilities.
- Only workers with contractor codes of AA (General Electric), HH (Douglas United Workers), VV or WC (Westinghouse Hanford) for any year.
- Subsequently, a few workers with significant X-ray doses were eliminated because this is seen only at Hanford plutonium facilities.

The query resulted in dose results for a total of 592 selected workers for which there were a total of 4,825 dose records with a collective dose of 3,301,070 mrem of photon penetrating dose. A scatter plot of the recorded annual shallow, neutron and extremity dose normalized to the recorded deep (photon) dose for each worker and each year is shown in Figure E-3. The shallow and deep dose is closely associated as would be expected because the majority of the shallow dose results from penetrating photon radiation.

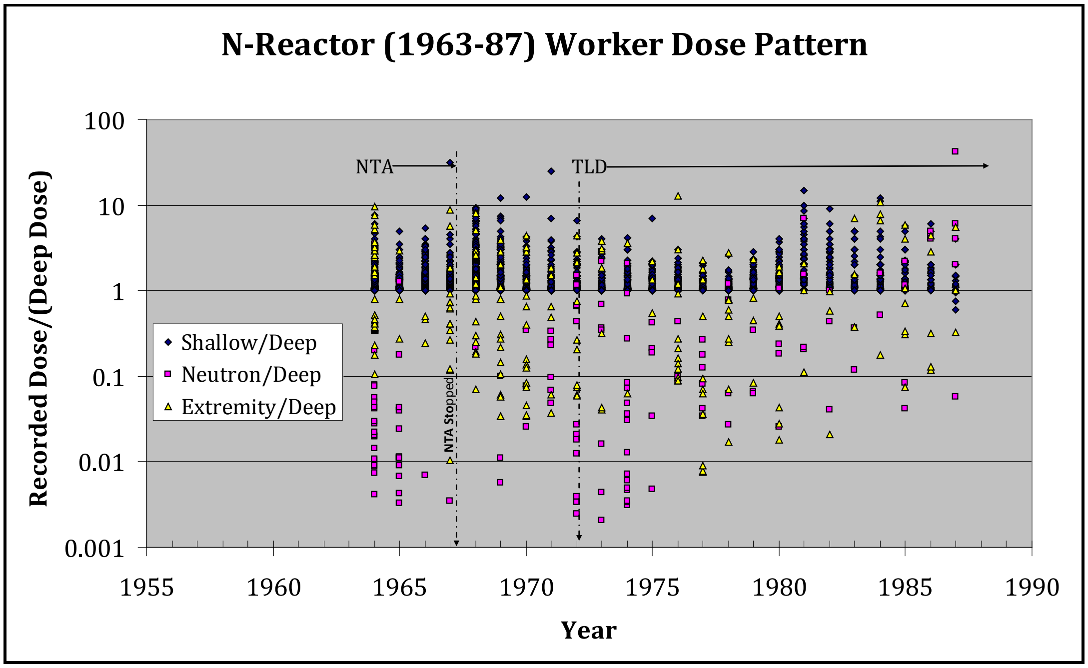

Figure E-3. Trend of recorded shallow, neutron, and extremity annual dose to recorded deep dose for 4,777 records with deep annual dose >0.

There is occasional high extremity dose for some workers likely associated with maintenance activities. There is also occasional neutron dose for some workers at generally much lower doses than the recorded deep dose. There also does not appear to be any significant change in the magnitude of the measured neutron dose prior to 1972 when either NTA or no neutron dosimeter was used and after 1971 when all workers were assigned the TLD which inherently measured any positive neutron dose. A plot of all of the data with a positive neutron dose and the NP ratio for each year of record is shown in Figure E-4. There is no distinct trend in the plotted data. A plot of the recorded annual photon dose for only those records with a positive recorded annual neutron dose is shown in Figure E-5. The data in Figure E-5 illustrate that there is essentially no correlation between the recorded neutron and photon doses overall. There are only 30 annual dose records with photon and neutron doses ≥30 mrem, respectively; and only 14 records for TLD only results. The explanation is likely that there are few occasions when workers receive a measurable neutron exposure, whereas significant photon dose is received in many routine work tasks including when the reactor is not operating and there is no neutron exposure. This was also observed by investigators analyzing a large amount of commercial power reactor neutron and photon measured doses (Eisenhauer and Schwartz 1983). All 30 of the dose results are shown in Table E-2[2]. A lognormal analysis of the 14 TLD results is presented in Table E-3.

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[2] Upon review, it was subsequently determined that a single worker was erroneously identified as a 100 N worker in 1964 and 1965. This worker had the highest observed NP ratio but the exposure occurred at the Hanford Plutonium Facility prior to this worker becoming a 100N worker.

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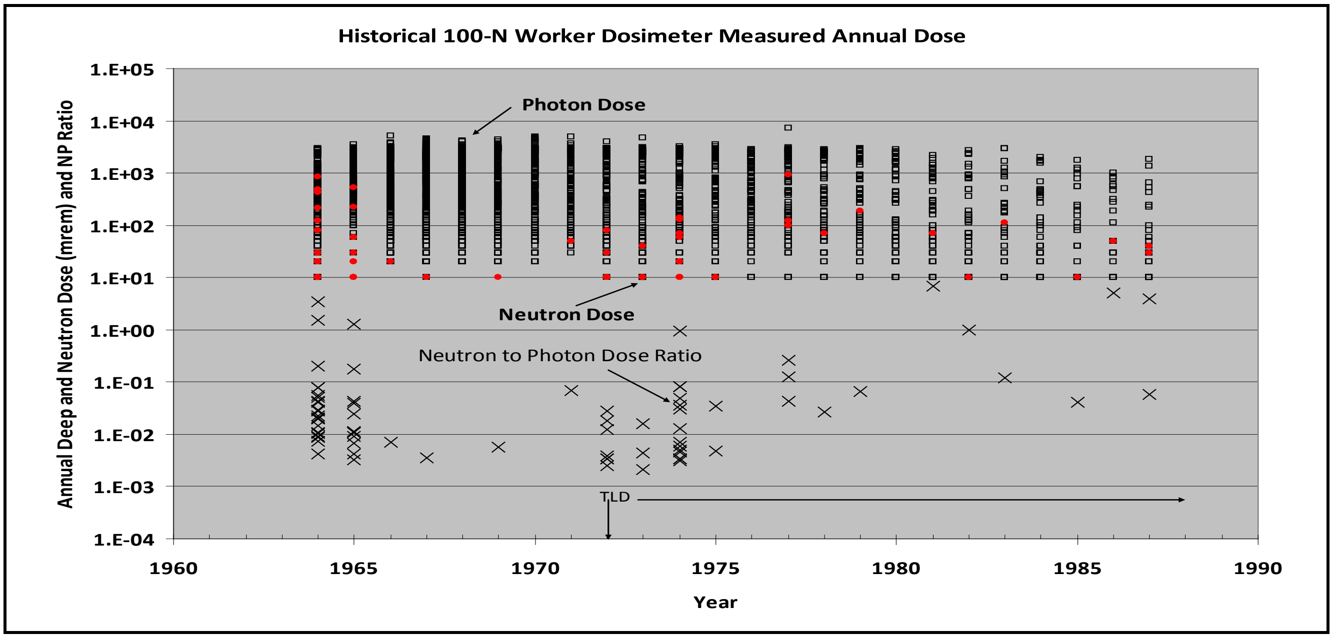

Figure E-4. Graph of N Reactor worker annual measured photon and neutron, and the calculated NP ratio.

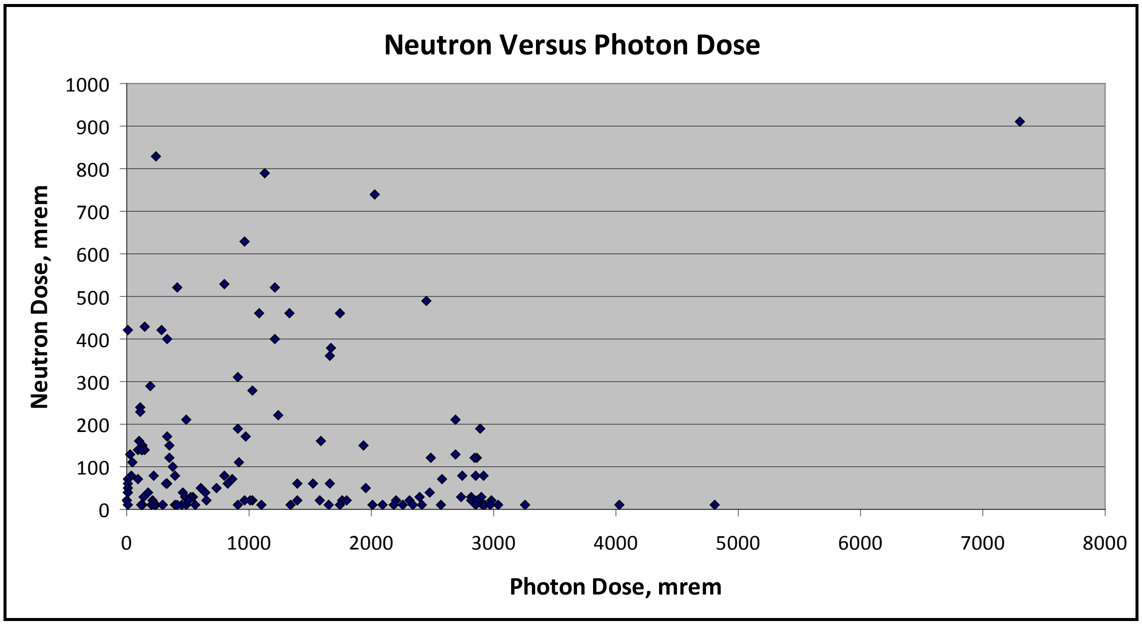

Figure E-5. Trend of recorded photon versus neutron dose for all >0 recorded neutron doses.

There is only one worker (i.e., unique REX-ID) who apparently received a TLD measurable neutron exposure in four different years as shown in Table E-4. Recorded doses for this person for all years are shown in Table E-5. Table E-5 also includes the pre-1972 Site Profile options to assign neutron dose using the GM = 0.04 and 95th percentile = 0.08 or to utilize the lognormal statistical parameters (GM = 0.06, 95th Percentile = 0.4) of the 14 positive TLD neutron dose measurements. The selection

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Table E-2. List of N Reactor worker measured neutron and photon dose, ≥30 mrem, respectively.

ID[a]	**Year**	**Dose (mrem)**			**NP ratio**
		Shallow	**Deep**	**Neutron**	
Pre-TLD determined neutron dose					
#1	1964	2,480	2,450	490	0.20
#2	1964	2,690	2,690	210	0.08
#3	1964	2,860	2,860	120	0.04
#4	1964	2,860	2,850	80	0.03
#5	1964	2,760	2,740	80	0.03
#6	1964	2,910	2,900	30	0.01
#7	1964	2,890	2,820	30	0.01
#8	1964	540	540	30	0.06
#9	1965	1,280	1,240	220	0.18
#6	1965	1,540	1,520	60	0.04
#3	1965	1,390	1,390	60	0.04
#10	1965	2,760	2,730	30	0.01
#11	1971	730	730	50	0.07
TLD-measured neutron dose					
#12	1972	2,960	2,920	80	0.03
#13	1972	2,640	2,390	30	0.01
#14	1973	2,550	2,480	40	0.02
#15	1974	240	150	140	0.93
#16	1974	2,740	2,690	130	0.05
#17	1974	930	860	70	0.08
#18	1974	2,340	1,660	60	0.04
#19	1977	7,770	7,300	910	0.12
#20	1977	2,980	2,840	120	0.04
#21	1977	400	380	100	0.26
#12	1978	3,040	2,580	70	0.03
#22	1979	3,110	2,890	190	0.07
#23	1983	2,050	920	110	0.12
#3	1987	580	520	30	0.06

a. Assigned unique worker number.

Table E-3. Lognormal statistical parameters to measured TLD neutron dose.

Process	**No. of values**	**GM**	**GSD**	**95th-percentile**	**Fit***
TLD Results	14	0.06	3.1	0.4	0.13

a. Kolmogorov-Smirnov test used as a measure of goodness of fit to a lognormal distribution.

of the statistical parameters certainly appears to be favorable-to-the-claimant based on the assigned neutron dose for this worker in that substantially greater neutron dose is assigned for the post-1972 period than measured with the TLD as shown in Table E-5.

Table E-4. Unique REX-ID worker annual dose records with positive neutron dose.

ID	Year of dose	Dose (mrem)			NP ratio
		Shallow	Deep	Neutron	
#12	1972	2960	2920	80	0.027
#12	1974	3180	2930	10	0.003
#12	1977	2980	2840	120	0.042
#12	1978	3040	2580	70	0.027

Table E-5. Unique REX-ID worker measured and assigned annual neutron doses for 1964–86.

ID	Year of dose	Recorded dose (mrem)			Assigned neutron dose options			
		Shallow	Deep	Neutron	GM= 0.04	95%=0.08	GM= 0.06	95%=0.4
#12	1964	1,480	1,450	0	58	116	87	580
#12	1965	2,770	2,590	0	104	207	155	1,036
#12	1966	2,460	2,460	0	98	197	148	984
#12	1967	2,130	2,130	0	85	170	128	852
#12	1968	2,920	2,920	0	117	234	175	1,168
#12	1969	2,990	2,990	0	120	239	179	1,196
#12	1970	2,760	2,760	0	110	221	166	1,104
#12	1971	2,900	2,850	0	114	228	171	1,140
Subtotal	1964–71	20,410	20,150	0	806	1,612	1,209	8,060
		TLD-measured doses below			Assigned neutron dose			
#12	1972	2,960	2,920	80	117	234	175	1,168
#12	1973	2,760	2,750	0	110	220	165	1,100
#12	1974	3,180	2,930	10	117	234	176	1,172
#12	1975	3,320	2,870	0	115	230	172	1,148
#12	1976	2,230	2,000	0	80	160	120	800
#12	1977	2,980	2,840	120	114	227	170	1,136
#12	1978	3,040	2,580	70	103	206	155	1,032
#12	1979	2,780	2,540	0	102	203	152	1,016
#12	1980	1,470	1,170	0	47	94	70	468
#12	1981	140	100	0	4	8	6	40
#12	1983	510	500	0	20	40	30	200
#12	1984	140	100	0	4	8	6	40
#12	1985	230	40	0	2	3	2	16
#12	1986	20	10	0	0	1	1	4
Subtotal	1972–86	25,760	23,350	280	934	1,868	1,401	9,340

This data seems very limited other than it does appear that neutron dose to N Reactor workers is low compared to the measured photon dose considering that during the period from 1972 through 1987 using the very neutron radiation sensitive Hanford TLD, only 14 dosimeters measured a dose ≥30 mrem, respectively.

E7.5 DOE REIRS ANNUAL DOSE SUMMARIES

The DOE/AEC required annual reports of the measured doses do include separation of dose according to a reactor facility category. The dose data for Hanford for the Reactor category and the

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dose ranges is shown in Table E-6 according to the total measured WB dose (i.e., photon plus neutron). This data does not include identification of the neutron dose component only.

Table E-6. Hanford reactor category REIRS/REMS reporting.

Year	Total	<MDL	<0.1	≤0.5	≤1.00	≤2	≤3	≤4	>4	Total collective dose, person (rem)
1981	868	39	199	217	119	194	99	1		698
1980	685	15	172	159	76	136	134	2		652
1979	667	13	85	88	87	140	157	12		761
1978	583	2	129	154	48	122	168	2		721
1977	568	4	16	124	86	138	183	13	4	827
1976	542	1	12	106	100	171	138	14		
1975	446	3	10	72	70	108	155	26	2	
1974	390		21	45	58	82	149	30	5	679

E7.6 UNC ANNUAL EXPOSURE SUMMARIES

The 1973 and 1974 UNC annual reports received from DOE RL contain an overview of dosimeter measured neutron doses to workers during 1973 and 1974. This is shown in Table E-7 along with the measured photon dose. It is evident that the collective neutron dose is a very small fraction of the collective photon dose (i.e., 1973-0.2%; 1974–0.4%). The Hanford multipurpose TLD was used for the monthly and quarterly exchanged dosimeters (i.e., basic dosimeter likely used for annual exchanged dosimeter). The Hanford TLD is comparatively very sensitive to workplace neutron radiation (Brackenbush et al. 1980). The distribution of the measured neutron dose is shown in Table E-8. This data confirms that there is comparatively very little neutron dose in comparison with the recorded photon dose.

Table E-7. UNC annual report identified dose components.

Year	Annual dose (mrem)					Reference
	Collective photon radiation dose					
	Month	Quarter	Annual	Total	Neutron	
1973	658,830	100,240	26,000	785,090	1,330	UNI-174
1974	665,890	108,620	43,450	817,960	2,700	UNI-372

Table E-8. Neutron dose distribution for UNC annual reports.

Year	Number of workers within annual mrem dose category					Reference
	<50	<100	<200	>200	Collective dose	
1973	13	3	5	1[a]	Total = 1,330 mrem	UNI-174
1974	56	5	2	0	Total = 2,700 mrem	UNI-372

a. Maximum dose = 210 mrem

E7.7 NRC MEASURED NEUTRON AND PHOTON DOSES IN COMMERCIAL NUCLEAR PLANTS

During the period of N Reactor operation, there were efforts underway by the NRC to evaluate personnel exposures to neutron radiation in commercial nuclear reactors. Hanford GE and subsequently PNNL staff were involved in these efforts using Hanford dosimeters along with a selection of dosimeters and instruments to measure neutron spectra and dose. A summary of the measurements pertinent to the N Reactor were basically, that the NTA film dose results failed to respond above levels needed for a positive indication of neutron dose and the TLD dosimeters showed a very high response that required spectral corrections for proper dose interpretation. It is very important to consider that these measurements were primarily conducted inside containment with the reactor operating at a reduced power level and would overestimate the doses received in work areas outside confinement at N Reactor. An evaluation was done of the potential use of the NP ratio, to assign a neutron dose (Eisenhouer and Schwartz 1983). Many of these dose measurements inside containment showed a ratio of about 1 between the measured photon and neutron dose, although there were some instances of much wider variation. This measured dose would tend to support the Hanford worker TLD measurements of a NP annual dose ratio substantially less than 1.0 in workplaces outside of N Reactor confinement.

E8. SUMMARY

There is comparably low level neutron dose received by some N Reactor workers on some occasions that was not reliably measured prior to the implementation of the thermoluminescent dosimeter on January 1, 1972. The photon dose was reasonably accurately measured throughout N Reactor Operation from December 1963 through January 1987. A feasible technical option to reconstruct a favorable to claimant neutron dose to N Reactor workers prior to the use of the TLD is to multiply the measured photon dose by a NP dose ratio. There is very little actual measured data on which to calculate a realistic NP ratio to be applied to the annual measured photon dose. The collective neutron dose during 1973 and 1974 was 0.002 and 0.004, respectively, of the collective photon dose measured with Hanford multipurpose TLDs. There appear to be two options. One option is to base the NP ratio on single worker who had TLD-measured neutron dose during 4 years (1972–0.027, 1974–0.003, 1977–0.042, 1978–0.027) and for the other years there was no measured neutron dose (1973, 1975, 1976, 1979, 1980, 1981, 1982, 1983, 1984, 1985 and 1986). In this option the 50th-percentile (i.e., GM) is equal to 0.04 and to the maximum NP ratio a factor of 2 greater (i.e., 0.08) which is assumed in this analysis to be approximately the 95th-percentile. The second option is to utilize the statistical parameters for a lognormal distribution of the 14 TLD results. There is a large difference in the assigned neutron dose between these two options (i.e., Option #1: GM = 0.04, 95th percentile = 0.08; Option #2: GM = 0.06, 95th Percentile = 0.4) as shown in Table E-5. Certainly, the most favorable to claimant option is provided using Option #2. The assigned neutron doses must also incorporate the ICRP Publication 60 weighting factor, which for the neutron category of 0.1 to 2 MeV is equal to 1.91 (ICRP 1991), and thus a further increase in assigned neutron dose of nearly a factor of 2 will occur.

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F1. EXECUTIVE SUMMARY

The neutron to photon dose (NP) ratio distribution presented in the 2003 Hanford ORAUT-TKBS-0006-6 External Dose Technical Basis Document (TBD-6) has been updated using substantially greater data than available in 2003. Analyses in 2003 used 186 thermoluminescent dosimeter (TLD) measured neutron and photon doses (respectively ≥ 20 mrem) that had been obtained from dosimetry records submitted by DOE Richland for Hanford claims existing in 2003. The available data currently consists of 1,419 selected TLD and instrument measured NP ratio records that have been obtained from the extensive DOE Richland archives of historical documentation. Based on this expanded data, the recommended dose reconstruction parameters to be applied for 200 Area plutonium workers are:

- TLD measured neutron dose should be used from January 1, 1972 to date.
- Prior to 1972, the measured (and missed) photon dose should be multiplied by a NP ratio to arrive at an assigned neutron dose.

The recommended favorable-to-claimant NP ratios are:

- For glovebox workers, the guidance in OCAS-TIB-010 for plutonium glovebox workers should be applied.
- Consistent with OCAS-IG-001 (2007) guidance, the measured and assigned neutron doses must incorporate the ICRP Publication 60 weighting factors for the respective neutron energy categories in Hanford plutonium workplaces (ORAUT-OTIB-0055) (i.e., < 0.01 MeV = 2.13, 0.01-0.1 MeV = 1.86, 0.1–2.0 MeV = 1.91).

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Process	GM	GSD	95th-percentile
Non-glovebox worker	1.1	2.3	4.5
Glovebox worker	1.7	2.6	7.9

Applying these NP ratios will result in significant assigned neutron dose prior to 1972.

F2. INTRODUCTION

The purpose of this attachment is to update the technical basis for neutron dose reconstruction for Hanford 200 Area Plutonium Facility Workers based on additional workplace measurement data obtained since preparation of the original TBD-6 in 2003. As described in TBD-6 (2003), neutron radiation exposures to workers in the Hanford 200 Area Plutonium Facilities were not accurately measured using personnel dosimeters prior to implementation of the Hanford thermoluminescent personnel dosimeter (TLD) on January 1, 1972. Prior to January 1, 1972, Hanford used four general methods (Wilson 1987) to measure and control neutron exposure to workers as follows:

1. 1940s to present: Workplace surveys using portable neutron radiation responsive instruments and time-keeping.

2. 1940s to present: Pocket Ionization Chambers (PICs) with originally a boron liner and later of other radiation sensitive materials.

3. 1950 through 1971: Eastman Kodak Nuclear Track Emulsion, Type A, (NTA) personnel neutron film beginning in 1950 with three different Hanford neutron personnel dosimeter designs (two-element, 1958 multi-element and 1962 multi-element).

4. 1954 to ~1972: Measurement and control of worker photon exposure to Hanford Operational dose limits (3 R/y) with the expectation that the total whole body dose (photon plus neutron) would be less-than Hanford official dose limits (5 rem/y).

These methods were used jointly to measure and control worker radiation exposures since dosimeters in Method #3 do not provide capabilities for effective workplace exposure control. Dosimeters were exchanged on a routine weekly, biweekly, monthly, or quarterly schedule with dose results received long after radiation exposure has been received. There are records of dose assessments with Methods #1 and #2 but it is not certain that the neutron doses were incorporated into the official Hanford radiological records in instances where NTA dosimeter results are less-than doses determined from Methods #1 or #2, or if NTA dosimeters were not used. Method #4 was incorporated in 1954 into Hanford Operational Radiation Protection Standards as discussed under Hanford Radiation Protection Standards in Attachment D of this document. This method has an implied bound on the ratio of the neutron to photon dose (i.e., 5 rem/3 R = 1.7) which was adopted to ensure Hanford workers did not exceed annual radiation protection dose limits. Based on the neutron dose record for the Hanford Worker Health and Mortality Study (Buschbom and Gilbert 1993) which includes essentially all Hanford workers employed with a primary Hanford contractor for a period longer than six months, there is no recorded neutron dose prior to 1950. The judgment in TBD-6 (2003) that the neutron dose is underestimated for workers at the Hanford 200 Area plutonium facilities prior to 1972 is consistent with findings of an AEC/HQ technical committee investigation conducted in 1972 involving dosimetry experts from other AEC sites and Hanford (Biles 1972). This investigation was conducted because of the significant increase in measured neutron dose with the

TLD compared to the NTA film (Fix et al 1997b). There is a set of files that contain NTA processing results for Hanford workers issued NTA film during the period of 1950 through 1961 (SRDB 38336) and additional years of records are available in DOE Richland record archives in the Seattle Federal Record Center. A timeline of significant events at Hanford associated with radiation protection of 200 Area plutonium workers is presented in Attachment D, Table D-2.

2003 Site Profile Neutron Dose Reconstruction Recommendations
TBD-6 (2003) recommended for 200-Area Plutonium Facility worker neutron dose reconstruction that:

- TLD measured neutron dose be used from January 1, 1972 to date.
- Prior to 1972, the measured (and missed) photon dose is multiplied by a neutron-to-photon dose ratio to arrive at an assigned neutron dose. The parameters of the 2003 determined neutron-to-photon dose distribution using available TLD dose measurements from claims were a geometric mean (GM) of 0.73, a geometric standard deviation (GSD) of 2.10 and a 95th-percentile of 2.47.

F3. HISTORY

The history of neutron radiation exposure to workers in Hanford 200 Area plutonium facilities extends to the beginning of the respective chemical processing and plutonium chemical/metallurgical facilities that produced plutonium. Radiation exposure hazards to workers in Hanford plutonium facilities increased slowly in proportion to the increasing amount of ^{239}Pu fissile material handled. In the earliest years, the comparably small quantities of ^{239}Pu were not fully converted to usable product forms at Hanford but rather provided to Los Alamos in the form of a nitrate paste. Hanford workers began processing the plutonium nitrate in the 234-5 Building Rubber Glove (RG) Line on July 5, 1949. A timeline of the expanding capabilities is shown in Figure F-1. There was substantial pressure during the 1950-60s for Hanford to meet ^{239}Pu production targets as a crucial component of the national mission to develop a wide array of nuclear weapon capabilities. Hanford was involved in a broad range of nuclear research activities regarding reactor fuels, reactor designs, spent fuel processing, nuclide recovery from waste, plutonium metrology, and fissile materials in support of the national mission. A description of significant events as noted in Hanford documents is presented in Attachment D, Table D-2.

F3.1 200 AREA PLUTONIUM FACILITIES

ORAUT-TKBS-0006-2 describes the various Hanford plutonium facilities and the respective operating histories. The facilities can be divided according to:

1. **Supporting** Facilities involved in testing processes, handling waste or preparing plutonium bearing solutions for delivery to the Hanford Plutonium Finishing Plant (PFP) as follows:

   200-East Area

   - 209-E, Critical Mass Laboratory (Hanford critical mass laboratory facilities were also located in the 100 [120 Bldg] and 300 [326 Bldg] Areas and these operations are examined in Attachment G “Bounding Estimate of Neutron Dose Based on Measured Photon Dose at Hanford 300 Area and Miscellaneous Facility Operations at the Hanford Site.”

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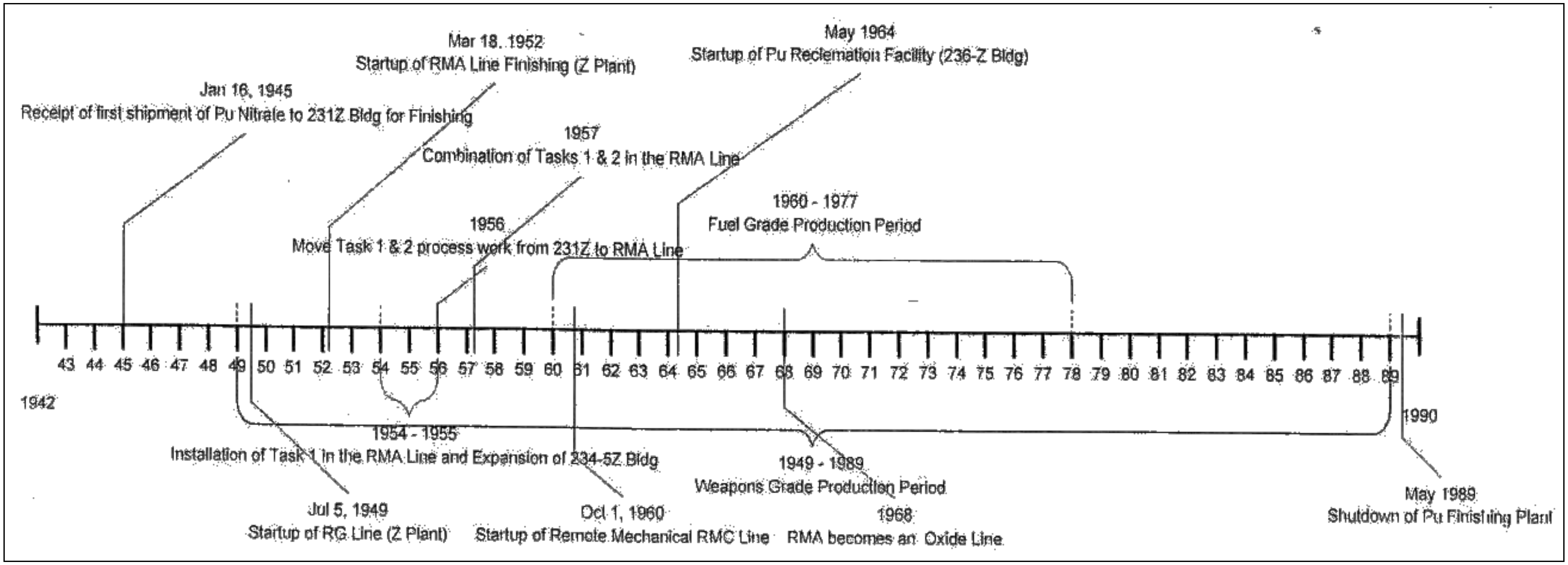

Figure F-1. Timeline of Hanford plutonium plant facilities and operational changes.

- 202-A PUREX Processing Plant N-Cell

- 224-B Plutonium Concentration Facility

200-West Area
- 216-Z-9 Covered Crib Facility
- 224-T Plutonium Concentration Facility
- 233-S REDOX Plutonium Processing Facility

2. **Primary** PFP Facilities involved in handling plutonium products include:

   - 231-Z Plutonium Isolation Facility
   - 232-Z Incinerator Facility
   - 234-5Z Plutonium Finishing Plant Complex
   - 236-Z Plutonium Reclamation Facility (PRF)
   - 242-Z Waste Treatment Facility
   - 2736-Z Plutonium Storage Vault

   There was intended duplication in capabilities among these facilities and between the 200-East and 200-West facilities. An approximate chronological history of the 200 Area facilities and a description of operations are provided in the following sections.

224-B, -T Concentration Buildings. The Hanford Irradiated Fuel processing capabilities originally involved the T, B and U Process Groups of buildings. The T Group consisted of the 221-T Building, also known as T-Plant or T-Canyon, which began operations in the Hanford 200 West Area on December 26, 1944 dissolving irradiated uranium fuel from the Hanford B-Reactor using a bismuth-phosphate chemical separation process. The operation was a batch, precipitation process that achieved separation of the plutonium by repeatedly dissolving and centrifuging plutonium-bearing solutions. The Hanford B Process Group facilities were built in the Hanford 200 East Area consisting of the 221-B Building (or B-Plant), 224-B Concentration Building and associated facilities also using the bismuth-phosphate chemical separation process that began operations on April 13, 1945. The Hanford U Process Group (221-U, 224-U) was built in the Hanford 200W Area but never dissolved irradiated uranium reactor fuels. The respective 224-T or -B Building received the plutonium bearing solution from the corresponding T or B processing plant through an underground pipe tunnel. The dilute plutonium solution was processed in batches with a starting volume of about 330 gallons that underwent several chemical steps to reduce volume, achieve higher purity plutonium, and eventually to form the plutonium nitrate that was transported to 231-Z in the early years and later to 234-5Z. The potential for neutron exposure to Hanford workers at these facilities handling plutonium solutions was similar to the transportation of plutonium nitrate among Hanford facilities.

231-Z Plutonium Isolation Building. The 231-Z, Plutonium Isolation Building, began the plutonium finishing process during January 1945 when the first plutonium nitrate solution was received (Lini, 2008) Throughout the early years, the mission of the 231-Z facility was to receive plutonium nitrate from the 224-B and 224-T facilities and to conduct further chemical treatment to purify the product. The eventual Hanford-produced plutonium nitrate (a “super-dried” thick paste) was placed in special shipping cans for transfer to Los Alamos prior to the construction of the Hanford 234-5Z facility to convert plutonium nitrate to plutonium metal. In later years, the 231-Z building was used for piece fabrication until about December 1965 and subsequently for metallurgical research. In the early years, the potential for neutron exposure to workers was associated with handling plutonium nitrate. In approximately 1956, the mission of 231-Z changed to a spectrum of plutonium chemical and metallurgical processes with significant potential for neutron exposure to workers.

234-5Z Plutonium Facility RG Line. Construction of the Hanford 234-5Z Plutonium Purification and Fabrication Building began in 1948. The original 234-5Z plutonium finishing equipment was termed the “RG” (Rubber Glove) line because its operation depended on personnel working with gloveboxes and manipulating the Pu mixtures through rubber gloves that served as contamination barriers. The RG Line was composed of 28 stainless steel hoods, and measured 180 feet in total length. “Hot” processing (i.e., processing using Pu nitrate as feed) in the 234-5Z Building RG Line began July 5, 1949. The basic plutonium finishing operations consisted of several standard steps known as “Tasks” as follows:

- Task I, Purification or Oxalate Precipitation (also known as Wet Chemistry or Feed Preparation), consisted of precipitating the Pu nitrate feed solution with oxalic acid and other agents.
- Task II, Hydrofluorination (also called Dry Chemistry in the very early years), hydrogen fluoride gas was diffused through the precipitate at a very high temperature in a furnace, producing a plutonium tetrafluoride powder.
- Task III, Reduction, the plutonium tetrafluoride was combined with calcium metal, a small percentage of other agents and fired at very high temperature, under an inert atmosphere, until it fused or “reduced” into Pu metal. The metal was produced in chunks roughly the size and appearance of a hockey puck and were known as “buttons.”
- Task IV, Casting, the plutonium metal was then rendered molten and ingoted, and cast into a mold roughly approximating one-half of the desired “pit.”
- Task V, Machining, the pit was formed and lathed to precise, specified dimensions.
- Task VI, Cleaning in which the pit is chemically cleansed.
- Task VII, Coating, the plutonium metal pit was placed on a tripod and coated with nickel using carbonyl gas through three separate applications to make sure that all portions of the bare Pu metal were covered. This coating served as a contamination barrier during inspection, transport and storage.
- Task VIII, Final Inspection, the pit was measured for thickness, uniformity of coating, neutron energy, isotopic content, dimensional precision, and cracking.
- Tasks IX through XIV were identified as topics, not actual process steps. Instrumentation was Task IX, Control was Task X, Ventilation was Task XI, the Conveyor System (not present in the RG Line, but present in later 234-5 Building process lines) was Task XII, Maintenance of equipment was Task XIII, and Sampling was Task XIV.

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234-5Z Plutonium Facility RMA Line. Even as processing using the RG Line was begun in the Hanford 234-5Z Building, efforts were underway to design a line that would operate remotely, in a mechanized manner or what was termed a Remote Mechanical (RM) line. The Remote Mechanical A (RMA) Line commenced hot operations on March 18, 1952 and performed all of the process steps in Pu metal production and fabrication except for Task I (feed make-up and purification). In early 1953, in response to the rapidly growing demand for increased plutonium production, the decision was made to “modify and expand” the RMA Line. In May, various design proposals coalesced into two key projects:

1. Activation of Task I focused on building into the RMA Line a new Task I process capable of bypassing the precipitation and purification activities then being carried out in Hanford’s 231-Z Isolation Building.

2. Expansion of Building 234-5Z focused on a sweeping series of revisions to Task II and III (hydrofluorination and reduction), aimed at increased production and efficiency in the facility.

During January and February of 1955, 234-5 production operations were shut down to enable modifications and new equipment to be installed for these two projects. The RMA Line then ran until mid-1957, when it was again closed briefly to install and activate equipment for Project GC-691, Improved Task I and Task II Facilities. This project installed a continuous calcination and hydrofluorination process that essentially combined the flow of Task I and II.

The RMA Line consisted of a row of 30 interconnected stainless steel glove boxes (e.g., hoods), 30 control desks, 10 control cubicles, 24 instrument panels, nine resistance furnaces, five induction furnaces, a sample can handling assembly, a 110-foot long general conveyor and manipulator, other smaller conveyors and furnace loaders, and miscellaneous support equipment. It was located in six rooms in the 234-5 Building.

234-5Z Plutonium Facility Recuplex. The Recovery of Uranium and Plutonium by Extraction Facility (RECUPLEX) solvent extraction process was developed to recover plutonium from 234-5 waste such as slag and crucible fragments, scrap powders from RMA line operations, oxidized plutonium turnings from Task V, and remnants from metal samples. The RECUPLEX facility began operation in July 1955. In April 1962, a criticality accident occurred resulting in high external radiation exposures to several workers. In May 1962, the AEC decided to deactivate this section of the 234-5Z Facility.

234-5Z Plutonium Facility RMC Line. Operations with the RMC Button Line and the RMC Fabrication Line with radioactive materials began in 1960. The RMC Line (both the button and fabrication components) consisted of a completely self-contained, remotely operated series of gloveboxes very similar to the RMA Line. Like the A Line, C Line functioned to convert Pu solutions to metal and then to fabricate actual pieces from the metal. It differed from the RMA Line in that it had an automatic vacuum cleaning system that served Tasks I-IV, greater radiation shielding, and improved radiography facilities. The RMC Line was placed where the former RG Line (removed in 1957) had stood. Associated PFP upgrades in the late 1950s and early 1960s included fire protection improvements, strengthening and refurbishing of the vacuum and exhaust systems, shielding upgrades, multiple waste management projects, improved plutonium storage facilities, laboratory modifications, and modifications to the Metallurgy Laboratory production equipment. The fabrication program concluded at PFP in December 1965. Shutdown of the fabrication portion of the RMA and RMC Lines (Tasks V onward) was undertaken immediately and essentially completed in March 1966.

The metal conversion portions of the RMC Line (Task I-III) continued to operate, while Task IV was converted to bag-out and sealing for shipment operations. The RMA Line was taken out of service completely. It remained closed until 1968, when Tasks I-IV equipment was cleaned out and re-activated to participate in PFP programs that prepared plutonium oxides in specified, tailored blends for commercial nuclear experiments and development. From that time forward, the A Line became known as the “oxide line” and the C Line became known as the “metal line.”

As PFP participation in fabrication was declining, initiatives were undertaken to support commercial nuclear industry needs. In late 1962, the AEC first investigated the feasibility and costs associated with receiving, storing and disbursing power reactor grade (”fuels grade”) plutonium. The plutonium recycle concept was being tested at the 309 Building Plutonium Recycle Test Reactor (PRTR). During 1965-66, receiving, re-packaging and storage facilities were built into the 234-5Z Building as the Plutonium Buy-Back Facility. This project was completed in May 1966. In the meanwhile, production of specially blended, non-defense Pu oxide for EURATOM (European Atomic Energy Community–a consortium of the governments of France, West Germany, Italy, the Netherlands, Belgium and Luxembourg) for commercial nuclear power development was begun in the PFP in September 1964. That same year, the 234-5Z Building began supplying non-defense Pu (known as “unclassified Pu”) nitrate or oxide to Hanford’s 209-E Critical Mass Laboratory for experimental purposes.

The RECUPLEX criticality accident during April 1962 led to deactivation of this area of the 234-5Z Building. During the 1970s, PFP operations continued to support the commercial nuclear industry, nuclear research customers and foreign nuclear customers until shutdown of PUREX in 1973. During this time PFP continued producing plutonium metal buttons that were sent to the DOE Rocky Flats Plant. The mid- and late-1970s were devoted largely to facility upgrades and to projects that achieved better control of effluents. During 1974-75, the Division of Military Application (DMA) equipment was removed from the PFP and disposed. This equipment included glove boxes from the A and C Lines.

In 1984 and 1985 respectively, the PRF and the RMC-Line re-opened in response to the late 1983 re-start of the PUREX Plant and the defense materials build-up ordered by President Reagan. Both facilities operated several campaigns on an as-needed basis until the PRF was permanently shut down in December 1987 and the RMC Line was permanently shut down in June 1989.

202-A Purex N-Cell and Redox 233-S Facility. The T- and B-Plant Reprocessing facilities were replaced with the more efficient continuous feed (i.e., not a batch process) reduction oxidation process (REDOX, 200 West Area, operation began January 1952) and plutonium uranium extraction (PUREX, 200 East Area, operations began January 1956) separation facilities. Plutonium nitrate was produced in the Redox (S-Plant) 233-S Facility and Purex (A-Plant), and transported to the 231-Z Plant or directly to 234-5Z following completion of Task I precipitation and purification capabilities incorporated into the RMA Line. Later, some plutonium oxide was produced in the N-Cell at Purex.

216-Z-9 Covered Crib Facility. Several soil disposal cribs were constructed and used near 231-Z and 234-5Z for discard of plutonium-bearing liquid waste solutions. Most notably, the 216-Z-9 below grade covered crib facility received about one million gallons of plutonium solvent extraction waste effluent from 1955 to closure of the crib in 1962. During the mid-1970s, plutonium contaminated soil in the Z-9 crib just south of the PFP was mined and partially remediated.

232-Z Incinerator Facility. The 232-Z incinerator began processing miscellaneous solid wastes to recover small quantities of plutonium in January 1962. The process involved incineration of combustible materials, leaching noncombustible materials in nitric acid, and wet leaching of ash. The recovered plutonium was transferred to RECUPLEX and later the Plutonium Reclamation Facility. The 232-Z facility operations were terminated in 1973.

242-Z Waste Treatment Facility. The 242-Z facility was placed into operation in 1963 to recover plutonium from aqueous waste streams from the PFP. An ^{241}Am recovery process was installed in a glovebox in 242-Z and began operation in May 1965. The product was americium nitrate. In 1969, equipment was installed to convert the ^{241}Am recovery operation from a batch to a continuous process and to increase the purity and concentration of the americium product. In August 1976 an explosion occurred with subsequent permanent shut down of the 242-Z facility.

236-Z Plutonium Reclamation Facility (PRF). The 236-Z facility was placed into operation in May 1964 to recover plutonium from liquid waste generated in the plutonium finishing plant operations. This facility was shut down in December 1975 for maintenance upgrades and reviews of criticality safety specifications and procedures. In 1976, PRF operated for only a short time after restart until the explosion in 242-Z resulting in shutdown of the facility during April 1976. The facility was cleaned up and operated in 1977 to process available plutonium, and later in the 1980s was operated again.

2736-Z Plutonium Storage Vaults. The 2736-Z Plutonium Storage vaults were finished during 1972-73 and used to store plutonium.

F4. PLUTONIUM GRADE

An important consideration in the analysis of neutron exposure to workers in relation to the photon dose concerns the specifics of the type of fuel (i.e., uranium natural or level of ^{235}U enrichment, mixed uranium and plutonium oxide or thorium) and the reactor exposure time in megawatt-days (MWD) because this is directly associated with the isotopic composition of the plutonium handled at PFP. There are also issues associated with the effectiveness of the respective T-Plant, B-Plant, REDOX and PUREX processing with respect to the type and concentration of potential contaminants (e.g., zirconium, ruthenium, etc.) as well as inventories handled at PFP associated with Buy-Back Program and various national and international research activities. Broadly speaking, the plutonium is categorized as weapons or reactor (or fuel) grade as shown in Figure F-2 (note: the production total in 1947 is actually the total production during 1944-47). Worker neutron exposure is highly associated with the concentration of ^{240}Pu which increases in the irradiated fuel with the total exposure (i.e., megawatt-days). Reactor grade fuel typically receives much higher exposures as compared to weapons grade fuel and will result in higher exposures to workers.

F5. RADIATION PROTECTION

A description of Hanford radiation protection standards, procedures and practices is described in Attachment D along with a historical review of applicable radiation protection limits in Table D-1 and a timeline of radiation associated events in Table D-2.

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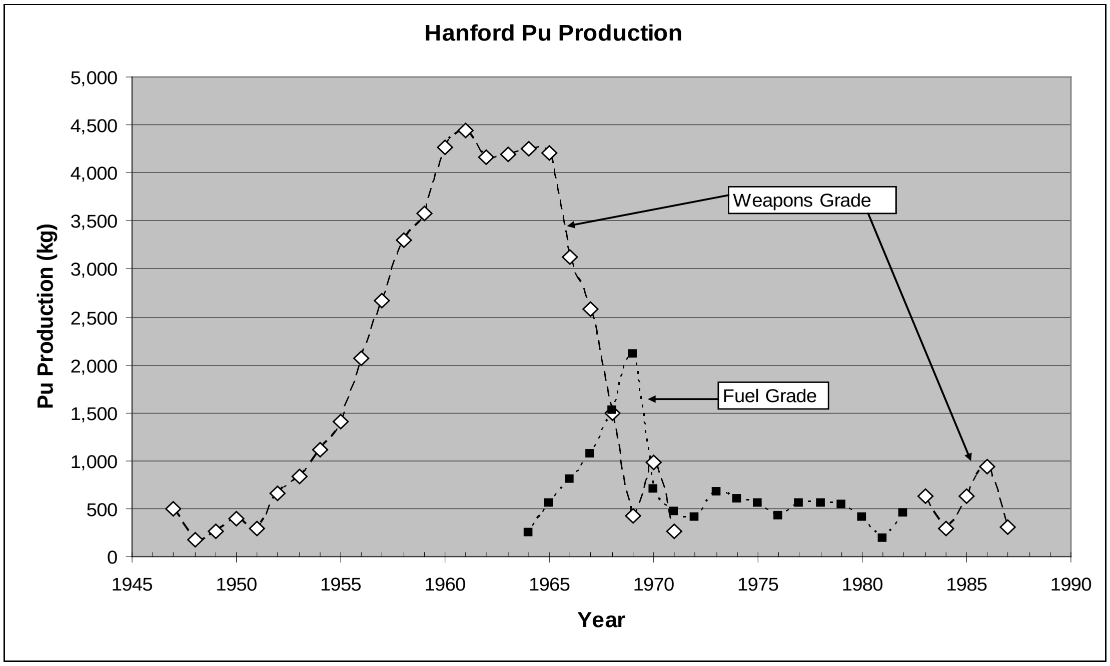

Figure F-2. Hanford plutonium production (DOE/DP-0137, Plutonium: The First 50 years).

F6. METHODS

There are several documented historical analyses of neutron exposure received by Hanford workers. In the earliest years during the 1940s and 1950s there was concern primarily for the potential dose to the hands of workers in the plutonium facility. The extent and primary findings from these studies can be viewed according to the publication date of the respective studies in Attachment D, Table D-2. Studies performed in the 1950 and 1960s were primarily motivated by a concern that the total whole dose limits (shown in Attachment D, Table D-1) were not exceeded.

F6.1 SITE EXPERT INTERVIEWS

Interviews with Site Experts were conducted and documented regarding their assessment of the potential for significant neutron exposure of Hanford 200 Area plutonium facility workers, the potential work areas, and work tasks. Tours of the Hanford 234-5Z facility and the 231-Z facility were made during June and November 2008 with persons with expert knowledge of Hanford plutonium facility design and operation. The respective site experts were asked to provide information concerning:

- Their knowledge of workplace radiation levels at the respective plutonium facilities, methods of measurement, exposure control practices and particularly information concerning significant neutron exposure.

- Their knowledge concerning changes in plutonium facility construction and/or operations important to understanding the applicability of statistical parameters determined from TLD measured doses to the pre-1972 period.

- Their knowledge concerning performance of workplace surveys and particularly feasibility of access to the documented surveys, access to the plutonium facility worker measured doses, and specifically access to the measured TLD measured neutron and photon doses during the period of 1972 through 1987.

- Their knowledge concerning any other information that may be relevant to the reconstruction of neutron dose to Hanford 200 Area plutonium facility workers prior to 1972.

F6.2 DATA IDENTIFICATION

There are extensive Hanford historical records of instrument survey results of photon exposure rate and contamination levels (i.e., instrument alpha and beta radiation surveys) in the 200 Area plutonium facility workplaces, and personnel beta/photon dosimeter measured doses. An Excel database is available that shows the assignment of NTA dosimeters to Hanford workers according to operating area during the period of 1950 through 1961 (SRDB 23028). Typically, a brief description of the relevant data is included in Attachment D, Table D-2. The survey results were primarily used for defining workplace radiological control zones and workplace hazards such as in the preparation of the Special Work Permits (SWPs) which number into many tens of thousands each year. Data searches of the various DOE Hanford archive record systems was done using numerous combinations of words or abbreviations "survey," "control," "neut," "NTA," "A-film," repetitive, etc., associated with neutron radiation or monitoring surveys, neutrons, nuclear track emulsion, Type A (NTA) film, A-film, routine and repetitive (R&R) surveys. Substantial efforts have been made to find actual original records of instrument measured photon and neutron doses done at the same time and location (i.e., paired data).

F6.3 DATA CAPTURE

Data capture trips to DOE Richland with the expressed objective to obtain detailed monitoring data occurred during: April 18-19, 2007; September 18-20, 2007; October 9-15, 2007; December 2-7, 2007; June 2-6, 2008; July 7-11, 2008; September 22-26, 2008; October 13-17, 2008; and November 17-24, 2008. Keyword searches were conducted of the multiple Hanford record systems by DOE Richland, DOE Hanford contractors and ORAUT staff using DOE Richland-provided database indexes to identify pertinent technical reports, survey forms and correspondence. Prior to these data collection trips, record indexes were received from DOE Richland and used in the prioritization of records of interest for workplace photon and neutron fields. A large number of boxes and documents were identified that potentially contained relevant records. The contents of these boxes and documents were reviewed during the respective data collection trips.

F7. RESULTS

F7.1 SITE EXPERT INTERVIEWS

Interviews with several Hanford Site experts were performed with the objective to identify potentially relevant information regarding the significance of photon and neutron radiation exposure and to the feasibility of dose reconstruction. Questionnaires were developed in conjunction with the respective interviews and used in the interview documentation. Each of these documented interviews was submitted to DOE for classification review. Abbreviated results from the respective interviews are described in the following:

Site Expert 1 (Fix 2008b). Documented interview with Hanford Site expert hired at Hanford in June 1951 with several site roles in chemistry and radiation protection, including dismantling the RG line in the 234-5Z Building. Site expert also provided special training for operators and monitors involved in plutonium work. Expert was one of the first persons to use the DePanger double moderator neutron counter for workplace neutron measurements and was involved in the development of improved monitoring and dosimetry capabilities.

Site Expert 2 (Fix 2008c). Documented interview with Hanford Site expert hired at Hanford in 1959. Site expert worked in the 308 Building making and performing quality assurance measurements on plutonium-aluminum coextruded fuel elements. Site expert participated in investigations of radiation exposure issues associated with processing of Hanford higher exposure plutonium and the increase in the gamma dose rate with plutonium isotopic composition, age since separation, and glovebox through-put. Site expert has performed neutron dose and spectra measurements at several Hanford and other DOE laboratory workplaces and was the lead technical author of a DOE complex analysis of personnel neutron dosimetry in DOE facilities.

Site Expert 3 (Fix 2008d). Documented interview with criticality safety expert who began employment at Hanford during October 1948 and, during the period from approximately 1952 to 1959, was tracking plutonium production units through the plutonium product lines. Expert recalled the philosophy that the highest dose rates were primarily dependent on the mass of plutonium. So it followed that spills, dust coating the equipment, residual powder in corners, etc., should be kept to a minimum to keep dose rates low. Hood cleanups were made accordingly. Expert recalled that visibility into the powder processing gloveboxes was sometimes a problem. Expert said it was common knowledge that the PuF_4 gloveboxes were the highest neutron dose rate areas. In dealing with dose rates, there is another factor that might not have been considered regarding the powder pan and the button storage conveyors. These were down around Tasks II and III. The powder pans were part of the RMC and held PuF_4 batches. The storage areas held many plutonium units and would be expected to have commensurate higher exposure.

Site Expert 4 (Fix 2008e). Documented interviews with Hanford Site expert who spent several years providing technical health physics support to the PFP, where he was involved in reviewing procedures and work plans for compliance with Hanford radiological standards and practices. Expert maintained a detailed monthly radiological protection performance report for plant management and support organizations. Site expert participated in Readiness Reviews for the restart of the PRF and the RMC Line. Site expert also supported operation and outages at all 100 Area reactors; charge, discharge, storage and shipment of irradiated fuel elements; and control room assistance for reactor startup and operation.

Site Expert 5 (Fix 2007c). Documented interview with Hanford Site expert hired at Hanford in June 1956 who worked in various research activities such as in the 326 Building Exponential Pile Physics Laboratory and in 326 Building working with radiation sources such as ^{238}PuBe, developing neutron spectrometer capabilities, performing work to characterize the NTA energy response, and working to develop TLD systems. Expert had several non-Hanford project roles including a multiyear NRC Project to measure neutron spectra and dose in U.S. commercial nuclear reactors, which is described in several NUREG reports.

Site Expert 6 (Fix 2008f). Documented interview with Hanford Site expert hired at Hanford in February 1959 who worked on 234-5Z personnel exposure issues such as extremity dose, dosimetry systems, and instrument capabilities. Expert described measurements at Hanford in which photon dose rate was measured with a CP and, for neutron radiation, the Snoopy and DePanger double moderator was used. The Snoopy was often used because the signal could be integrated for an extended measurement, thereby obtaining a better result. The Long Counter was used to measure neutron yields and was used during measurements at the Hanford 234-5Z and 308 Buildings as well as many other DOE sites. TEPC and personnel dosimeters were also used. Expert has been involved in various national committees, projects, etc., and has been involved in neutron and photon spectra and dose measurements at numerous DOE sites. Expert was a primary author of the original DOE Good Practices Standard in Plutonium Facilities.

Site Expert 7 (Fix 2007f). Documented interview with Hanford Site expert hired at Hanford in 1947 who worked with health physics instruments and later managed Hanford site-wide personnel radiation dosimetry and radiological records projects.

Site Expert 8 (Fix 2008g). Documented interview with Hanford Site Expert hired at Hanford in June 1948 who worked with technical function tests, calibration and distribution of health physics instruments to the 100, 200, and 300 Areas. The results of these tests were documented. Expert mentioned that the calibration technicians were actually receiving significant exposures and steps were taken to build a Well calibration facility whereby the technicians were not directly exposed to the calibrating source. Expert was directly involved in 234-5Z Building radiation exposure measurements and efforts to resolve radiation exposure problems that existed in the 234-5Z and 231-Z Buildings. Expert recalled being involved in "time and motion studies" to determine the length of time required to do specific tasks. Expert wrote many Hanford technical reports and subsequently was involved in national and international measurements of radiation.

Site Expert 9 (Fix 2007b,g). Documented interviews with Hanford Site expert involved in radiological physics issues throughout his career, handling issues such as personnel dosimeter performance, calibration, and, in particular, neutron radiation measurements using, for example, the DePanger Precision Long Counter developed at Hanford. The Long Counter was used to evaluate the neutron fluence when health physics dosimeters or health physics instruments were irradiated. The DePanger double moderator instrument was invented for monitoring neutron dose in the workplace. The instrument could measure a ratio that could be applied to the measurement to get the correct neutron dose as a function of neutron energy. Expert spent significant time in 100 Area reactors (i.e., B, D, KE, KW, N, and perhaps F), 200 Area plutonium facilities, and 300 Area accelerator facilities, which were used to evaluate all Hanford neutron instrument and dosimeter systems. Expert stated that the original values to reconstruct 234-5Z worker exposures in the 1972 AEC investigation depend on the method used to determine the ratios from the TLD data. For example, the calibration with the TLD implemented in 1972 involved consideration of the combined phantom and dosimeter neutron response because of the so-called albedo effect. The TEPC was used to evaluate the TLD response on-phantom at 234-5Z workplaces and to use this in the development of the routine neutron calibration. Fundamentally, the distance of the midpoint of the phantom from the Hanford calibration source was used in routine calibration exposures and not the distance from the dosimeter mounted on the phantom to the source.

Site Expert 10 (Scalsky 2007b). Documented interview with Hanford Site expert involved in the Hanford personnel dosimetry program beginning in the mid-1950s. Expert had numerous radiation safety individual contributor and management roles in the centralized Hanford radiological services organization involving calibrations, radiation standards and engineering, and radiological records and in AEC/DOE-HQ health physics programs.

Site Expert 11 (Fix 2008h). Documented interview with Hanford Site expert hired at Hanford as a process engineer in July 1969 working throughout his career primarily in Hanford 200 Area production operations such as 234-5Z. Expert's responsibilities included analyses of radiation exposures with respect to process source material and options, and personally gathered a few years of monthly PFP button line production and dosimetry records for evaluation of worker exposure and process options.

Site Expert 12 (Fix 2008i). Documented interview with Hanford Site expert who worked as an engineer and production supervisor at PFP during the period from 1956 through 1994.

Site Expert 13 (Scalsky 2007a, Fix 2008l). Documented interview with Hanford Site expert hired for work at Hanford plutonium facilities in 1947. Expert worked in all Hanford areas during his career, participated in activities associated with the AEC 1972 Investigation of the increase in TLD-measured worker neutron doses in comparison with the NTA measured doses. Expert wrote numerous technical reports including historical reviews of the Hanford radiation dosimetry program.

Site Expert 14 (Fix 2007e). Documented interview with Hanford Site expert hired at Hanford in 1950 for work in radiation protection with primary responsibilities in the 200 and 300 Areas, and as the HP assigned to 100 Area biology operations. Later, this expert assumed responsibilities for Hanford site-wide compliance with AEC/DOE H&S orders, directives, etc., as a senior health physicist.

F7.2 WORKPLACE MEASUREMENTS OF NEUTRON RADIATION

The respective boxes of DOE Richland archival records available from the federal repository in Seattle generally contain either technical reports or data of one type or another. Technical reports in which data have been gathered and analyzed are particularly helpful and tend to minimize uncertainty in the overall analysis.

F7.3 TECHNICAL REPORTS

Numerous boxes containing Hanford technical reports and workplace radiation survey sheets were reviewed by a team of health physicists. Several Hanford documents were identified that contained paired neutron and photon radiation survey data as follows:

- Early 1950s reports of radiation measurements of Hanford 231-Z and 234-5Z processes that collectively provide information regarding relative neutron and photon doses.

- Routine quarterly publications entitled "Radiation Control Report" for the Hanford 231-Z and 234-5Z facilities from 1962 through the first quarter of 1976. These documents typically contain paired photon and neutron workplace dosimeter and instrument measurements stated to be representative of potential worker exposures.

- An appendix to the 1972 AEC Investigation of neutron doses contained several neutron and photon ratio results collected for the purpose to estimate the potential career whole body (neutron and photon) doses for selected highly exposed workers.

- NP ratio results of measurements taken in 1959 (Unruh 1962)

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- BNWL-B-127 (Nichols et al 1972) that provides dose results from parallel field tests of the TLD along with the Hanford beta/photon film and, for some workers, NTA film. Information from this document is presented in Table F-1 since it illustrates one approach to determining a NP ratio. In Table F-2 the NP ratios for various processing or storage environments in the 234-5Z Bldg were calculated based on the photon and neutron instrument and TLD dose measurements shown in the original document.

Table F-1. NP ratio determined from 1971 workplace study of neutron dose measurements (BNWL-B-127).[a]

Bldg.	Location	Exp time (hrs)	Instrument			NP ratio	TLD (mrem)				NP ratio
			Snoopy	CP	TEPC		Derma	Pen	SN	FN	
234-5Z	228-17DC	72.4	200	150		1.33	210	150	—	200	1.33
	192-194	72.7	950	150		6.33	210	140	138	1360	10.70
	228-HC-11	2.34	330	60		5.50	80	80	18	650	8.35
	228-9-B	72.5	360	510		0.71	450	450	135	730	1.92
	228-H618BS	72.5	360	510		0.71	100	100	6	170	1.76
	194	2.75	550	90		6.11	60	60	9	390	6.65
	221-center	73	660	1,460		0.45	1,470	1,470	18	940	0.65
	221-N	73	1,310	2,480		0.53	1,640	1,640	24	1,060	0.66
105-KE	X-1		60		270				57	530	
	Top #23		1,400		1,700				141	4,100	
	Mon		0		0				<3	60	
	Front face		50		900				7	250	
308	Room 208		2,000		2,700				84	3,700	
	Corr #7		4,200		14,100				390	11,100	
	Vent room		30		30				3	0	
	Room C		70		730				18	870	
234-5Z	17DC		340						6	100	
	HC-11		280						12	180	
	9B top stairs		410						11	440	
	9B under stairs		280						18	450	
	Room 221		410		790				18	460	
	Room 192		510		620				66	490	
	Room 192-C		150		230				6	240	
	Room 193		380		500				36	600	
	2731-Z		200						<3	50	

a. Dosimeters mounted on carboys in workplace for designated exposure duration.

Attachment D, Table D-2 provides a chronological listing of a large number of technical references along with brief summaries of those with particularly relevant information. There is an Excel database (SRDB 38336) of Hanford NTA dosimeter assignments at Hanford with the reported neutron dose which was developed in the preparation of PNNL-11196 (Fix et al 1997).

Another type of examination regarding the accuracy of TLD neutron dose measurements is made of summaries of field measurements published in 1981 (PNL-3536) and 1982 (PNL-3736) which are presented in Tables F-2 and F-3, respectively. These tables do not include a photon dose measurement, only a comparison of different methods to measure the workplace neutron dose.

Table F-2. Summary of 1981 Hanford workplace neutron dose measurements (PNL-3536).

Bldg	Location	Energy keV[a]	Neutron dose (mrem/hr) according to measurement method[b]					
			MS	**Snoopy**	**Rascal**	**TEPC**	**TLD**	**TLD***
308	Pu storage vault	576	1.2		17.7			
	Above fuel storage pit	530	0.9			0.54	0.96	
	Above pit storage pit	1,100	0.8		2.0	1.3	1.2	
							0.46[c]	
	Fuel pin storage boxes on wall	660			4.1			
	Bare fuel subassembly	1,500			17.6	11		
234-5Z	HA-9A Glovebox	395	4.4	4		4.7	1.7	0.9
	HC-9B Glovebox	390	12.1	11.5		12.7	14	7.4
							18.7	9.8
2736-Z	Vault 3 3EE-3FE	300	26.9	26		23.4	1.5	0.6
							3.7	1.6
	Vault 3 3CE-3DE	346	69.3	65		71.9		
	Vault 4 4ED-4FD	290	41.8	40		39.0		
	Vault 4 4GE-4NE	290	46.9	45		47.8	50.7	21.1
							60.2	25.1
	Hallway	146	1.3	0.8		1.0		
	Nuclear criticality detector	374	27.1	40				

a. Average energy of neutron spectra
b. Measurement method: MS = multisphere, TEPC–Tissue Equivalent Proportional Counter, TLD–Hanford
c. Multipurpose Dosimeter using normal algorithm, TLD* using alternate algorithm.
d. Phantom on floor.

Table F-3. Summary of 1982 Hanford workplace neutron dose measurements (Fix et al 1981).

Bldg	Location	Measurement method[a]						
		MS	**TEPC**	**PTEPC**	**He-3**	**Rascal**	**Snoopy**	**TLD**
324	Pu storage vault	2.8	4.6	5.1	2.1	—	5.0	6.5
FFTF	Location 8	3.8	5.6	—	14.7	13.0	18.0	29.1
	Location 10	1.9	1.2	—	4.1	5.3	12.0	12.3
209-E	Location 13	—	3.1	3.8	—	—	2.0	1.8
	Location 17	—	—	0.6	—	—	0.4	0.5
234-5Z	Maintenance office	—	0.4	0.4	—	—	0.5	0.4
	Duct level, Col. 16	—	—	1.6	—	—	0.8	0.6
	Duct level, under 52	—	—	1.7	—	—	<0.1[b]	2.7
	Duct level, over HA23	—	—	2.6	—	—	0.1[b]	5.1
	Pu hood, top	2.8	14.7	12.3[b]	3.2	—	10.5[c]	—
	Pu hood, side	—	—	7.2	—	—	7.0	—
	General background	—	—	1.2	—	—	1.5	—

a. MS–Multisphere, TEPC–Tissue Equivalent Proportional Counter, PTEPC–Portable Tissue Equivalent Proportional Counter, He-3–Helium-3 counter, TLD–Hanford Multipurpose Dosimeter.
b. These Snoopy readings are suspect due to geometry differences.
c. Average of four readings shown in table.

The estimate of the actual neutron dose in well shielded work areas because of its significant response to measurements in these reports were performed with the objective to identify Hanford work areas in which analysis of the Hanford TLD could result in incorrect dose estimates to personnel. The studies included examination of workplace energy spectra and radiation type as well as a comparison of the neutron dose between several techniques of measuring neutron dose. The Tissue

Equivalent Proportional Counter (TEPC) method is generally accepted as providing the best estimate of the actual neutron dose. As noted in these reports, the TLD tended to over-estimate the instrument measured neutron dose on average. The TLD albedo dosimetry method is well known to over-lower-energy neutrons.

The Hanford TLD measured dose in 234-5Z locations compared with measurements with a Snoopy, TEPC, multisphere, and PNR-4 (i.e., common portable neutron instruments used to measure neutron dose based on 9-inch to 3-inch sphere ratio) as reported in Roberson et al (1985) is presented in Table F-4. These measurements show close agreement in estimated dose between the Hanford TLD and the respective instruments.

Table F-4. 200 Area workplace measurement comparisons with HMPD (Roberson, Cummings and Fix 1985).

	Ratio of TLD dose to instrument dose[a]			
Location	**Snoopy**	**PNR-4**[b]	**TEPC**	**Multi-sphere**
2736-Z, storage vault, Room 4	0.98 (0.37)	0.84 (0.18)	1.02 (0.18)	1.28 (0.24)
2736-Z, storage vault, Room 1	0.92 (0.14)	0.87 (0.56)	0.84 (0.10)	0.95 (0.13)
236-Z, gloveboxes 5-6	0.85 (0.18)	0.95 (0.43)	1.03 (0.41)	1.13 (0.41)
234-5Z, process line C, Room B	0.88 (0.28)	0.88 (0.21)	1.17 (0.26)	1.17 (0.25)
Average	0.90 (0.10)	0.87 (0.13)	0.92 (0.08)	1.05 (0.10)

a. Numbers in parentheses represent one-standard deviation.
b. Portable neutron REM instrument based on 9” to 3” sphere measurements.

F7.4 RADIATION SURVEY DATA

A team of health physicists examined many boxes of archive records containing Hanford workplace radiation survey sheets with the objective to identify those with paired photon and neutron measurements. Many records were identified and tagged for scanning. The selected records were included in the SRDB and the respective SRDB references have been included in the analysis files. An example of a few fields from this type of record is shown in Table F-5. The distance of the respective photon and neutron dose measurement is included in the file as noted on the original survey documentation. This is an important consideration in that the measured NP ratio typically varies with distance. An example of this dependency for measurements at various distances from the same, single source (PuF_4, 836.4 grams) is shown in Figure F-3 from data taken from SRDB 36984 (HW-28918). The cause of this variation may in fact be associated with the “field of view” of the respective gamma and neutron instrument measurements. Figure F-3 does show a typical $1/r^2$ relationship for either the measured photon or the neutron dose at distances greater than about 8 inches. In the analysis of the NP ratio to be applied to dose reconstruction, only the measurements indicating a field (“F”) measurement (i.e., at a large distance) were used to avoid this potential cause of variability. It is also interesting in that the measurements in Figure F-3 show a consistent ratio (at greater than 8 inches) of about 5 for this single source of PuF_4 with little shielding to scatter the radiation.

F7.5 ANALYSIS OF NP RATIO MEASUREMENT DATA

Originally, 2,050 paired neutron and photon dose measurements from workplace instrument survey measurements, NTA dosimeters, TLDs, technical reports, TLD dose histories for workers included in AEC 1972 Study, and TLD dose histories for Hanford claims selected in 2003 were collected by the team of health physicists as summarized in Table F-6. Certain of the workplace records of measured

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Table F-5. SRDB references containing neutron and photon dose survey measurements.

Document title	SRDB #	Date of reading	Building number	Room number	Survey specific description	General location description
234-5Z Survey Log Sheets 17285–17784, June 23–July 24, 1953	60723	6/25/1953	234-5Z	166	Box containing sand paper Hd 14 sample residue	Monthly survey of vault
234-5Z Survey Log Sheets 17285–17784, June 23–July 24, 1953	60723	6/25/1953	234-5Z	166	Box containing sand paper Hd 14 sample residue	Monthly survey of vault
Survey Log Sheets 14244–14732 December 26, 1952–January 24, 1953	60724	12/29/1952	234-5Z	166	Boxes crucibles avg box	Operations to move boxes crucibles from 166 to waste storage hutment
Survey Log Sheets 14244–14732 December 26, 1952–January 24, 1953	60724	12/29/1952	234-5Z	166	Avg reading boxes & crucibles	Operation to remove boxes & crucibles from rm 166 to waste storage hutment
Radiation Survey for Neutron Building 235	60793	12/9/1955	234-5Z	221	@ face of hood	ER requested @ charging hood Rm 221 recuplex
Radiation Survey for Neutron Building 235	60793	1/20/1956	234-5Z	221	H-9 base of gloves	Routine surveys recuplex

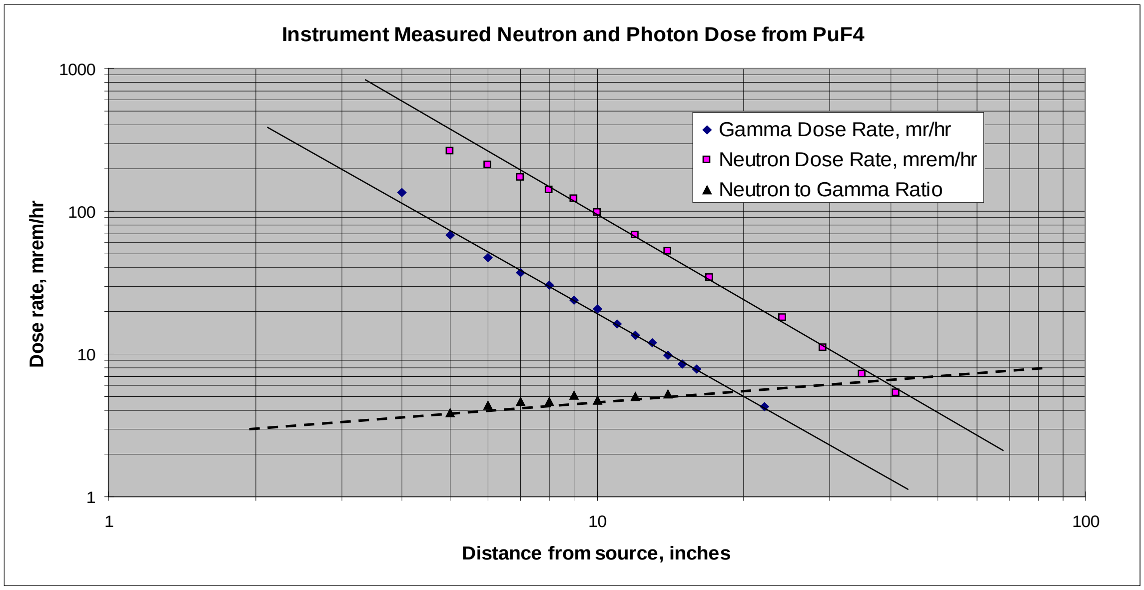

Figure F-3. Variation in measured neutron and photon dose rates with distance, and the associated calculated NP ratio (SRDB 36984, HW-28918).

NP ratios are considered to be of lesser quality and were not selected for the primary analysis as noted in Table F-6. Notably, the NTA film data were not selected and a set of area TLD results were not selected since the measured neutron dose was comparatively low and it was not known if a phantom was included in the measurements which is essential for accurate dose response with the TLD albedo dosimeter. Reviews of this data resulted in the selection of 1,419 records of NP ratio

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measurements that were unique and had a documented pedigree to the respective source documents. The records of this data in the analysis file include notation of the original document and page where the data was obtained. The distribution of NP ratios in the Hanford TBD prepared in 2003 used only a selection of the TLD data (i.e., ≥20 mrem for photon and neutron dose, respectively). For years prior to 1972, Hanford policy was to control worker total (i.e., photon plus neutron) whole body external radiation dose using the photon component only.

Table F-6. Hanford 200 Area plutonium facility NP ratio survey records.

Description	No. of records	Selected for NP analysis	Basis for selection
2003 Claim TLD Data	186	186	TLD measurements after 1971 with paired neutron and photon doses, respectively ≥ 20 mrem.
1972 AEC Study, Film Data	189	0	Paired pre-1972 NTA data are suspect.
1972 AEC Study, TLD Data	113	113	Paired TLD measurements after 1971 with paired neutron and photon doses, respectively ≥ 20 mrem.
1962-71 Radiation Control Report, Film Data	177	0	Paired pre-1972 NTA data are suspect.
1972-76 Radiation Control Report, TLD Data	16	0	TLD area measurement data are suspect because of comparatively low measured neutron dose. The presence of an albedo material, which is essential for accurate TLD performance is not known.
1962-76 Radiation Control Report, Instrument Data	161	161	Routine workplace instrument measured doses.
Technical Reports, Instrument Data	114	114	These documents results from various Hanford initiated studies
Workplace Surveys, Instrument Data	1,194	845	All of the instrument measured doses by trained HP technicians were considered to be of good quality. Reduction in records analyzed was primarily associated with elimination of duplicate records.
Total	2,150	1,419	

Figure F-4 is a graph of the 1,419 records of NP ratios according to the time and method of measurement, and the source of information. From this data there does not appear to be a clear trend over time. There is substantial variability for essentially all years of measurement which is likely associated with the location of measurements, the method of measurement as well as variations in process. The Radiation Control Data reports are monthly doses in 1963, and quarterly thereafter from 1964 through first quarter 1976, based on daily and weekly measurements. The TLD data are measured monthly or quarterly doses for dosimeters assigned to workers. These longer-term measurements tend to have less variability. The workplace survey instrument measurements are short term measurements for a specific place and time as noted on the survey forms. Undoubtedly, there are many thousands of these workplace survey records which could be retrieved given sufficient time and resources. The data available however are expected to provide a reasonable basis to determine the distribution of the NP ratio. The various Technical Reports describe instrument measured NP ratios during 1956-57. The Radiation Control Report instrument measured and worker assigned TLD measured NP ratios cover a period from 1963 through 1994.

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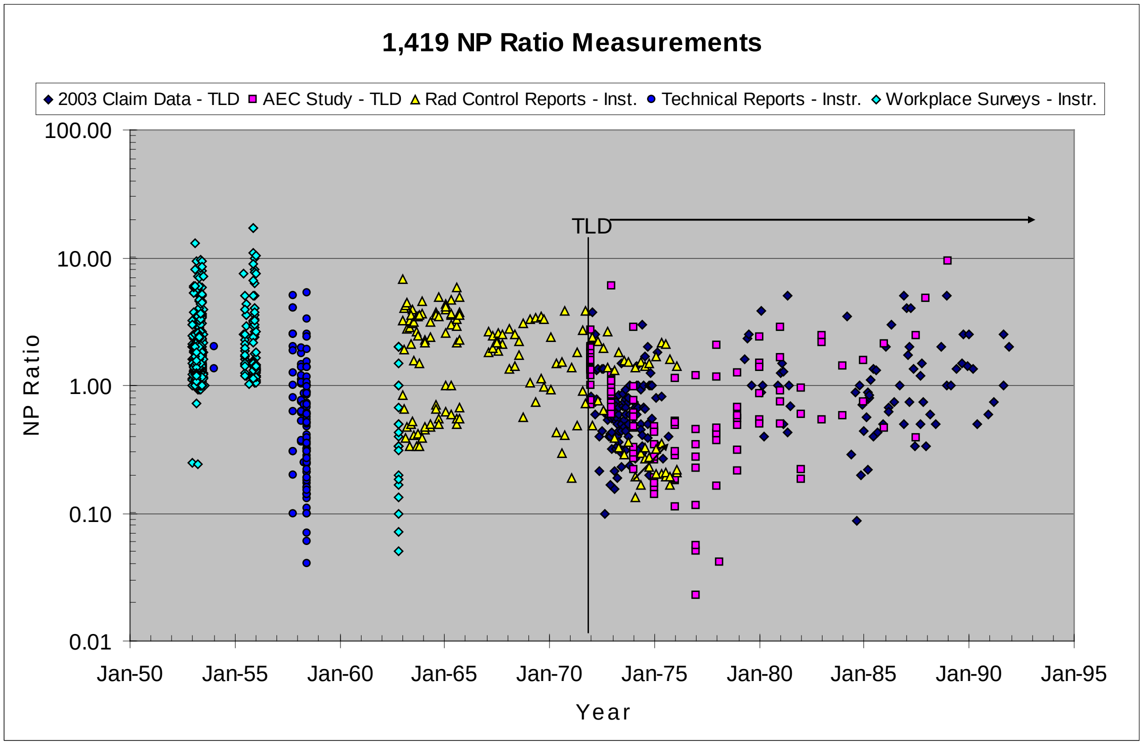

Figure F-4. 1,419 measured NP ratios in Hanford 234-5Z plutonium facility.

There are many considerations in the analysis of neutron and photon dose measurements based on the history of 234-5Z operations as follows:

- The most significant radiological constituents of interest are those of the various plutonium isotopes (^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu and ^{242}Pu) and their decay products which include ^{241}Am, ^{234}U, ^{235}U, ^{236}U, ^{237}U, ^{238}U, ^{237}Np and a lesser amount of other isotopes. The relative abundance of these nuclides depends upon the characteristics of the nuclear fuel and the extent of burnup (i.e., extent of nuclear fuel exposure in the reactor).

- The nuclide ^{241}Am poses one of the most significant long-term photon exposure sources. Plutonium with higher burnup, and thus higher amounts of ^{240}Pu and ^{241}Pu, will have significantly higher concentrations of ^{241}Am, eventually, beginning from an abundance of about zero shortly after separation to a peak concentration in approximately 73 years.

- Plutonium containing a higher percentage of ^{240}Pu will normally have a lower NP ratio shortly after separation because there is a higher photon yield due to shorter half-life isotopes (^{238}Pu, ^{240}Pu, ^{241}Pu).

- The NP ratio can be significantly affected by fission product (e.g., Ru, Nb, Zr) contamination of the plutonium which was greater in the earlier years.

- At Hanford, a major shift in plutonium isotopic content occurred around 1965 in the switch from weapons-grade (lower burnup) to fuel-grade (higher burnup) plutonium as shown in

Figure F-2. Considering only this issue, the NP ratio would be expected to be greater prior to 1965 because of the lower ^{240}Pu content in the relatively lower-exposed weapon-grade fuel.

The historical trend in the NP ratio in the workplace was considered in the 1972 AEC/HQ investigation using a committee of technical experts from throughout the DOE complex. The committee was formed to evaluate a significant increase in recorded neutron dose with the implementation of the Hanford TLD on January 1, 1972 compared with the previous measured neutron dose with NTA film.

The NP ratios identified by the committee for use in retrospective dose reconstruction for highly exposed workers (i.e., to view career dose compliance with the 5 (N-18) rem whole body dose limit) are shown in Table F-7. The analysis by the committee showed an expectation that the earlier NP ratios in the workplace would be lower. The basis for these NP ratios used to evaluate worker cumulative doses include:

Table F-7. 1972 AEC NP ratios used to reconstruct maximum worker dose.

	Neutron to gamma ratio		
Worker description	**1961–72**	**1956–60**	**1948–55**
Plutonium workers	2.01	1.36	1.23
Maintenance workers	1.60	1.09	1.00

- Recorded gamma radiation dose as measured by the film badge dosimeter is reasonably accurate for this type of radiation.
- The gamma radiation dose measured with TL and film dosimeters is comparable.
- For the period of 1961 through 1971, the ratio of the neutron to gamma radiation dose as measured by the TL dosimeter during the period of use, January 1, 1972 through June 30, 1972, is reasonably representative of production conditions since introduction of heavy shielding materials (lead, lead glass, water walls).
- For the period of 1956 through 1960, approximately one-third reduction in the neutron to gamma ratio is assumed when less shielding was in place primarily to reduce exposure from lower energy X and gamma radiation emitted by plutonium and plutonium compounds. On the average about one-third reduction in gamma dose was observed during the period following 1960 when heavy shielding was installed and production was comparable.
- For the period of 1948 through 1955, another reduction of approximately 10 percent in the neutron to gamma ratio is assumed when essentially no shielding other than thin plastic hood windows was used in the process areas. It was estimated that low energy photons contributed about 10 percent of the penetrating gamma dose.

The analysis of the workplace measurements is complex because the NP ratio depends upon the workplace, work task, the distance of the measurement and the instrument used. The original workplace measurements were not taken with the understanding that these would be used to prepare a NP ratio to be used in dose reconstruction. As such, care must be taken in the selection of the data used to determine the NP ratio.

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A scatter plot of the 1,346 measured neutron and photon dose results is presented in Figure F-5 and a lognormal probability graph of the measured 1,419 NP ratio values (i.e., Bramson 1962 reference only provided measured NP ratios without measured neutron and photon doses) in Figure F-6.

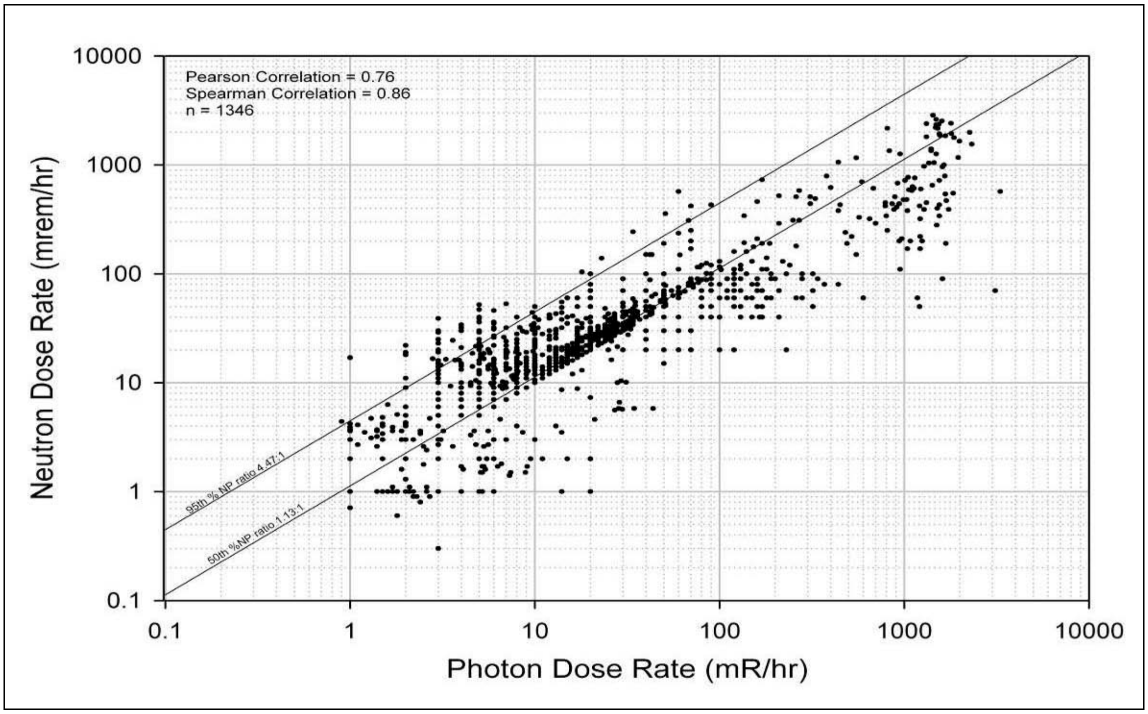

Figure F-5. Scatter plot of 1,346 measured neutron and photon doses.

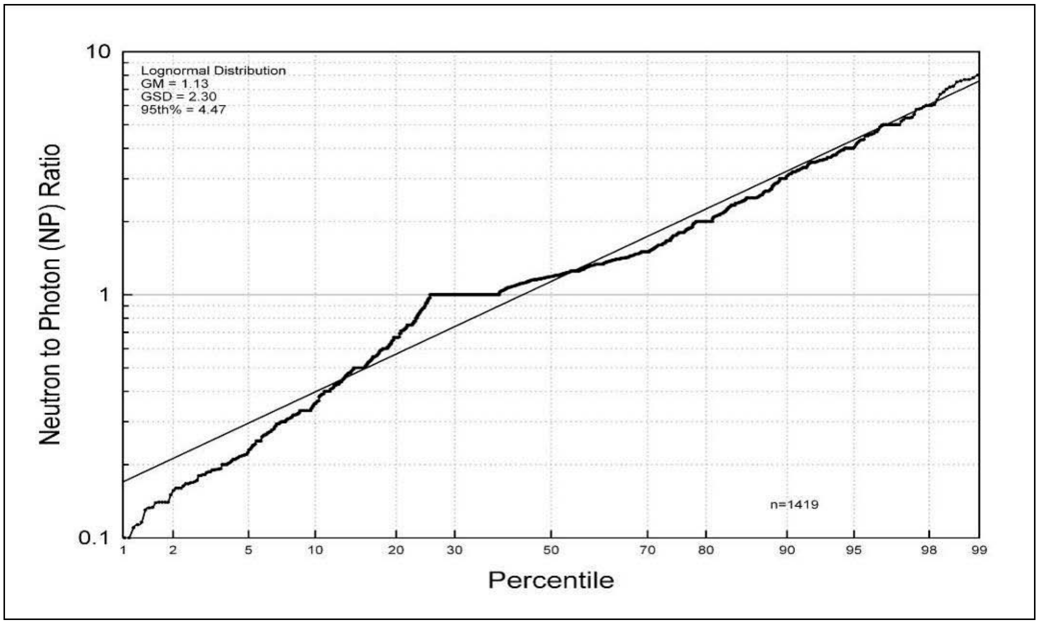

Figure F-6. Lognormal probability plot of 1,419 measured NP values.

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These figures show a Pearson rank correlation between the neutron and photon measurements of 0.76. The NP ratio best fits a lognormal distribution with a GM = 1.13, a GSD = 2.30 and the upper 95th-percentile of 4.47.

Statistical lognormal distribution parameters for each category of workplace measurements are presented in Table F-8. It is evident in the tabled values that the TLD measurements are significantly less variable perhaps because the neutron and photon doses, respectively, are measured within a single device. The TLD data generally show a good lognormal distribution fit as noted in the last column of Table F-8.

Table F-8. Statistical parameters for lognormal distribution for the respective selections of NP ratio measurement data.

Workplace measurements	No.	GM	GSD	95th%	Fit[a]
All data: TLDs + instruments	1,419	1.13	2.30	4.47	0.18
TLD data–ALL	299	0.69	2.36	2.83	0.06
TLD data–2003 claims	186	0.73	2.10	2.47	0.09
TLD data–AEC study	113	0.63	2.77	3.37	0.06
Instrument data–all	1,120	1.29	2.17	4.64	0.22
Instrument data–radiation control reports	161	1.23	2.74	6.45	0.13
Instrument data–fluorination hoods 7A/9A & 7C/9B	71	1.68	2.57	7.94	0.19
Instrument data–hood 7A/9A	17	1.95	2.61	9.47	0.23
Instrument data–hood 7C/9B	54	1.60	2.57	7.56	0.20
Instrument data–technical reports	113	0.53	2.83	2.94	0.06
Instrument data–workplace surveys	846	1.47	1.80	3.85	0.23
Fluorination hoods instrument plus TLD worker measured	370	0.82	2.56	3.85	0.07

a. Kolmogorov–Smirnov test is used as a measure of goodness of fit to a lognormal distribution.

The highest quality instrument measurement data available for analysis of the NP ratio are the respective 1963 monthly and 1964–1976 (1st quarter only) quarterly reports prepared by PFP Radiation Protection staff. These measurements represent an average of daily and weekly measurements and are stated to be representative of worker exposures. This measurement data cover the period of weapons-grade plutonium prior to 1965 and primarily reactor-grade plutonium thereafter. The data are separated according to selected workplace categories (i.e., Plutonium processing, Plutonium Reclamation, Maintenance, 234-5Z Technical services, Button Line, Fluorination Hoods 7C-9B and 7A/9A). The RMA Line produced only oxides from 1968 on and the RMC Line mostly metal. Hanford Site personnel referred to the RMA Line as “the oxide line” and to the RMC Line as “the metal line” (DOE 2002). Three figures are provided for this data described as follows:

- Figures F-7 and F-8, respectively, contain graphs of instrument measured monthly neutron and photon dose rates with callouts for the PFP fluorination 7C/9B and 7A/9A hoods, button line and other line workplace locations during the period of 1963 to 1976. The dose results reported quarterly after 1963 were divided by 3 to obtain a monthly average to compare to the earlier reported monthly measurements.

- Figure F-9 presents NP ratios calculated from the original data used to prepare Figures F-5 and F-6.

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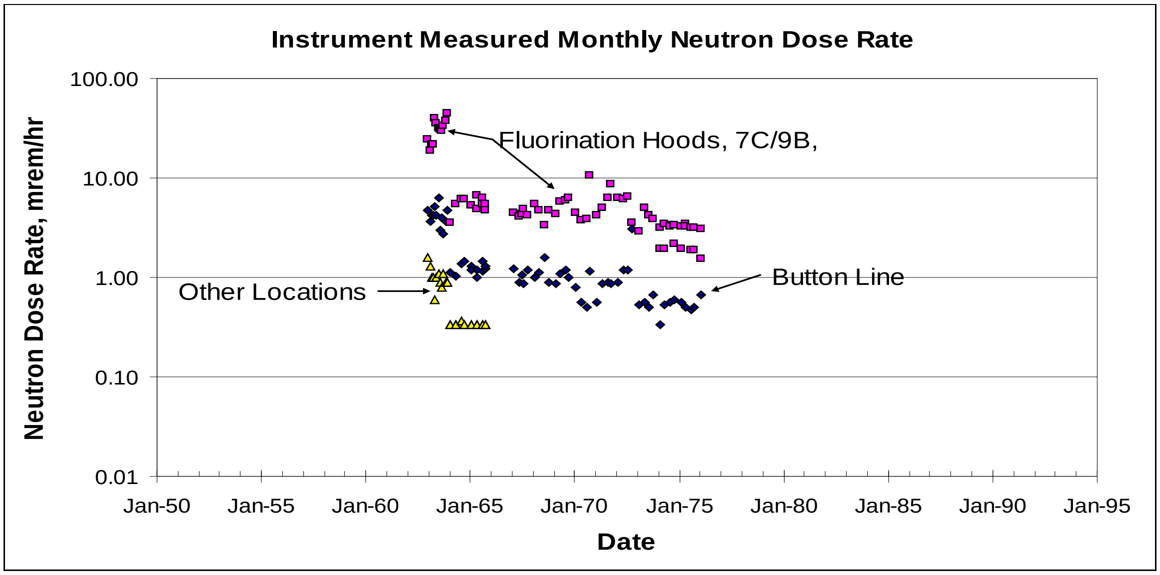

Figure F-7. Radiation control report instrument measured monthly neutron dose rates with callouts for the PFP fluorination 7C/9B and 7A/9A hoods, button line and other line workplace locations during the period of 1963 to 1976.

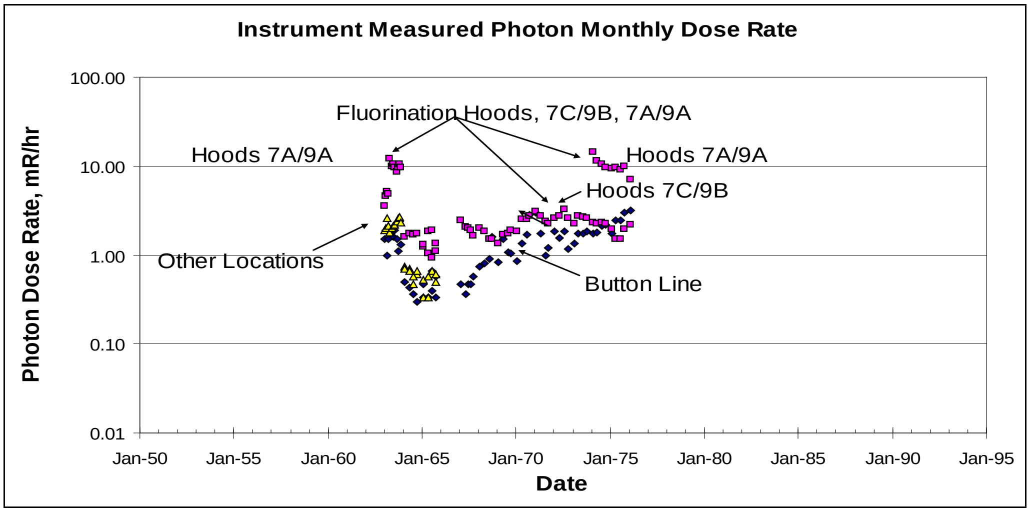

Figure F-8. Radiation control report instrument measured monthly photon dose rates with callouts for the PFP fluorination 7C/9B and 7A/9A hoods, button line and other line workplace locations during the period of 1963 to 1976.

These figures illustrate the comparatively greater NP ratio for the 7C/9B and 7A/9A fluorination hoods, and significantly, the comparatively greater photon (and neutron) dose rate compared to other locations along the process line. As such, assigning neutron doses prior to January 1, 1972 using the fluorination hood measured NP ratio multiplied times the measured photon dose will result in a favorable-to-claimant evaluation. The significance of worker exposures from the fluorination hoods was the basis for selecting this location to develop a workplace neutron dose calibration of the

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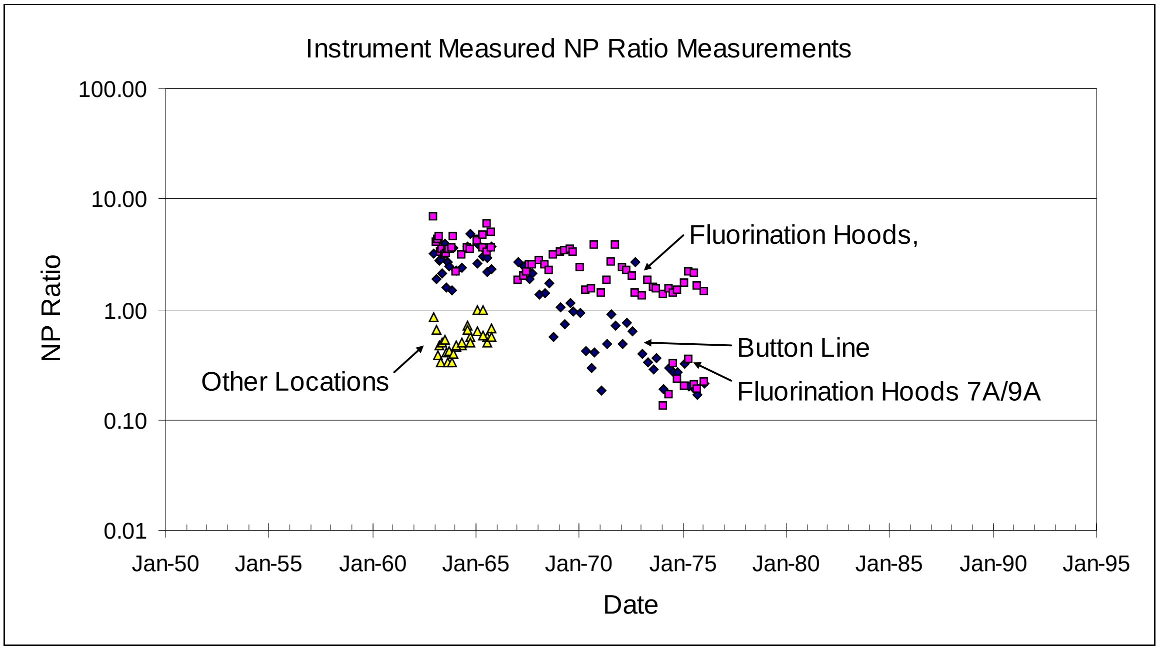

Figure F-9. NP ratios calculated from the data contained in Figures F-5 and F-6.

Hanford TLD. In this process the PuF_4 calibration source geometry in the Hanford Radiological Calibrations Facility 3745A was adjusted to arrive at an “equivalent workplace” neutron calibration (SRDB 48446, 54554; Fix et al 1997b) based on workplace neutron dose and dosimeter measurements (i.e., dosimeter response calibrated to TEPC measured neutron dose).

Personnel TLD measurements after 1971 are considered to be of comparatively good quality because the dosimeter measures the photon and neutron dose simultaneously in a single device, the dosimeter response has been verified with instrument workplace measurements on several occasions and the TLD tends to over-estimate, rather than under-estimate, the neutron dose in Hanford work locations. Two figures are presented as follows:

- Figure F-10. Correlation of TLD measured neutron and photon doses.
- Figure F-11. Lognormal Probability Plot for TLD measured neutron-photon ratios.

These figures show a Pearson rank correlation between the neutron and photon measurements of 0.69. As noted in Table F-8, the TLD data NP ratio best fits a lognormal distribution with a GM = 0.69, a GSD = 2.36 and the upper 95th-percentile of 2.83.

Fluorination 7C/9B and 7A/9A hoods instrument measurements plus the personnel TLD results after 1971 are shown in Figure F-12. As noted in Table F-8, the NP ratio best fits a lognormal distribution with a GM = 0.82, a GSD = 2.56 and the upper 95th-percentile of 3.85. In Figure F-12, it does appear as though the instrument measured NP ratio prior to 1972 is greater than the personnel TLD measurements after 1971. As such, the instrument measurements for the fluorination hoods 7A/9A and 7C/9B were selected as representing the bounding workplace. As noted in Table F-8, the fluorination hood instrument measured NP ratio best fits a lognormal distribution (Kolmogorov-Smirnov fit = 0.1) with a GM = 1.68, a GSD = 2.57 and the upper 95th-percentile of 7.94. This is also the workplace with the highest measured photon (and neutron) dose rates.

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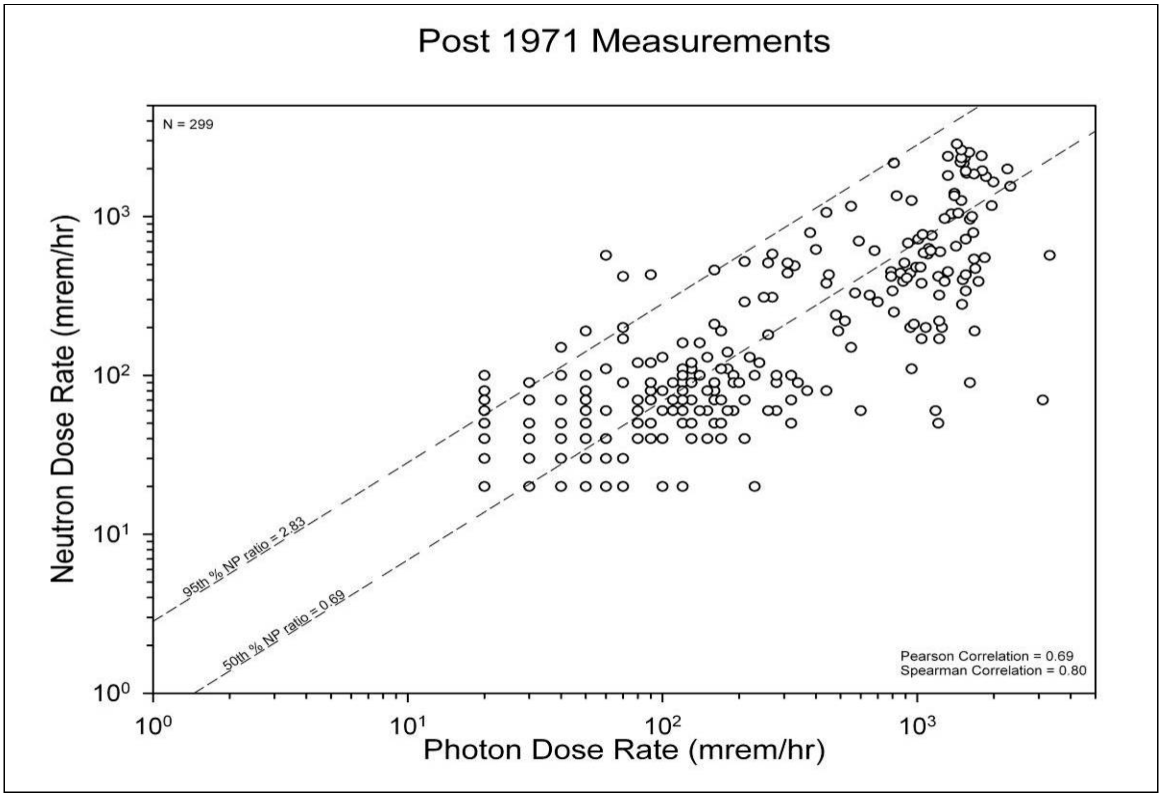

Figure F-10. Correlation of TLD measured neutron and photon doses.

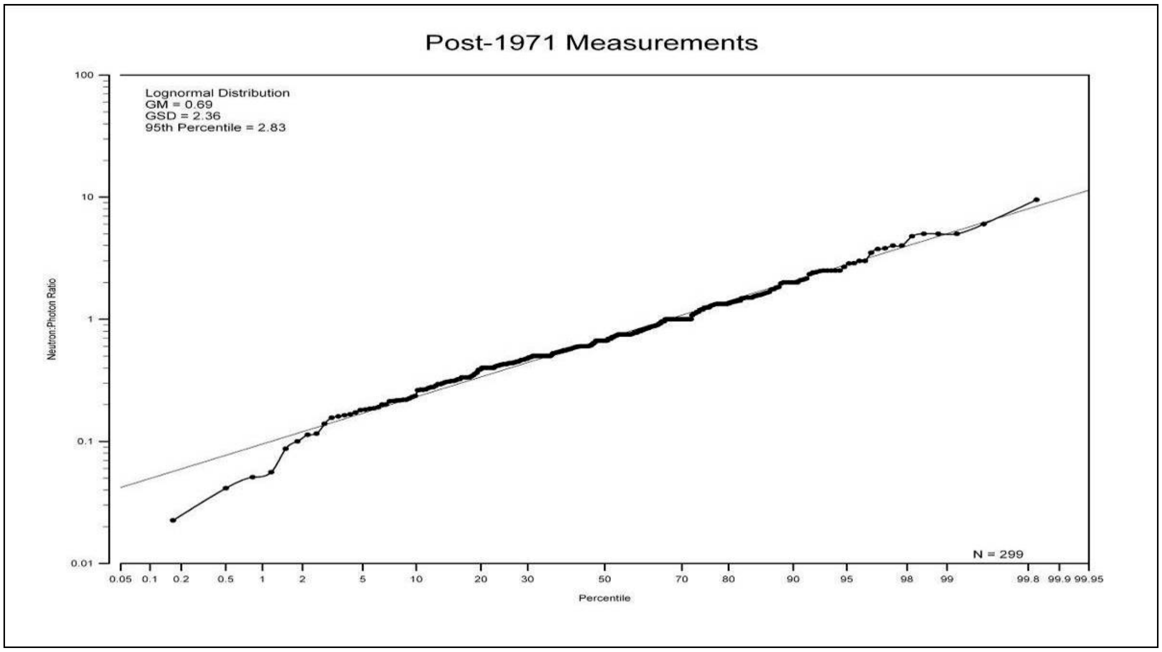

Figure F-11. Lognormal probability plot for TLD measured neutron-photon ratios.

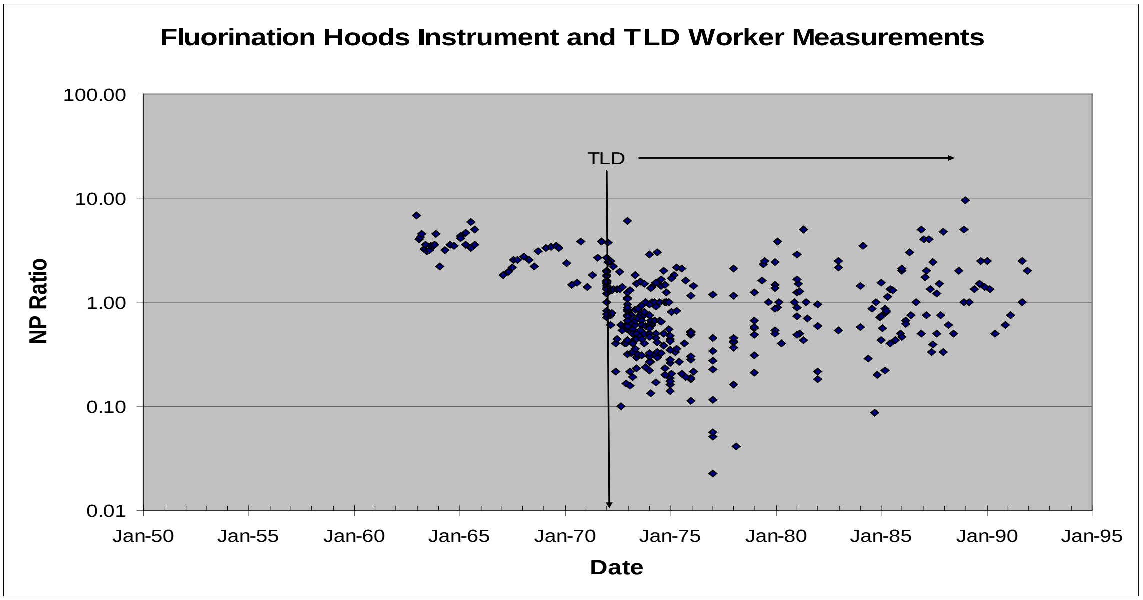

Figure F-12. Fluorination 7C/9B and 7A/9A hoods instrument and worker TLD NP ratio measurements.

F7.6 RECOMMENDED NP RATIOS

Workplace instrument and thermoluminescent dosimeter measurements were obtained from the extensive DOE Richland archives of historical documentation. A summary of the analysis of the 1,419 NP ratio measurements is presented in Table F-8 for each of the major categories of measurement data.

The recommended favorable-to-claimant NP ratios are:

- For glovebox workers, the guidance in OCAS-TIB-010 for plutonium glovebox workers must be applied.
- Consistent with OCAS-IG-001 (2007) guidance, the measured and assigned neutron doses must incorporate the ICRP 60 weighting factors for the respective neutron energy categories in Hanford plutonium workplaces (ORAUT-OTIB-0055) (i.e., < 0.01 MeV = 2.13, 0.01-0.1 MeV = 1.86, 0.1–2.0 MeV = 1.91).

Worker	GM	GSD	95th-percentile	Basis
Non-glovebox worker	1.1	2.3	4.5	Lognormal statistical parameters for 1,419 instrument and TLD measurements
Glovebox worker	1.7	2.6	7.9	Lognormal statistical parameters for Fluorination Hoods 7C/9B, 7A/9A instrument measurements

F7.7 ILLUSTRATION OF THE APPLICATION OF NP RATIO

An illustration of the significant assignment of neutron dose using a NP ratio multiplied times the recorded photon dose is presented in Table F-9 using the dose record for a single higher exposed worker. For this worker, the record of recorded doses after 1972 with the Hanford TLD is also included in Table F-9 for comparison. For this worker, the film dosimeter measured WB dose (i.e., photon plus neutron) from 1958 through 1971 is 33 rem. The assigned WB dose using the 95th-percentile NP ratio (7.9) results in an assigned WB dose, during the period of film dosimeter use prior to 1972, of 219 rem. Applying guidance in TIB-010 for a lower abdominal organ results in an assigned organ dose of 480 rem assuming the organ dose conversion factor is 1.0. The TLD measured doses from 1972 through 1987 are considered to be reasonably accurate. For this worker employed from 1958 through 1987, there is a recorded Hanford career WB dose (photon and neutron dose) of 60 rem, and assigned WB dose of 246 rem, and for a lower abdominal organ an assigned organ dose of 539 rem assuming the organ dose conversion factor is 1.0. These values are illustrated in Table F-9.

Table F-9. Illustration of assigned dose to long-term PFP worker.

	Recorded dose components				**Assigned WB dose**		
Year	**Shallow**	**Deep**	**Neutron**	**X-ray**	**Recorded**[a]	**NP ratio**[b]	**TIB-010**[c]
Hanford film/NTA dosimeter							
1/1/58	2,520	2,520	60	440	2,734	23,799	52,119
1/1/59	2,170	1,990	120	330	2,226	18,739	41,038
1/1/60	1,370	1,370	340	70	1,735	12,411	27,180
1/1/61	1,460	1,460	1,110	200	2,640	13,617	29,821
1/1/62	1,080	930	1,880	300	2,915	9,212	20,173
1/1/63	2,010	1,470	800	360	2,396	14,204	31,108
1/1/64	1,830	1,730	1,060	290	2,892	16,300	35,698
1/1/65	2,100	2,100	570	530	2,856	20,341	44,547
1/1/66	640	640	120	250	848	6,475	14,180
1/1/67	2,080	1,880	250	310	2,239	17,698	38,758
1/1/68	1,780	1,400	840	310	2,349	13,426	29,402
1/1/69	1,760	1,670	370	820	2,327	17,417	38,144
1/1/70	1,430	1,400	270	610	1,884	14,360	31,449
1/1/71	2,180	2,180	710	520	3,072	21,022	46,038
Film subtotals	**24,410**	**22,740**	**8,500**	**5,340**	**33,109**	**219,020**	**479,654**
Hanford TLD							
1/1/72	2,240	1,540	2,360	0	3,900	3,900	8,541
1/1/73	3,120	2,260	1,990	0	4,250	4,250	9,308
1/1/74	1,600	1,110	630	0	1,740	1,740	3,811
1/1/75	1,570	1,210	420	0	1,630	1,630	3,570
1/1/76	1,500	1,220	220	0	1,440	1,440	3,154
1/1/77	1,390	1,180	60	0	1,240	1,240	2,716
1/1/78	700	520	220	0	740	740	1,621
1/1/79	810	570	330	0	900	900	1,971
1/1/80	1,110	790	420	0	1,210	1,210	2,650
1/1/81	1,250	920	680	0	1,600	1,600	3,504
1/1/82	1,180	970	210	0	1,180	1,180	2,584
1/1/83	1,350	1,130	610	0	1,740	1,740	3,811
1/1/84	1,010	890	510	0	1,400	1,400	3,066
1/1/85	1,520	1,050	770	0	1,820	1,820	3,986

ATTACHMENT F
A BOUNDING ESTIMATE OF NEUTRON DOSE BASED ON MEASURED PHOTON DOSE AT 200 AREA PLUTONIUM FACILITY OPERATIONS AT THE HANFORD SITE

	Recorded dose components				Assigned WB dose		
Year	Shallow	Deep	Neutron	X-ray	Recorded[a]	NP ratio[b]	TIB-010[c]
1/1/86	1,450	1,030	480	0	1,510	1,510	3,307
1/1/87	460	490	190	0	680	680	1,489
TLD subtotals	22,260	16,880	10,100	0	26,980	26,980	59,086
Career totals	46,670	39,620	18,600	5,340	60,089	246,000	538,740

a. Hanford WB Dose = Deep + Neutron + 0.35 * X-ray.

b. NP 95th-percentile = 7.9

c. Lower abdomen organ dose only geometry correction, GM = 2.19.

ATTACHMENT G
A BOUNDING ESTIMATE OF NEUTRON DOSE BASED ON MEASURED PHOTON DOSE AT HANFORD 300 AREA AND MISCELLANEOUS FACILITY OPERATIONS AT THE HANFORD SITE

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G1. EXECUTIVE SUMMARY

The Hanford 300 Area Reactor and plutonium research, development and testing facilities, the 300 Area Radiological Calibrations facilities, and the site critical mass laboratory facilities did involve neutron radiation exposure of workers as evidenced by (1) the types of operations, (2) routine assignment of nuclear track emulsion (i.e., NTA) film, and (3) information in the routine radiation monitoring periodic reports. Operations in these facilities supported the much larger 100 Area reactor and 200 Area chemical processing and plutonium chemical-metallurgical facilities. Extensive radiation surveys were taken of these facilities because Hanford radiation safety standards applied to all facilities in the 100, 200 and 300 Area facilities. Workers in the 300 Area would often travel to the 100 and 200 Areas. A feasible neutron dose reconstruction option is to apply favorable-to-claimant NP ratios determined for the Hanford 100 Area single-pass cooling production reactor (Taulbee et al. 2008) and Hanford 200 Area plutonium (Attachment F) facilities to 300 Area workers according to their work activities. In this approach, NP ratios determined from workplace measurements in the 100 Area reactor and 200 Area plutonium facilities would be applied to workers in the 300 Area reactor and plutonium facilities, respectively, based on a favorable-to-claimant judgment by the dose reconstructor. Neutron exposures in the 120 Building and 209-E critical mass laboratories to workers did occur but were relatively insignificant for routine operations because of the significant shielding and remote operation. Under all circumstances, there was substantial photon radiation that was reasonably accurately measured in all facilities and for all periods that accompanied the neutron radiation.

Dose reconstruction would involve:

- TLD-measured neutron dose be used from January 1972 to date for all workers and Hanford facilities.
- Prior to 1972, the measured (and missed) photon dose is multiplied by an NP dose ratio to arrive at an assigned neutron dose. The selection of NP dose ratio distribution parameters should be based on comparison with the extensive measured dose rates in Hanford single-pass cooling (Taulbee et al. 2008), Hanford N Reactor (Attachment E), and Hanford 200 Area Plutonium Facilities (Attachment F).

The estimated neutron dose calculated using NP ratios and the measured photon dose must be adjusted to incorporate the ICRP Publication 60 weighting factors (ICRP 1991). The assumed neutron energy IREP input category is assumed to be 0.1 to 2 MeV.

G2. INTRODUCTION

The focus of this attachment concerns a technical basis for neutron dose reconstruction for workers at Hanford 300 Area plutonium, reactor, and radiological research and development laboratory facilities and Hanford Site critical mass laboratories during the periods of operation of these facilities. A technical basis for neutron dose reconstruction for several Hanford facilities is provided as follows:

- Hanford single-pass cooling plutonium production reactors (B, C, D, DR, F, H, KE, and KW) constructed during the period from 1943 through 1954 that operated from 1944 through 1971 (Taulbee et al. 2008).

ATTACHMENT G
A BOUNDING ESTIMATE OF NEUTRON DOSE BASED ON MEASURED PHOTON DOSE AT HANFORD 300 AREA AND MISCELLANEOUS FACILITY OPERATIONS AT THE HANFORD SITE

- Hanford 100 Area N Reactor operations during the period from December 1963 through January 1987 (Attachment E).

- Hanford 200 Area Plutonium Facilities operations during the period from about 1944 through the 1990s (Attachment F).

Hanford 300 Area research and development facilities were used to test and evaluate processes to be incorporated into the much larger 100 Area Reactor and 200 Area Chemical Processing and Metallurgical production facilities. Hanford critical mass laboratories used to test process methods and tolerances were located in typically isolated facilities in the 100, 200 and 300 Areas. The 300 Area did have the primary roles to fabricate fuel for the Hanford Reactors and to provide site-wide radiological calibrations, radiation instruments and dosimetry capabilities. Because of the research nature of Hanford 300 Area and Miscellaneous Facilities a wide range of nuclear science activities occurred. Activities with some potential for significant neutron exposure to workers can be generally categorized as:

- Prototypes of reactor testing, research and development facilities

- Plutonium research and development laboratory processes

- Critical Mass Laboratories

- Nuclear Science Research and Development

- Hanford site-wide technical support involving radiological research, calibrations, instrument development and dosimetry capabilities.

As noted in the Hanford Site Profile External Radiation Technical Basis Document ORAUT-TKBS-0006-6 prepared originally in 2003, neutron radiation exposures to workers in Hanford facilities were not accurately measured using personnel film NTA dosimeters prior to implementation of the Hanford thermoluminescent personnel dosimeter (TLD) on January 1, 1972. Prior to January 1, 1972, Hanford used four general methods (Wilson 1987) to measure and control neutron exposure to workers as follows:

- Method #1. Eastman Kodak Nuclear Track Emulsion, Type A, (NTA) personnel neutron film beginning in 1950 with three different Hanford neutron personnel dosimeter designs (i.e., Two-Element, 1958 multielement and 1962 multielement).

- Method #2. Pocket ionization chambers (PICs) with a boron liner [examples, HEW (1947–1949, 1949–1952)].

- Method #3. Workplace surveys using portable neutron radiation responsive instrument and time-keeping.

- Method #4. Measurement and control of worker photon exposure to Hanford Operational dose limits with the expectation that the total WB dose (photon plus neutron) would be less than MED/AEC officially identified dose limits.

ATTACHMENT G
A BOUNDING ESTIMATE OF NEUTRON DOSE BASED ON MEASURED PHOTON DOSE AT HANFORD 300 AREA AND MISCELLANEOUS FACILITY OPERATIONS AT THE HANFORD SITE

These methods were used jointly to measure and control worker radiation exposures because dosimeters in method #1 do not provide capabilities for effective workplace exposure control. Dosimeters are exchanged on a routine weekly, biweekly, monthly, or quarterly schedule with dose results received long after radiation exposures have been received. There are records of dose assessments with methods #2 and #3 but it is not certain that the neutron doses were incorporated into the official Hanford radiological records. This could be important if neutron doses determined from these methods were greater than the NTA film measured doses. Method #4 was incorporated in 1954 into Hanford Operational Radiation Protection Standards as discussed under Radiation Protection Standards in this document. This method has an implied bound on the ratio of the NP dose (i.e., 5 rem/3 R = 1.7) which was adopted to ensure Hanford workers did not exceed annual dose protection limits. Based on the recorded neutron dose record for the Hanford Worker Health and Mortality Study (Buschbom and Gilbert 1993) which includes essentially all Hanford workers employed with a primary Hanford contractor for a period longer than six months there is no recorded neutron dose prior to 1950. The judgment in ORAUT-TKBS-0006-6 that the neutron dose is underestimated for workers at Hanford plutonium facilities prior to 1972 is consistent with findings of an AEC/HQ technical committee investigation conducted in 1972 involving dosimetry experts from other AEC sites and Hanford (Biles 1972). This investigation was conducted because of the significant increase in measured neutron dose with the TLD compared to the NTA film (Fix et al. 1997).

Recommendations developed in 1972

The recommended neutron to gamma ratios identified by the committee in 1972 are shown in Table G-1.

Table G-1. AEC 1972 Committee NP ratio recommendations.

Worker description	Neutron to gamma ratio		
	1961–72	**1956–60**	**1948–55**
Plutonium workers	2.01	1.36	1.23
Maintenance workers	1.60	1.09	1.00

The stated reasons for these recommended NP ratios include:

- Recorded gamma radiation dose as measured by the film badge dosimeter is reasonably accurate for this type of radiation.
- The gamma radiation dose measured by TL and film dosimeters is comparable.
- The ratio of the neutron to gamma radiation dose as measured by the TL dosimeter during the period of use, January 1, 1972 through June 30, 1972, is reasonably representative of production conditions since introduction of heavy shielding materials (lead, lead glass, water walls).
- Approximately one-third reduction in the neutron to gamma ratio is assumed for the period from 1956 through 1960 when less shielding was in place primarily to reduce exposure from lower energy X-ray and gamma radiation emitted by plutonium and plutonium compounds. On the average about one-third reduction in gamma dose was observed during the period following 1960 when heavy shielding was installed and production was comparable.

- Another reduction of approximately 10 percent in the neutron to gamma ratio is assumed for the period from 1948 through 1955 when essentially no shielding other than thin plastic hood windows was used in the process areas. It was estimated that low energy photons contributed about 10 percent of the penetrating gamma dose.

There is a set of spreadsheets that contain NTA processing results for Hanford workers according to Hanford Operating Areas during the period from 1950 through 1961 (Yamauchi, 2006) and additional years of records are available in DOE-RL record archives in the Seattle Federal Record Center. Technically, neutron radiation is easy to detect but determination of the spectra and dose to workers is complex. The AEC/DOE has attempted to address the complexities of Personnel Neutron Dosimetry in a series of workshops organized to share technology among sites beginning in 1969 (Vallario, Hankins, and Unruh 1969). Even in the present time, personnel neutron dosimeter performance is not equivalent to the accuracy and reliability of photon (X-ray and gamma) dosimeter performance. There are portable instruments available since approximately the mid-1950s that do provide reasonably accurate measurements of the neutron dose. The TLD-measured neutron dose is considered to be reasonably accurate with a significant potential to overestimate rather than to underestimate the actual neutron dose. A timeline of significant events at Hanford associated with radiation protection of 300 Area workers is presented in Attachment D, Table D-2. A detailed timeline of Hanford operations and processes is presented in RHO-HS-ST-10 Vol. 1 ATT (RHC 1987).

The option to retrospectively estimate a neutron dose to workers in these facilities by multiplying the measured photon dose by a NP (NP) ratio avoids significant issues concerning:

- NTA neutron dosimeters might not have been assigned to all Hanford workers in these 300 Area facilities prior to the TLD implemented January 1, 1972,

- The assigned NTA dosimeters did not reliably provide a reasonably accurate estimate of the actual neutron dose for Hanford workers.

Certainly, the challenge in this approach is the determination of the NP ratio (i.e., distribution of values to select GM, GSD, 95th-percentile) for use in neutron dose reconstruction and in estimating the uncertainty.

2003 Site Profile Neutron Dose Recommendation

The Hanford Site Profile External Radiation Technical Basis Manual prepared originally during 2003 recommends reconstruction of the neutron dose as follows:

- Use TLD measured neutron dose from January 1972 to date along with the missed neutron dose using OCAS-IG-001 External Dose IG Guidance (NIOSH 2007b).

- Prior to 1972, multiply the neutron-to-photon NP dose ratio times the measured and missed (using OCAS-IG-001 guidance) photon dose using ratios determined for Hanford 100 Area reactor and 200 Area plutonium facilities based on evaluation of similar workplace fields (i.e., 305 reactor would utilize 100 Area single-pass cooling NP ratio and 308 Building would utilize 200 Area plutonium facility NP ratio).

G3. HISTORY

The history of Hanford 300 Area Plutonium and Miscellaneous 100 and 200 Critical Mass facilities was centered around testing of various processes being considered for incorporation into the much larger 100 Area Reactor and 200 Area Chemical and Chemical/Metallurgical Production facilities. Notable historical documents include the following:

- Ballinger, M. Y., and R. B. Hall, 1991, *A History of Major Hanford Facilities and Processes Involving Radioactive Material*, PNL-6964 HEDR, Pacific Northwest Laboratory, Richland, Washington, March.

- Gerber, M. S., 1993a, *Multiple Missions: The 300 Area in Hanford Site History*; M. S. Gerber, PhD, WHC-MR-0440, Westinghouse Hanford Company, Hanford Site, Richland, Washington, September.

- Gerber, M. S., 1992, *Past Practices Technical Characterization Study – 300 Area – Hanford Site*, WHC-MR-0388, Westinghouse Hanford Company, Hanford Site, Richland, Washington, December.

- DOE (U.S. Department of Energy), 1997, *Linking Legacies: Connecting the Cold War Nuclear Weapons Production Processes to Their Environmental Consequences*, DOE/EM-0319, Office of Environmental Management, Washington, D.C., January.

During the period from 1944-49, all research and development (R&D) work at Hanford was in support of plutonium production (Ballinger and Hall 1991). The principal R&D activity was the cold semiworks activities in the 321 Building, where pilot-plant scale work was conducted for the REDOX Plant, and, later, the PUREX Plant. Because radioactive contamination in this facility was limited to uranium, which represented a much smaller radiation hazard than plutonium, radiation dose rates were comparably low. REDOX and PUREX operating crews were trained here. In the 1950s, facilities in the 300 Area were greatly expanded, including construction of the Plutonium Fuels Pilot Plant (PFPP) and the 309 Bldg Plutonium Recycle Test Reactor (PRTR), where work was directed toward developing peaceful uses for plutonium.

G3.1 HANFORD 300 AREA PLUTONIUM AND SITE MISCELLANEOUS FACILITIES

G3.1.1 Test Reactor Facilities

As described in ORAUT-TKBS-0006-2, the Hanford 300 Area was the location of several test reactors (ORAUT 2007c). The 305 Building housed a small reactor for testing samples of graphite, uranium and other materials used in the construction of the large 100 Area plutonium production reactors. The Physical Constants Test Reactor and the Thermal Test Reactor were also located in the 305 Building. Other 300 Area Test Reactors included the 309 Building Plutonium Recycle Test Reactor (PRTR) and the 318 Building High Temperature Lattice Test Reactor (HTLTR). A brief description of these test reactors all built and operated prior to the use of the TLD follow:

305 Building Hanford Test Reactor. The HTR operated at a low power level (usually less than 50 Watts) from 1943 until 1972 to test samples of each lot of graphite, uranium, aluminum tubes, aluminum canning material (for fuel rod jackets), and other materials to be used in the Hanford production reactors. Instrumentation for the 100 Area reactors including counter tubes, gas chambers, thermopiles, shim-stock chambers and neutron and gamma radiation chambers were also tested in the 305 Test Reactor. The reactor consisted of a graphite pile and was air-cooled. The pile was removed from the 305 Building during 1976-77. There was undoubtedly some external radiation exposure to Hanford workers from operations at this facility.

305 Building Physical Constants Test Reactor (PCTR). The 800 Watt PCTR operated from 1954 to 1970 for the purpose of measuring reactor changes as a result of use of different reactor fuels. External radiation exposures to workers were negligible because the reactor was located in a shielded underground room and operated remotely.

305 Building Thermal Test Reactor (TTR). The 1000 Watt TTR operated from 1954 through 1978 for the purpose of measuring thermal dependence of various material fission cross-sections. External radiation exposures to workers were minimal because the reactor was operated remotely.

309 Building Plutonium Recycle Test Reactor (PRTR). The heavy water cooled and moderated PRTR began operating in November 1960 and reached full power of 70 MW in July 1961. The reactor operated through 1969 for the purpose of testing mixed oxide reactor fuels using various methods of manufacture. External radiation exposure to personnel was minimized because of shielding and remote operation. The Plutonium Recycle Critical Facility (PRCF) also operated in the 309 Building from 1962 through 1976 for the purpose of testing geometric arrangements of fissionable materials in a reactor.

318 Building High Temperature Lattice Test Reactor (HTLTR). The 2 MW HTLTR operated from 1968 to 1971 to test advanced reactor physics technology. Six different cores were used in the reactor. External radiation exposure was negligible during operation because the reactor was heavily shielded and operated remotely. This building and the shielded reactor room were modified in the early 1980s and used thereafter as the Hanford Radiation Calibration Facility replacing operations originally conducted at the 3745A Building.

G3.1.2 Critical Mass Laboratory Facilities

Hanford critical mass laboratories were operated at the 120 Building near the 100-F Area and later in the 209-E building in the 200 East Area. A brief description of the Hanford critical mass laboratory facilities follows:

120 Critical Mass Laboratory. The 120 Bldg Critical Mass Laboratory started in 1950 conducting nuclear physics research and development studies of plutonium solutions and solids with the objective to avoid a criticality accident in an operating facility. During a critical mass study on November 16, 1951 the reactor suddenly went out of control. The primary and secondary safety systems automatically shut down the reactor promptly. However, all six workers in the P-11 area at the time were overexposed to gamma and neutron radiation. Total WB dose estimates ranged from 300 to 600 mrem [see Attachment D, Table D-2, November 16, 1951, for more details (Adams 1951)].

209-E Critical Mass Laboratory. The 209-E Critical Mass Laboratory was placed into operation during July 1961 and shut down in 1986. The building located in the central 200 East Area contained a critical assembly room with a minimum wall thickness of 3 ft, a mixing room with gloveboxes and a mixing hood, and a control room from which experiments could be remotely conducted. Because of the shielding external radiation exposure to personnel is considered to have been minimal.

G3.1.3 Radiological Calibration Laboratory Facilities

3745 Radiological Calibrations and Standards Laboratory. Operations at this laboratory began in October 1944 using various beta, gamma and neutron radiation sources, and X-ray systems, to test and calibrate Hanford Site dosimetry and instrument capabilities. A supporting facility, 3745-A, was built in 1950 to house a 2 MeV negative ion Van de Graff accelerator. A similar supporting facility, 3745-B, was built in about 1955 to house a 4-MeV Van de Graff positive ion accelerator. These accelerator facilities were used to perform fast neutron radiation calibrations of Hanford instruments and dosimeters. The process of testing and calibration of Hanford portable radiation detection instruments and personnel dosimeters does involve radiation exposure to the workers. Operations in this facility were moved to the 318 Building in 1983.

318 Hanford Radiological Calibrations Facility. The 318 Building was originally built in 1967 to house the High Temperature Lattice Test Reactor (HTLTR). In the early 1980s, the reactor was removed and the facility converted to house Hanford Radiological Calibrations capabilities from the 3745 Building. The process of calibration and testing Hanford portable radiation detection instruments and personnel dosimeters does involve radiation exposure to the workers.

G3.1.4 300 Area Laboratory Facilities

G3.2 FACILITIES OPERATIONAL IN THE 1940S

3706 Radiochemistry Laboratory. Radiochemistry activities in the 300 Area began in 1944 in the 3706 building, where work was limited to low-level radioactivity handled in hoods. Chemistry performed included support for fuel fabrication and REDOX process development, which was occurring in the 321 Building. There was plutonium contamination of some laboratory rooms within this facility (Gerber 1992) that required use of protective clothing, time limitations and other SWP protective actions.

3708 Radiation Measurements Building. The 3708 Radiation Measurements Building was built in 1948 to process personnel dosimeters and pencils. This function was relocated to the 3705 building in 1963. The 3708 building was later renovated as a fuel fabrication facility in the early 1960s. In the early 1970s, the north end of the 3708 Building was used for experimental canning of americium oxide and curium oxide fuel blends (Gerber 1992).

321 Building Semi-Works Facility. The 321 Building was constructed in the 1940s as a cold “semi-works,” or pilot scale plant for testing chemical “process improvements” for the 200 Area chemical processing facilities using unirradiated or low-activity substances. A series of cells and tanks were located in the building.

326 Pile Physics Technology and Metallurgical Facility. The mission of the 326 Pile Physics Technology and Metallurgical Facility was to conduct the exponential pile physics development work necessary to achieve continuity of operations for the production reactors. The facility began in 1953 and continued developmental work originally performed in the 120 Building Critical Mass Laboratory (i.e., P-11 Facility) and later in 189-D. The earliest and most intense radioactive work in the 326

Building was the operation of the exponential piles in the basement beginning in about 1953. Piles shielded only by lead bricks using PoBe and RaBe neutron sources emitting 10^8 n/s were used to irradiate Co, Cu and other metallic foils. Some of this work was transferred to the 209-E facility when it became operational in 1961. In 1983, the 326 Building became the "Chemical Science Building." The facility is still in operation.

G3.3 Facilities Operational IN THE 1950s

325 Radiochemistry Laboratory. The 325 Building Laboratory began operations in 1953 to permit multicurie level chemical development work to be done in support of production and process improvement analyses. There were three large hot cells for isotope research activities involving selected fission and plutonium nuclides. Radiochemistry performed in these cells included radionuclide separation and concentration for special programs, which included promethium-147, plutonium-238, plutonium-239, americium-241, cesium-137, and strontium-90. Radiochemistry was also performed in support of the solidification of high-level waste in conjunction with the 324 Building.

327 Radiometallurgy Laboratory Facility. The 327 Radiometallurgy Laboratory was built in 1953 and provided shielded cells for the destructive examination of irradiated materials including fuels. Activities in the 12 shielded cells were standard for metallurgical examination except that sectioning, grinding, polishing, and microphotography were performed by manipulators and other remote handling devices (Ballenger and Hall 1991). The 327 Building was renamed the "Post Irradiation Testing Laboratory" in the 1980s. The facility was deactivated in 1987.

G3.4 FACILITIES OPERATIONAL IN THE 1960S

308 Plutonium Fuels Pilot Plant. This facility became operational in 1960 to perform research and development of fuels used in the PRTR and subsequently fuels used in the liquid breeder reactor program including the Fast Flux Test Reactor. In the mid-1960s, the PRTR fuel work was terminated. In the late 1960s, neptunium-aluminum alloy fuel target elements were produced for use in N Reactor for a ^{238}Pu production run. This facility was used from 1977 to 1991 for production of FFTF fuel elements. The 308-A annex was added in 1979 to accommodate additional plutonium fuels work. A 250-kW Training Research Isotopes, General Atomics (TRIGA) reactor was installed in the annex in the late 1970s to perform neutron radiography. The 308 facilities were deactivated in 1990.

324 Building Chemical and Materials Engineering Laboratory. This laboratory began operations in 1966 to provide research and development studies in support of PRTR operations. The laboratory was used first as a fuel recycle pilot plant by housing chemical reprocessing and metallurgical examination capabilities used for PRTR fuel elements. Two groups of large shielded cells were used for radiochemical and metallurgical studies. The chemistry cells were connected to an air lock where studies of high-level liquid waste were performed. A special underground liquid waste pipe line connected the hot cells in 324 and 325-Annex. Because the majority of work was performed in hot cells, external and internal exposures were minimal.

G4. RADIATION PROTECTION

A description of Hanford radiation protection standards, procedures and practices is provided in Attachment D along with a historical timeline of radiation associated events in Table D-2.

G5. METHODS

Monitoring of radiation exposure to workers in the Hanford 300 Area operations was done using the same capabilities and procedures used for workers at the 100 Area production reactor and 200 Area facilities. Similar practices were used for workplace surveys, SWPs and exposure controls.

G5.1 SITE EXPERT INTERVIEWS

Interviews with Site Experts were conducted and documented regarding their assessment of the potential for significant neutron exposure of Hanford 300 Area plutonium facility and Miscellaneous Facility work areas and work tasks with potential neutron exposure. Tours of the Hanford 200 Area 234-5 facility and the 231-Z facility with known significant neutron exposures of workers were made during June and November 2008 with persons with expert knowledge of Hanford plutonium facility design and operation. The site experts were asked to provide information concerning:

- Their knowledge of workplace neutron radiation levels at Hanford facilities supporting 200 Area plutonium production particularly information concerning significant neutron exposure.

- Their knowledge concerning changes in 200 Area and other facility construction and/or operations important to understanding the applicability of statistical parameters determined from TLD-measured doses to the pre-1972 period.

- Their knowledge concerning performance of workplace surveys and particularly feasibility of access to the documented surveys, access to the facility worker measured doses, and specifically access to the measured TLD-measured neutron and photon doses during the period from 1972 through 1987.

- Their knowledge concerning any other information that might be relevant to the reconstruction of neutron dose to Hanford 300 Area and Miscellaneous facility workers prior to 1972.

G5.2 NTA RESULTS DATABASE

The spreadsheet containing NTA processing results during the period from 1950 through 1961 (Yamauchi 2006) was examined to determine which 100 Area and 300 Area facilities might have been considered to have a significant neutron exposure potential.

G5.3 DATA IDENTIFICATION

Data searches of the various DOE Hanford archive record systems were done using numerous combinations of keywords or abbreviations “survey,” “control,” “neut,” “NTA,” “A-film,” repetitive, etc., associated with neutron radiation or monitoring surveys, neutrons, NTA film, A-film, and R&R surveys. Prior to the data collection trips, record indexes were received from DOE-RL and used in the prioritization of records of interest for workplace photon and neutron fields.

G5.4 DATA CAPTURE

Data capture trips to DOE-RL with the expressed objective to obtain detailed monitoring data occurred during: October 9-15, 2007; December 2-7, 2007; June 2-6, 2008; July 7-15, 2008; September 22-26, 2008; October 13-17, 2008; and November 17-24, 2008. Substantial efforts were made by a team of health physicists to find actual original records of instrument measured photon and neutron doses done at the same time and location (i.e., paired data). A large number of boxes and documents were identified that potentially contained relevant records. The contents of these boxes and documents were reviewed during the data collection trips.

G6. RESULTS

G6.1 SITE EXPERT INTERVIEWS

Several of the site experts interviewed for the 100 and 200 Area facilities were actually located in 300 Area facilities because the site-wide radiological technical support staff; instrument development, maintenance and calibration; and site-wide dosimetry processing and record capabilities were in 300 Area facilities. The 300 Area R&D facilities were much smaller than the 100 and 200 Area production facilities. Questionnaires were developed in conjunction with the interviews and used in the interview documentation. The documented interviews were submitted to DOE for classification review. Abbreviated results from the interviews are described in the following:

Site Expert 1 (Fix 2008c). Documented interview with retired Hanford Site expert hired in 1959 located for many years in the 300 Area. Person worked in the 308 Building making and performing quality assurance measurements on plutonium-aluminum coextruded fuel elements. Site Expert later analyzed nuclear fuel burnup data as part of the Plutonium Utilization Program. Site Expert participated in investigations of exposure issues associated with processing of Hanford higher exposure plutonium and the increase in the gamma dose rate with plutonium isotopic composition, age since separation, and glovebox through-put. Site Expert performed neutron dose and spectra measurements at several Hanford and other DOE laboratory workplaces and was a lead author of a DOE complex report on personnel neutron dosimetry in DOE facilities.

Site Expert 2 (Fix 2007b). Documented interview with retired Hanford Site expert hired in 1956 located in the 300 Area originally working in reactor physics. Site Expert spent substantial time in various 300 Area research activities such as in the 326 Bldg Exponential Pile Laboratory working with radiation sources such as PuBe-238, developing neutron spectrometer capabilities, which were very crude in the beginning, and performing work to characterize the NTA energy response. This person was very involved in the effort to develop the Hanford thermoluminescent dosimeter (TLD) systems. Expert had several non-Hanford project roles including a multiyear U.S. Nuclear Regulatory Commission Project to measure neutron spectra and dose in U.S. commercial nuclear reactors which is described in several NUREG reports.

Site Expert 3 (Fix 2008g). Documented interview with Hanford Site Expert hired at Hanford in 1948 who worked with technical function tests, calibration and distribution of health physics instruments to the 100, 200, and 300 Areas. The results of these tests were documented. Site Expert mentioned that the calibration technicians were actually receiving significant exposures (see also HW-28532) and steps were taken to build a Well calibration facility whereby the technicians were not directly exposed to the calibrating source. Site Expert was directly involved in 234-5Z Building radiation exposure measurements and efforts to resolve radiation exposure problems that existed in the 234-5Z and 231-Z buildings. Site Expert recalled being involved in "time and motion studies," to determine the length of time required to do specific tasks. Site Expert authored many Hanford technical reports and subsequently was involved in national and international measurements of radiation.

Site Expert 4 (Fix 2007b,g). Documented interviews with Hanford Site Expert involved in radiological physics issues throughout Hanford career, handling issues such as personnel dosimeter performance, calibration and, in particular, performing neutron radiation measurements using, for example, the DePanger Precision Long Counter developed at Hanford. The Long Counter was used to evaluate the neutron fluence when health physics dosimeters or health physics instruments were irradiated. The DePanger double moderator instrument was invented for monitoring neutron dose in the workplace. The instrument could measure a ratio that could be applied to the measurement to get the correct neutron dose as a function of neutron energy. Expert spent significant time in various 100 Area reactors (i.e., B, D, KE, KW, N and perhaps F), 200 Area plutonium facilities, and 300 Area accelerator facilities, which were used to evaluate all Hanford neutron instrument and dosimeter systems. Site Expert stated that the original values to reconstruct 234-5Z worker exposures in the 1972 AEC investigation depend on the method used to determine the ratios from the TLD data. For example, the calibration with the TLD dosimeter implemented in 1972 involved consideration of the combined phantom and dosimeter neutron response because of the so-called albedo effect. The TEPC was used to evaluate the TLD response on-phantom at 234-5Z workplaces and to use this in the development of the routine neutron calibration. Fundamentally, the distance of the mid-point of the phantom from the Hanford calibration source was used in routine calibration exposures and not the distance from the dosimeter mounted on the phantom to the source.

Site Expert 5 (Scalsky 2007b). Documented interview with Hanford Site Expert involved in the Hanford personnel dosimetry program beginning in the mid-1950s. Site Expert had numerous radiation safety individual contributor and management roles in the centralized Hanford radiological services organization involving calibrations, radiation standards and engineering, and radiological records and also in AEC/DOE Headquarter health physics programs.

Site Expert 6 (Scalsky 2007a)). Documented interview with Hanford Site Expert hired for work at Hanford plutonium facilities in 1947. Expert worked in all Hanford areas during his career at Hanford, participated in activities associated with the AEC 1972 Investigation of the increase in TLD-measured worker neutron doses in comparison with the NTA measured doses. Expert authored numerous technical reports including historical reviews of the Hanford radiation dosimetry program.

Site Expert 7 (Fix 2007e). Documented interview with Hanford Site Expert hired at Hanford in 1950 for work in radiation protection with primary responsibilities in the 200 and 300 Areas, and also as the HP assigned to 100 Area biology operations. Later, this Site Expert assumed responsibilities for Hanford site-wide compliance with AEC/DOE Health and Safety (H&S) orders, directives, etc., as a senior health physicist.

G6.2 NTA PROCESSING FILES

Examination of the spreadsheet of Hanford NTA dosimeter processing during the period from 1950 through 1961 (Yamauchi, 2006) shows dosimeter results for 300 Area located personnel beginning in 1950. The number of 300 Area and the Hanford Site Total NTA processing results, respectively, for each of the files is shown in Table G-2. These results imply that Hanford radiation protection staff were aware of circumstances in 300 Area facilities with potential for neutron exposures. Unfortunately, the processing records shown in the Excel file do not identify the specific facility.

G6.3 WORKPLACE MEASUREMENTS OF NEUTRON RADIATION

The priority of data collection from the DOE-RL archival records concerned exotic chemicals at Hanford and neutron radiation surveys at the 100 Area reactors and the 200 Area plutonium facilities. Undoubtedly, radiation survey data for the 300 Area facilities is available from the federal repository in Seattle. Technical reports in which data have been gathered and analyzed are particularly helpful and tend to minimize uncertainty in the overall analysis.

Table G-2. 300 Area and Hanford NTA processing results.

	Processing dates		NTA results[a]	
File name	**Start**	**End**	**Hanford total**	**300 Area**
Person1.xls	3/13/1950	1/06/1953	13,535	63
Person2.xls	12/30/1952	4/3/1955	15,525	993
Person3.xls	4/4/1955	12/25/1955	7,139	599
Person4.xls	12/15/1955	6/17/1957	16,322	930
Person5.xls	6/17/1957	6/27/1958	13,738	400
Person6.xls	6/17/1958	5/26/1959	13,619	312
Person7.xls	5/27/1959	12/30/1959	9,109	38
Person8.xls	12/28/1959	11/14/60	16,330	187
Person9.xls	12/27/1960	6/27/1961	9,680	1,130
Person10.xls	7/14/1961	12/26/1961	9,776	1,739

a. Some test irradiation dosimeters included in totals.

G7. TECHNICAL REPORTS

Hanford documents identified that contained relevant 300 Area information concerning worker neutron exposure conditions follow:

- Operating standards (DuPont 1943–1946) that describe 300 level procedures in early 1944 to load, operate and calibrate the 305 Test reactor with specific safety notes that exposure to workers is a concern, there is a need to leave the immediate area and that boron lined proportional counters must be available to monitor potential exposures (i.e., neutron) to workers.

- HW-32643, Monthly report, Class II Incident, neutron exposure 326 Building

- HW-32571, Monthly report, neutron exposure 326 Building

- BNWL-B-127 (Nichols et al. 1972) that provides dose results from parallel field tests of the TLD in the 308 Building along with the Hanford beta/photon film and, for some workers, NTA film. Information from this document is presented in Table G-3 because it illustrates one approach to determining a NP ratio. In Table G-3 the NP ratios for the 308 Bldg were calculated based on the photon and neutron instrument and TLD dose measurements shown in the original document.

Attachment D, Table D-2 provides a chronological listing of a large number of technical references along with brief summaries of those with particularly relevant information.

Table G-3. NP Ratio determined from 1971 Workplace Study of Neutron Dose Measurements (Nichols et al. 1972)[a]

		Exp time (hrs)	Instrument			NP ratio	TLD (mrem)				NP ratio
Bldg.	Location		Snoopy	CP	TEPC		Derma	Pen	SN	FN	
234-5	228-17DC	72.4	200	150		1.33	210	150	—	200	1.33
	192-194	72.7	950	150		6.33	210	140	138	1360	10.70
	228-H611	2.34	330	60		5.50	80	80	18	650	8.35
	228-958	72.5	360	510		0.71	450	450	135	730	1.92
	228-H618BS	72.5	360	510		0.71	100	100	6	170	1.76
	194	2.75	550	90		6.11	60	60	9	390	6.65
	221-Center	73	660	1,460		0.45	1,470	1,470	18	940	0.65
	221-N	73	1,310	2,480		0.53	16,40	1,640	24	1,060	0.66
105-KE	X-1		60		270				57	530	
	Top #23		1,400		1,700				141	4,100	
	Mon		0		0				<3	60	
	Front face		50		900				7	250	
308	Room 208		2,000		2,700				84	3,700	
	Corr #7		4,200		14,100				390	11,100	
	Vent room		30		30				3	0	
	Room C		70		730				18	870	
234-5	17DC		340						6	100	
	HC-11		280						12	180	
	9b top stairs		410						11	440	
	9B Under stairs		280						18	450	
	Room 221		410		790				18	460	
	Room 192		510		620				66	490	
	Room 192-C		150		230				6	240	
	Room 193		380		500				36	600	
	2731-Z		200						<3	50	

a. Dosimeters mounted on carboys in workplace for designated exposure duration.

Another type of examination regarding the accuracy of TLD neutron dose measurements is made of summaries of field measurements published in 1981 and 1982 (Fix et al. 1981, 1982) which are presented in Tables G-4 and G-5, respectively. Measurements were done at the 308, 324 and 209-E buildings. These tables do not include a photon dose measurement, only a comparison of different methods to measure the workplace neutron dose. The measurements in these reports were performed with the objective to identify Hanford work areas in which analysis of the Hanford TLD could result in incorrect dose estimates to personnel. The studies included examination of workplace energy spectra and radiation type as well as a comparison of the neutron dose between several techniques of measuring neutron dose. The Tissue Equivalent Proportional Counter (TEPC) method is generally accepted as provided the best estimate of the actual neutron dose. As noted in these reports, the TLD tended to overestimate the instrument measured neutron dose on average. The TLD albedo dosimetry method is well known to overestimate the actual neutron dose in well shielded work areas because of its significant response to lower energy neutrons.

G8. RADIATION SURVEY DATA

As a component of the examination at DOE Hanford archive records containing workplace radiation survey sheets the team of health physicists was also attempting to identify potential documents

ATTACHMENT G
A BOUNDING ESTIMATE OF NEUTRON DOSE BASED ON MEASURED PHOTON DOSE AT HANFORD 300 AREA AND MISCELLANEOUS FACILITY OPERATIONS AT THE HANFORD SITE

Table G-4. Summary of 1981 Hanford workplace neutron dose measurements (Fix et al. 1981).

			Neutron dose (mrem/hr) according to measurement method[b]					
Bldg	**Location**	**Energy keV[a]**	**MS**	**Snoopy**	**Rascal**	**TEPC**	**TLD**	**TLD***
308	Pu storage vault	576	1.2		17.7			
	Above fuel storage pit	530	0.9			0.54	0.96	
	Above pit storage pit	1,100	0.8		2.0	1.3	1.2	
							0.46*	
	Fuel pin storage boxes on wall	660			4.1			
	Bare fuel subassembly	1,500			17.6	11		
234-5Z	HA-9A glovebox	395	4.4	4		4.7	1.7	0.9
	HC-9B glovebox	390	12.1	11.5		12.7	14	7.4
							18.7	9.8
2736-Z	Vault 3 3EE-3FE	300	26.9	26		23.4	1.5	0.6
							3.7	1.6
	Vault 3 3CE-3DE	346	69.3	65		71.9		
	Vault 4 4ED-4FD	290	41.8	40		39.0		
	Vault 4 4GE-4NE	290	46.9	45		47.8	50.7	21.1
							60.2	25.1
	Hallway	146	1.3	0.8		1.0		
	Nuclear criticality detector	374	27.1	40				

a. Average energy of neutron spectra

b. Measurement method: MS=multisphere, TEPC=Tissue Equivalent Proportional Counter, TLD=Hanford multipurpose dosimeter using normal algorithm, TLD* using alternate algorithm.

Table G-5. Summary of 1982 Hanford workplace neutron dose measurements (Fix et al. 1982).

		Measurement method[a]						
Bldg	**Location**	**MS**	**TEPC**	**PTEPC**	**He-3**	**Rascal**	**Snoopy**	**TLD**
324	Pu storage vault	2.8	4.6	5.1	2.1	—	5.0	6.5
FFTF	Location 8	3.8	5.6	—	14.7	13.0	18.0	29.1
	Location 10	1.9	1.2	—	4.1	5.3	12.0	12.3
209-E	Location 13	—	3.1	3.8	—	—	2.0	1.8
	Location 17	—	—	0.6	—	—	0.4	0.5
234-5	Maintenance office	—	0.4	0.4	—	—	0.5	0.4
	Duct level, Col. 16	—	—	1.6	—	—	0.8	0.6
	Duct level, under 52	—	—	1.7	—	—	<0.1[b]	2.7
	Duct level, over HA23	—	—	2.6	—	—	0.1[b]	5.1
	Pu hood, top	2.8	14.7	12.3[b]	3.2	—	10.5[c]	—
	Pu hood, side	—	—	7.2	—	—	7.0	—
	General background	—	—	1.2	—	—	1.5	—

a. MS–Multisphere, TEPC=Tissue Equivalent Proportional Counter, PTEPC=Portable Tissue Equivalent Proportional Counter, He-3=Helium-3 counter, TLD=Hanford multipurpose dosimeter.

b. These Snoopy readings are suspect due to geometry differences.

c. Average of four readings shown in table.

concerning 300 Area facilities. Although undoubtedly extensive radiation surveys of 300 Area facilities were done, substantial records of these surveys for 300 Area facilities have not been collected to date likely because of the priority for the data collections for the single-pass cooling reactors, 100-N reactor, and Hanford 200 Area plutonium facilities. An example of workplace measurements obtained for 300 Area 305, 308 and 3745 facilities was obtained (BNL 1969–1970) and there is a 1953 examination of 3745 facility calibration staff exposures (Unruh 1953). However, at this time, there is insufficient workplace survey data for the facilities to be included in an analysis.

G8.1 ANALYSIS OF NEUTRON TO PHOTON DOSE RATIO

An analysis file to be used in the analysis of workplace instrument measured NP dose ratio has not been prepared because currently there is only one file (BNL 1969–1970) with 300 Area facility data.

G9. SUMMARY

The Hanford 300 Area Reactor and Plutonium research, development and testing facilities, the 300 Area Radiological Calibrations facilities, and the site critical mass facilities did involve neutron radiation exposure of workers as evidenced by: 1) the types of operations, 2) routine assignment of nuclear track emulsion (i.e., NTA) film, and 3) information in the routine radiation monitoring periodic reports. The operations in the 300 Area facilities supported the much larger 100 Area reactor and 200 Area chemical processing and plutonium chemical-metallurgical facilities. Undoubtedly, extensive radiation surveys were taken of the 300 Area facilities because Hanford radiation safety standards applied to all facilities in the 100 Area, 200 Area and 300 Area facilities. Workers in the 300 Area would often travel to the 100 and 200 Areas. Additional data collection is necessary to determine a NP dose (NP) ratio for each of the facilities based on measured instrument results. Until this is done however, a feasible option is to adopt the dose reconstruction recommendation in the main body of this document to apply favorable-to-claimant NP ratios determined for the Hanford 100 Area single-pass cooling production reactors (Taulbee et al. 2008), Hanford 100 Area N Reactor (Attachment E) and Hanford 200 Area plutonium facilities (Attachment F) to workers according to their 300 Area work experience (i.e., apply NP ratios respectively for 100 Area reactor facilities and 200 Area plutonium facilities to 300 Area reactor and plutonium facilities) based on judgment by the dose reconstructor. Neutron exposures in the 120 Building and 209-E critical mass laboratories to workers did occur but were relatively insignificant because of the significant shielding and remote operation. Under all circumstances there was substantial photon radiation that was reasonably accurately measured in all facilities and for all periods that accompanied the neutron radiation.

As noted in this attachment, dose reconstruction would involve:

- TLD-measured neutron dose be used from January 1972 to date for all workers and Hanford facilities.

- Prior to 1972, the measured (and missed) photon dose is multiplied by a NP dose ratio to arrive at an assigned neutron dose. The parameters of the NP dose distribution are taken from recommendations in the main document based on extensive measurements at the Hanford 100 Area single-pass cooling reactors and the 200 Area plutonium facilities.

The NP ratios must be adjusted to incorporate the ICRP Publication 60 weighting factors, which for the neutron categories in Hanford workplaces less than 2 MeV is a factor of about 2 (ICRP 1991). It is evident that using this approach will result in significant assigned neutron dose for the period prior to January 1, 1972.