<table>
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</table>

## TABLE OF CONTENTS

Section | Page

## LIST OF TABLES

## LIST OF FIGURES

**RECORD OF ISSUE/REVISIONS**

| ISSUE AUTHORIZATION DATE | EFFECTIVE DATE | REV. NO. | DESCRIPTION |
|---|---|---|---|
| Draft | 10/23/2003 | 00-A | New Technical Basis Document for the Rocky Flats Site – Occupational External Dose. Initiated by Robert Meyer. |
| Draft | 11/26/2003 | 00-B | Incorporates NIOSH and ORAU comments. Initiated by Robert Meyer. |
| Draft | 12/19/2003 | 00-C | Incorporates additional NIOSH comments. Initiated by Robert Meyer. |
| Draft | 12/24/2003 | 00-D | Incorporates DU dose energy range split modification per T. Taulbee comment. Initiated by Robert Meyer. |
| 01/20/2004 | 01/20/2004 | 00 | First approved issue. Initiated by Robert Meyer. |

## ACRONYMS AND ABBREVIATIONS

| | |
| --- | --- |
| AEC | U.S. Atomic Energy Commission |
| AED | aerodynamic equivalent diameter |
| AP | anterior-posterior |
| BVO | boiler vent operator |
| CDH | Colorado Department of Public Health and Environment (previously Colorado Department of Health) |
| Cf | californium |
| cm | centimeter |
| cpm (or c/m) | counts per minute |
| Cs | cesium |
| CY | calendar year |
| D&D | decontamination and decommissioning |
| DAC | derived air concentration |
| DDE | deep dose equivalent |
| DOE | U.S. Department of Energy |
| DOELAP | DOE Laboratory Accreditation Program |
| DOL | U.S. Department of Labor |
| dpm | disintegrations per minute |
| DU | depleted uranium |
| EEOICPA | Energy Employees Occupational Illness Compensation Program Act |
| Emax | maximum energy |
| EPA | U.S. Environmental Protection Agency |
| EU | enriched uranium |
| G-M | Geiger-Müller |
| HEU | highly enriched uranium |
| HIS-20 | Health Physics Information System |
| H*(d) | ambient dose equivalent |
| Hp(d) | personal dose equivalent |
| Hp,slab(d) | personal dose equivalent (slab phantom) |
| HPS | Health Physics Services (company) |
| HSDB | Health Sciences Database |
| ICRP | International Commission on Radiological Protection |
| in. | inch |
| IREP | Interactive RadioEpidemiological Program |
| ISO | isotropic |
| keV | kilo electron volt |
| LANL | Los Alamos National Laboratory |
| Lc | critical level |
| LOD | limit of detection |

| | |
|---|---|
| MeV | mega electron volt |
| mm | millimeter |
| mR | milliroentgen |
| mrem | millirem |
| NBS | National Bureau of Standards |
| NCRP | National Council on Radiation Protection and Measurements |
| NDRP | Neutron Dose Reconstruction Project |
| NDT | nondestructive testing |
| NIOSH | National Institute for Occupational Safety and Health |
| NRC | National Research Council |
| NTA | Nuclear Track Type A (film) |
| OCAS | Office of Compensation Analysis and Support (NIOSH) |
| OR | Oak Ridge |
| ORAU | Oak Ridge Associated Universities |
| Pa | protactinium |
| PDF | portable document file (Adobe Acrobat) |
| pen | penetrating (deep) dose |
| PoBe | polonium-beryllium |
| PNAD | personal nuclear accident dosimeter |
| PNL | Pacific Northwest Laboratory |
| PPE | personal protective equipment |
| Pu | plutonium |
| $PuF_4$ | plutonium tetrafluoride (or fluoride) |
| R | roentgen |
| RATCHET | Regional Atmospheric Transport Code for Hanford Environmental Tracking |
| RCT | Radiation Control Technician |
| rem | roentgen equivalent man |
| RFETS | Rocky Flats Environmental Technology Site |
| RFP | Rocky Flats Plant |
| RHRS | Radiological Health Records System |
| ROT | rotational |
| SOE | stationary operating engineer |
| TBD | Technical Basis Document |
| TLD | thermoluminescent dosimeter |
| TRU | transuranic |
| U | uranium |

## 6.1 INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is responsible for developing the technical capabilities and guidance for use in implementing the Energy Employees Occupational Illness Compensation Program Act (EEOICPA). Oak Ridge Associated Universities (ORAU) is leading a team to support NIOSH in the performance of this major program. This technical basis document (TBD) represents a specific area of support to the ORAU Team concerning documentation of historic practices at the Rocky Flats Plant (RFP) regarding evaluation of external exposure data for monitored and unmonitored workers to be used as a supplement to or substitute for recorded individual worker dose.

### 6.1.1 Purpose

The purpose of this document is to describe RFP external dosimetry systems and practices. The ORAU Team will use this information to evaluate external occupational doses for EEOICPA claimants.

### 6.1.2 Scope

RFP operations played an important role in the U.S. nuclear weapons program. These operations included production of fissionable weapons components and waste management. This TBD contains supporting documentation to assist in the evaluation of occupational external doses from these processes using the methodology in the *External Dose Reconstruction Implementation Guideline* (NIOSH 2002).

The methods and concepts of measuring occupational external doses to workers have evolved since the beginning of RFP operations. An objective of this document is to provide supporting technical data to evaluate, with claimant-favorable assumptions, the external RFP occupational doses that can reasonably be associated with worker radiation exposures covered under EEOICPA legislation. These doses include occupational external exposures in RFP facilities and onsite exposures to RFP environmental releases. This document addresses the evaluation of unmonitored and monitored worker exposure and missed dose. Consistent with NIOSH Implementation Guidelines, this document identifies how to adjust the historic occupational external recorded dose to account for current scientific methods and protection factors.

In addition, this document presents the technical basis of methods used to prepare RFP worker external dose records for input to the NIOSH Interactive RadioEpidemiological Program (IREP) used to evaluate worker dose. Information on measurement uncertainties is an integral component of the NIOSH approach. This document describes the evaluation of uncertainty for RFP exposure and dose records.

This document comprises one part of the overall Rocky Flats Plant Site Profile. The Site Profile describes plant facilities and processes, historic information related to occupational internal and external doses and environmental data for use if individual worker recorded doses are unavailable. This document contains Section 6 - Occupational External Dosimetry, of the Rocky Flats Site Profile. It provides necessary background information and critical data for the dose reconstructor to perform individual claimant dose reconstructions.

## 6.2 EXTERNAL DOSIMETRY OVERVIEW

Over the years RFP used a variety of dosimeters to measure occupational ionizing radiation dose. Between 1951 and 1959, the Plant used a stainless-steel film badge based on an Oak Ridge design

(Baker 2002). This was a two-element film badge with an open window and a 1-mm cadmium filter. In 1960, a brass filter with half the filtration of the cadmium filter was added to cover half the open window. This provided separation of the 60-keV photons from the lower energy component. Very little information has been located on the performance of this dosimeter (Figure 6-1).


Figure 6-1. Oak Ridge-style film badge (including brass filter).

In 1963, a plastic film badge was introduced at Rocky Flats that included additional filters. In addition to the photon dosimetry system, this badge contained a personal nuclear accident dosimeter (PNAD; Figure 6-2). This portion of the badge was not used for routine personnel dosimetry.

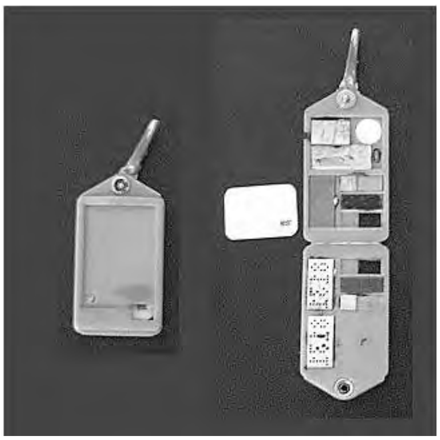
Figure 6-2. RFP multielement film badge.

In 1969, a combination film/thermoluminescent dosimeter (TLD) badge was introduced at Rocky Flats, using TLD chips to measure photon dose. There were three TLDs in the lower part of the badge, covered with the same brass filter (two chips) and a thin cover (one chip) providing an open window. Film was used for neutron dose measurement. This badge contained a PNAD and was an interim badge until the introduction of the TLD neutron system (Figure 6-3).

In 1971, a full TLD badge was introduced at Rocky Flats that used TLD chips manufactured by Harshaw Chemical Company (Figure 6-4). Referred to as the "Harshaw badge," it contained a four-chip albedo neutron dosimeter (Falk 1971). Although the dosimeter did have a location for including a neutron film, this feature was not used. Photon measurement used three filter-covered TLDs, similar to those in the previous badge. This badge contained a PNAD.

In 1983, an automated Panasonic dosimetry system was introduced at Rocky Flats (Figure 6-5). This badge contains two Panasonic dosimeters, one for measuring photon and beta dose and one for measuring neutron dose. The beta/photon dosimeter contains two TLD phosphors and a lead filter over one of the elements. The neutron dosimeter contains three neutron-sensitive elements and one neutron-insensitive element, under cadmium or tin filters. This badge includes a PNAD.

Table 6-1 summarizes the history of dosimeter use at RFP. The implementation dates listed in the table and used throughout this document are not exact. In many cases, dosimeters were phased in over a period of 1 to 3 years. Determining from an individual employee's dosimetry record which dosimeter was worn is not possible, which adds a degree of uncertainty to the dose reconstruction. Further research is necessary to identify exact dates for each dosimeter type.


Figure 6-3. RFP interim TLD/film badge.

Figure 6-4. RFP Harshaw badge.

The following sections discuss each of these dosimeter types with respect to each necessary dose reconstruction parameter.

## 6.3 INTERPRETING THE EXTERNAL DOSIMETRY RECORD

When the U.S. Department of Labor (DOL) requests an individual dosimetry record (file), the RFETS Radiological Health Department provides a significant amount of effort in reviewing and organizing the external dosimetry records. Both hardcopy and electronic files are reviewed. They provide comments if discrepancies are found. If there are hardcopy results that are not in the electronic file, the electronic file is updated. If the electronic file includes a reading that is not indicated in the paper file, it is noted as a comment, but left in place. The claimant-favorable assumption is to include discrepant data in the annual total, unless notes explain why the data should not be included.

External dosimetry results are reported as:

- Penetrating (pen) or deep - deep dose + neutron
- Skin - shallow dose + neutron
- Forearm (measured or estimated)
- Hand (estimated).

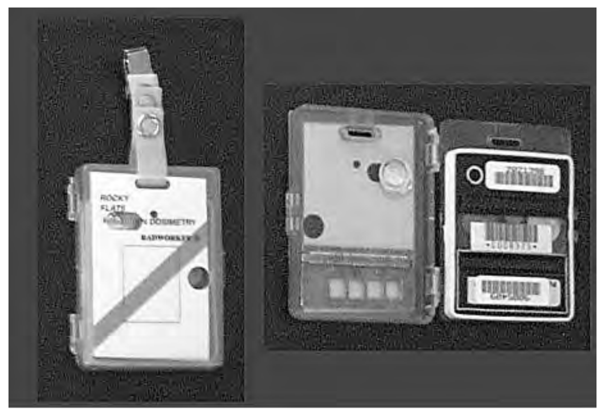

Figure 6-5. RFP Panasonic dosimeter.

The penetrating or deep dose is reported as the sum of the deep gamma and the neutron dose. The skin dose is reported as the deep dose unless the low-energy detector on the dosimetry badge indicates a response greater than the deep dose, in which case shallow gamma plus neutron were reported. RFP does not used finger rings on a routine basis, but estimates the hand dose using the forearm dose measured by a wrist badge and the application of a hand-to-wrist ratio.

### 6.3.1 <u>Dosimetry Records Systems</u>

In the 1950s, external dosimetry data were handwritten and reported manually. In the 1960s and early 1970s, information was maintained on early computer systems. The detailed data have not been carried forward. For the early years, the dose detail has been lost and only quarterly totals are available. RFP typically summed the deep gamma dose and the neutron dose into a "penetrating" value. In the early years, the neutron and deep gamma numbers were not retained and only the penetrating value remains.

Electronic systems for which detailed data have been maintained include:

- HSDB (Health Sciences Database)–1976 to 1990
- RHRS (Radiological Health Records System)–1990 to 1999
- HIS-20 (Health Physics Information System, Canberra Industries)–1999 to present.

Table 6-1. Rocky Flats external dosimeter history.

| | | Beta/gamma | | | | Neutron | | Extremity | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Filtration | | | | | | |
| **Year** | **Holder** | **Detector** | **Deep** | **Shallow** | **Processor** | **Detector** | **Processor** | **Holder** | **Detector** |
| 1951[1] | SS OR[2] design | Std. X-ray | 1mm Cd | None | LANL | Track Plate | LANL | SS OR design | Std. X-ray |
| 1952 | | | | | | | | | |
| 1953 | | | | | | | | | |
| 1954 | | | | | | | | | |
| 1955 | | | | | | | | | |
| 1956 | | | | | HPS | | HPS | | |
| 1957 | | | | | | NTA Film | | | |
| 1958 | | | | | RFETS | | RFETS | | |
| 1959 | | | | | | | | | |
| 1960 | | | 1/2 brass[3] | | | | | 1/2 brass[4] | |
| 1961 | | | | | | | | | |
| 1962 | | | | | | | | | |
| 1963 | Plastic | | Multiple | Multiple | | | | | |
| 1964 | | | | | | | | | |
| 1965 | | | | | | | | | |
| 1966 | | | | | | | | | |
| 1967 | | | | | | | | | |
| 1968 | | | | | | | | | |
| 1969 | Interim Plastic | TLD 700 | | | | | | | |
| 1970 | | | | | | | | | |
| 1971 | Harshaw | | | | | TLD 600/700 | | Harshaw | TLD 600/700 |
| 1972 | | | | | | | | | |
| 1973 | | | | | | | | | |
| 1974 | | | | | | | | | |
| 1975 | | | | | | | | | |
| 1976 | | | | | | | | | |
| 1977 | | | | | | | | | |
| 1978 | | | | | | | | | |
| 1979 | | | | | | | | | |
| 1980 | | | | | | | | | |
| 1981 | | | | | | | | | |
| 1982 | | | | | | | | | |
| 1983 | Panasonic | UD-802 | | | | UD-809 | | | |
| 1984 | | | | | | | | | |
| 1985 | | | | | | | | | |
| 1986 | | | | | | | | | |
| 1987 | | | | | | | | | |
| 1988 | | | | | | | | | |
| 1989 | | | | | | | | | |
| 1990 | | | | | | | | | |
| 1991 | | | | (DOELAP) | | | | Panasonic | UD-813AS11 |
| 1992 | | | | | | | | | |
| 1993 | | | | | | | | | |
| 1994 | | | | | | | | | |
| 1995 | | | | | | | | | |
| 1996 | | | | | | | | | |

Table 6-1. (Continued)

| Year | Holder | | Beta/gamma | | | | | | | | Neutron | | | | Extremity | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Detector | | Filtration | | | | Processor | | Detector | | Processor | | Holder | | Detector | |
| | | | | | Deep | | Shallow | | | | | | | | | | | |
| 1997 | | | | | | | | | | | | | | | | | | |
| 1998 | | | | | | | | | | | | | | | | | | |
| 1999 | | | | | | | | | | | | | | | (DOELAP) | | | |
| 2000 | | | | | | | | | | | | | | | | | | |
| 2001 | | | | | | | | | | | | | | | | | | |
| 2002 | | | | | | | | | | | | | | | | | | |
| 2003 | | | | | | | | | | | | | | | | | | |

1. Dates are approximate, overlap occurred during changeover
2. Oak Ridge
3. Brass not used on beta open window
4. Brass not used on beta open window, no brass on wrist-side

In general, data migrated from one system to another. Little is known, or at least documented, about the precise method and decisions made during the migration of the HSDB to RHRS. However, the result of examining the contents of the data tables and hardcopy reports can be described.

### 6.3.2 <u>Observed Data Discrepancies</u>

#### 6.3.2.1 Rounding

An annoying but manageable problem is exhibited by the rounding of individual deep dose values as well as the yearly or quarterly totals. The electronic data in RHRS and many of the reports contain both gamma and neutron components as well as a deep dose equivalent.

It appears that rounding to the nearest millirem (mrem) value occurred on the external deep dose after the values were added to calculate the deep dose equivalent (DDE). In many cases, this results in a discrepancy on the report cards of 1 mrem per measurement. Depending on the exchange frequency, there could be a difference of several mrem.

#### 6.3.2.2 Deep Not Equal to Gamma Plus Neutron

In this case, the problem is clearly not due to rounding but rather to a discrepancy between the deep dose components and the deep dose value that is stored separately. The magnitude of the discrepancy is greater than 1 mrem. Two specific situations have been identified, as described in the following sections.

##### 6.3.2.2.1 Possible Algorithm Issue

A group of results for a period, roughly July to October 1984, appear to indicate a reporting problem with the dosimetry algorithm used to calculate dose equivalents. In general, these results contain a gamma component that was calculated to be zero and a neutron dose that was calculated to be between about 15 and 50 mrem. However, the deep dose on both the report cards and in the electronic record was zero.

A review of a paper copy of the dose algorithm from that time (Rocky Flats 1983) and discussion with the algorithm developer indicates that the algorithm was developed in such a way that it should not have been possible to have a zero gamma dose with a non- zero neutron dose. In such a case, the algorithm would set the neutron dose to zero.

In these cases, however, the deep dose is reported as zero, and the neutron component was not set to zero before it was reported.

##### 6.3.2.2.2 Possible Manual Correction

In another group of records, the deep dose is much greater than the gamma and neutron components. In the electronic data, these records appear during a period identified as "1976." A review of a number of these records from the archive at the Federal Center found in all cases a letter in the file instructing the staff to modify the individual’s data due to a dose reconstruction or reevaluation. It appears that dose components were not provided in the letter and, therefore, were not made to add up to the deep dose.

The date of 1976 appears to have no relationship to the actual date associated with the dose record. According to the reports, many of the actual doses were assigned from 1984 to 1986.

### 6.3.3 Database Table-Specific Issues

Two database tables contain the external dosimetry data in RHRS, as discussed in the following sections. Each table has specific information on the external monitoring period, and the distinctions between the tables are notable.

#### 6.3.3.1 RHRST_ED_TLD_HISTORY

This table contains external dosimetry data for years generally before 1991, the time of RHRS implementation. These data migrated from earlier computer records systems such as the Health Sciences Data Base. Most of the records contain only a date referred to as "Activity Date." In general, the activity date is close to the dosimeter return date if the actual return date is available.

To migrate these data to the current electronic database, HIS-20, an issue date had to be fabricated. Because the activity date is closer to the return date and there was no information on the exchange frequency, the issue date was set to 1 day before the return date.

##### 6.3.3.1.1 1976 Records (individual employed after 1976)

This table contains a record dated 31-DEC-1976 for every individual in the database who was hired before 1989, even if they did not start work until after that date. This appears to have been an artifact from the initial migration of data from HSDB to RHRS. Therefore, a data record might appear in Health Physics file reports called “External Dosimetry (TLD) Detail” (from RHRS) and ‘’Dosimetry History by Individual” (from HIS-20) for 1976 when the individual was not yet hired.

**Zero Dose Records**
As a general rule, these records are not attributed to the individual, and they report a deep dose of zero.

**Nonzero Dose Records**
A 1976 record appears occasionally with a deep dose greater than zero. Such records are regarded as valid, and the official dose is attributed to the individual even though it is outside the employment period (see Section 6.3.2.2.2).

##### 6.3.3.1.2 1976 Records (individual employed before 1976)

For individuals employed before 1976, the 1976 record represents a lump sum total of the deep dose for all prior years. However, the details for each year should be available during a review of report cards for an individual.

In addition, a database from the Colorado Department of Health (Ruttenber et al. 2003) was used to replace the lump sum with an annual deep dose values. Again, there is no electronic source for the deep dose components (neutron and gamma) or for skin and extremity values.

##### 6.3.3.1.3 Post-1976 Records

Because the only date available before 1991 was the "Activity Date,” records can appear in reports that are outside the employment period. The activity date was used to document a "wear period" if there was no knowledge of the frequency of the dosimetry exchange. Therefore, the records might appear before the hire date or after the termination date.

#### 6.3.3.2 RHRST_ED_TLD_DOS

This table, which has an identical structure to RHRST_ED_TLD_HISTORY, contains post-1991 data. The records are from a download of the external dosimetry computer system called FALCON. This system collects and processes data directly from the Panasonic TLD readers. The records generally contain values for each column, including a variety of dates – issue date, return date, and activity date.

There could be discrepancies between the monitoring period and the employment period. Individuals who did not check out properly might not have an accurate employment termination date. In addition, the computer systems typically documented the dates that the person wore dosimetry, and not necessarily an employment period. This is particularly true for subcontractors.

**Dose History Hardcopy File Contents**

The RFP Radiological Health organization reviews the individual dose record and summarizes it in an *Occupational Dose Report* worksheet (Attachment 6A-1). This document shows the measured dose on an annual basis, summarizing dose data available from the printed record in the rest of the file. These data are compared with the computerized data, which are in the *Dosimetry History by Individual* report (Attachment 6A-2). Prior to 1976, the data were entered on an annual basis. A review of the rest of the external dosimetry file might indicate some detail of what went into the annual total. After 1975, this report provides a dosimeter-by-dosimeter reading. The "End Date" indicates the end of the wear period. Looking at the previous "End Date" can indicate the exchange frequency. If the "Begin Date" was not known, it was set to one day before the "End Date." In this case, it can be assumed that the badge was worn from approximately the day after the previous "End Date" to the indicated "End Date" for that period.

Several other reports are included, some of which contain more dosimetry result detail:

- Early years are reported on the *Health Physics External Exposure Run*, which provides a quarterly breakdown. Even though dosimeters might have been exchanged more frequently, data are summarized by quarter and more detailed data are not included.

- The 1953-1958 report *Health Physics External Exposure Activity Run Yearly* (Attachment 6A-3) contains a quarterly summary of the exposure data for an individual. The dose equivalent values reported are "skin," "pen" (penetrating; the deep dose to the whole body), and "hand" (regarded as the dose to the extremity, if monitored).

- The 1959-1963 report *Health Physics Yearly External Exposure Run* (Attachment 6A-4) contains all details for each measurement for an individual. Each reading is on a separate line, revealing the frequency of the monitoring. The dose equivalents are reported as "skin," "penet" (the deep dose to the whole body), and "wrist" (the dose to the extremity, if monitored).

- The 1964 report *Health Physics External Exposure Activity Run Yearly* (Attachment 6A-5) appears to be a transition report. It contains a quarterly summary of exposure data for an individual. The dose equivalent values reported are "skin," "pen" (the deep dose to the whole body), and "hand" (the dose to the extremity, if monitored).

- The *External Dosimetry (TLD) Detail, Computerized Information Through xx-xx-xx* or *External Dosimetry (TLD) Detail, Computerized Information for CY 19xx* (Attachment 6A-6) provides dosimeter reading detail for the years indicated. The "Activity Date" indicates the nominal (a few days to either side) end date of the dosimeter wear period. "Time Code" indicates the identified exchange period for the badge:

- Time Code 1 - biweekly (once every 2 weeks)
- Time Code 2 - monthly
- Time Code 4 - quarterly.

During the transition between the Harshaw and the Panasonic badges, RFP used a code to indicate the source of the dosimetry result:

- Type Code C, "Calculated" - Panasonic badge result (calculated in Panasonic computer system), no wrist dosimeter data.

- Type Code R, "Raw" - Harshaw badge chip readings (raw chip readings, result calculated in RHRS database system), no wrist dosimeter data.

- Type Code H, "Hybrid" - Panasonic badge result and Harshaw wrist dosimeter chip readings.

- The *Health Physics External Radiation Exposure Report for Year XX* ("report card") (Attachment 6A-7) provides quarterly totals for the year. Because dose limits were on a per-quarter basis, the purpose of this report was to monitor compliance with these limits. The dosimeter detail was lost.

- The 1965-1989 report *Health Physics External Radiation Exposure Report* contains a quarterly summary of exposure data for an individual. The dose equivalent values reported are "pen" (the deep dose to the whole body), "skin," and "hand" (the dose to the extremity, if monitored). In addition, these reports contain a "lifetime" (career) deep dose for exposure at Rocky Flats. After 1976, a column was added to the report for a value described as "forearm." This dose equivalent appears to be similar to that for the hand. In 1977, the dose to the hand was set to the greater of the skin of the whole body and the measurement calculated from the actual wrist dosimeter.

- Occasionally, for individuals employed after 1976 and until about 1986, there might be a report called *External Dosimetry (TLD) Detail*. This report contains greater detail on each measurement made during this period and a breakdown of gamma and neutron components.

- The *Radiation Dosimetry Detail Report* (Attachment 6A-8) provides very little detail other than a verification of the Reported Lifetime Dose. This includes offsite doses (from previous employers), which should be detailed in the file.

- *Radiological Health Records System (RHRS) Data* report (Attachment 6A-9) provides details of the dosimeter results. The advantage of this report is that it shows the breakdown of the deep dose into neutron and gamma components.

- *Radiation Dosimetry Detail Report, Termination Report* (Attachment 6A-10) provides a verification of lifetime and post-1987 exposure.

- *Occupational Radiation Exposure Information* (Attachment 6A-11) provides annual "Whole Body" dose, "Hand," "Forearm," and Accumulated Rocky Flats "Whole Body" doses. It is assumed the whole-body dose is penetrating.

These data enable compilation of an external dosimetry history, as follows:

- 1951 – 1976, quarterly dose history (RHRS data will provide a neutron/gamma breakdown)
- 1977 – present, dosimeter exchange history.

In some cases additional data are available. The dose reconstructor is responsible for using the information in this TBD to provide claimant-favorable assumptions to fill in unavailable detail for a claimant's external dosimetry record.

### 6.3.4 Additional Data Available

Additional sources of information, which are known to exist, contain detail that is not in the dose history file. These data would provide additional detail that could be useful in refining dose estimates for some claimants.

#### 6.3.4.1 Rocky Flats Work History File

The Rocky Flats Human Resources department kept job assignment records for many years on 5 in. x 7 in. cards. Images of these cards could provide a further indication of the type(s) of work performed by the claimant. This information is not in the dose history file.

#### 6.3.4.2 Neutron Dose Reconstruction Project File

As part of the Neutron Dose Reconstruction Project (NDRP) to reevaluate neutron film dosimetry, the original dosimetry laboratory worksheets were retrieved and arranged chronologically. The worksheets were grouped by building. A database has been constructed to include data for only those workers who were monitored for neutrons using film during the period between 1951 and 1970. Because the focus of the NDRP is on neutron dose, the database primarily contains data on plutonium workers and not on uranium or nonradiation workers. The database would provide a breakdown of the penetrating dose (neutron and gamma) and dosimeter-by-dosimeter data for some of the period during which data were lost when quarterly totals were generated from 1951 to 1975. This information is not in the dose history file.

#### 6.3.4.3 Job Exposure Matrix

A U.S. Department of Energy-funded study performed by the University of Colorado Health Sciences Center and the Colorado Department of Public Health and Environment (Ruttenber et al. 2003) developed a Job Exposure Matrix that identified the building assignment and a job title snapshot during September for each year from 1952 to 1989. This matrix was matched with external dosimetry results and would provide dose distributions for groups and job titles to assist in estimating dose for unmonitored workers. These data are unavailable to DOE and are not in the DOE dose history file.

## 6.4 HISTORICAL ADMINISTRATIVE PRACTICES

### 6.4.1 Badged Population

When plant operations began in 1951, there was no external dosimetry, and there was not much radioactive material at the Plant. In September 1952, dosimeters became available for use. Some individuals in Building 991 received neutron dosimeters. The use of dosimetry expanded to other RFP production operations. In 1964, the security badge was incorporated in the dosimetry badge, which ensured that each individual wore a dosimetry badge (Putzier 1982). This design was maintained until the early 1990s, when the security badge was separated from the dosimeter and individuals unlikely to receive occupational radiation exposure greater than 100 mrem were no longer issued dosimeters.

### 6.4.2 Badge Exchange Frequency

The determination of badge exchange frequencies was based on the potential for external dose and the necessity to control dose to administrative limits. Badges were exchanged at various frequencies. Early dosimetry was exchanged on a weekly basis, which later became semimonthly and monthly. In later years, dosimetry was exchanged on semimonthly, monthly, and quarterly frequencies. In the 1990s, exchange frequencies went to monthly, quarterly, and semiannually. An option for annual exchanges was identified, but never used.

Badge exchange frequency records have not been maintained. The exchange frequency for an individual can be determined by reviewing the external dose record, if individual dosimeter readings were maintained. After 1976, the dose record will show a dosimeter reading for each exchange. For earlier years, the dose has been combined into quarterly records for which the exchange frequency has been lost, although it is reasonable to assume badges were exchanged at least quarterly.

To determine the exchange frequencies used before 1976, original dosimetry laboratory worksheets were reviewed, many of which have been assembled as part of the NDRP. Dosimetry laboratory worksheets from 1951 through 1970 have been assembled and organized. A sample was obtained by selecting the September folder for each year. A review of each worksheet determined the exchange frequency, building, and dosimeter type (photon, beta, or neutron). These data were organized and reviewed to determine the most frequent exchange for the major job categories (see Attachment 6B) by year. The worksheets do not indicate job assignment. It was necessary to evaluate the job category based on the building and exchange frequency. In cases where multiple exchange frequencies were indicated for a major job category, the more frequent exchange frequency was selected. This provides a claimant-favorable assumption when determining missed dose. Dosimetry worksheets are not readily available from 1970 to 1976, so exchange frequencies were extrapolated forward for those years. This is appropriate because the Plant was relatively stable during that period. Table 6-2 lists the results of this analysis. These are the default values to use if the exchange frequency cannot be determined. If no job category can be determined, the dose reconstructor should use the most frequent exchange for that year.

### 6.4.3 Field-Specific Calibration Factors

Film dosimeters required the use of workplace-specific calibration factors, so it was necessary to know the facility in which the individual worked. The Dosimetry department determined this by using facility assignment rosters, issuing and retrieving badges to each major facility. Individuals sometimes worked in other facilities on temporary or overtime assignments, which the Dosimetry department could not detect. Area-specific calibration factors were necessary to evaluate readings from X-ray/gamma dosimeters used in the plutonium areas and the beta/gamma dosimeters used in the uranium areas. If a dosimeter was exposed in a different field, this could not be detected, which introduced a source of uncertainty.

TLD systems use more tissue-equivalent detection elements, which do not require a field-specific calibration factor. This source of uncertainty is minimal with these dosimeters.

Table 6-2. Conservatively determined default dosimeter exchange frequencies.

| Year | Chemical operators | | Metallurgical operators | | Maintenance workers | Support personnel | Analytical laboratory technicians | Site support personnel | Radiation control technicians |
|---|---|---|---|---|---|---|---|---|---|
| | Pu | U | Pu | U | | | | | |
| 1951 | sm | sm | sm | sm | m | m | sm | m | sm |
| 1952 | sm | sm | sm | sm | m | m | sm | m | sm |
| 1953 | sm | sm | sm | sm | m | m | sm | m | sm |
| 1954 | sm | sm | sm | w | m | sm | sm | m | sm |
| 1955 | sm | sm | sm | w | m | sm | sm | m | sm |
| 1956 | sm | sm | sm | w | m | sm | sm | m | sm |
| 1957 | sm | sm | sm | w | m | sm | sm | m | sm |
| 1958 | w | w | w | w | m | sm | sm | m | w |
| 1959 | w | sm | w | w | m | sm | sm | m | w |
| 1960 | w | w | w | w | m | m | sm | m | w |
| 1961 | sm | sm | sm | w | m | m | w | m | sm |
| 1962 | sm | sm | sm | w | m | m | w | m | sm |
| 1963 | sm | m | sm | sm | m | m | q | m | sm |
| 1964 | sm | m | sm | m | q | m | q | q | sm |
| 1965 | m | -- | m | m | q | q | q | q | m |
| 1966 | m | -- | m | m | m | q | q | q | m |
| 1967 | sm | -- | sm | m | m | q | q | q | sm |
| 1968 | sm | -- | sm | m | m | m | m | m | sm |
| 1969 | sm | -- | m | m | m | m | m | m | m |
| 1970 | sm | -- | m | m | m | m | m | m | m |
| 1971 | sm | -- | m | m | m | m | m | m | m |
| 1972 | sm | -- | m | m | m | m | m | m | m |
| 1973 | sm | -- | m | m | m | m | m | m | m |
| 1974 | sm | -- | m | m | m | m | m | m | m |
| 1975 | sm | -- | m | m | m | m | m | m | m |
| 1976 | sm | -- | m | m | m | m | m | m | m |

w - weekly
sm - semi-monthly (twice per month)
m - monthly
q - quarterly

### 6.4.4 Minimum Reported Dose

RFP appears to have embraced a philosophy of reporting dose down to zero between 1951 and 1992. In 1993, the Plant adopted a minimum reported dose threshold to remove the bias associated with reporting low doses and truncating doses calculated to be small negative numbers to zero. In 1993, a minimum reported dose level of 10 mrem was adopted. Any dose below this level was reported as zero (RFETS 2001). This policy is consistent with the limits of detection reported elsewhere in this TBD.

## 6.5 COMMON ISSUES

This section discusses issues common to external photon, neutron, and electron dose measurement at RFP. These issues are addressed further only if there is an issue specific to that type of dose measurement.

### 6.5.1 Number of Zero Readings

At present, available dosimetry records do not provide individual dosimeter results for the early years. Therefore, it will be necessary to estimate the dosimeter exchange frequency for the period from 1951 to 1976. Table 6-2 provides an estimate based on major job category. If an individual's job assignment cannot be determined, the most frequent dosimeter exchange used during that year must be assumed. This is a claimant-favorable assumption.

Once the estimated exchange frequency has been established, the number of zero readings must be estimated. If the number of zero measurements cannot be determined, the missed dose becomes more complicated. When only the quarterly dose is known, the number of zero doses should be estimated based on the dose level and the monthly, quarterly, or annual limits for that year and the number of possible zero monitoring intervals. This would be the situation, for example, if an individual received a cumulative dose of 2,140 mrem in a given year at a facility that had a monthly monitoring frequency, and the maximum permissible exposure limit was 1,000 mrem per month. The minimum number of months in which this dose could have been received is 3. Therefore, the maximum number of missed dose months would be 9, and the minimum would be zero because the dose could have been received evenly throughout the year. The central estimated number of months should be the median, or 5; however, the upper bound would be 9 (NIOSH 2002).

Quarterly or annual limits: 1951 – 1967, 3 rem per quarter (Attachment 6A-7)

1968 – 1992, 5 rem per year (observed in Rockwell International 1985)

1993 – present, 2 rem per year (DOE 1992)

Table 6-3 divides these dose limits into exchange frequencies. Using the methodology of NIOSH (2002), it is possible to develop a claimant-favorable estimate of the number of zeros and ultimately the missed dose.

### 6.5.2 Discrepancies

If the employee's record contains discrepancies, it is claimant-friendly to use the higher dose in the dose reconstruction. Care must be taken to interpret dose numbers properly if units were not specified. RFP routinely used mR or mrem as the unit of dose. If a number has no unit indicated, it is probably not in rem. It is highly unlikely that a record would show a dose greater than the quarterly or annual limit without an additional record indicating an overexposure.

If no activity date is associated with a dose record, it is claimant-favorable to use that dose in the dose reconstruction. The dose reconstructor should use best judgment to credit the dose to the most likely year.

Corrections were noted in the dose record when calculation or computer errors occurred. Such corrections were usually noted on the hard-copy report, and a notation was entered if the electronic record was updated. If the record was updated and noted, the correction should not be applied again. If there is no obvious notation to indicate the incorporation of a correction, the claimant-favorable action is to incorporate the correction in the dose used for reconstruction.

Table 6-3. Dose limits (rem) based on exchange frequency.

| | | period | 52 | 26 | 12 | 4 | 2 |
|---|---|---|---|---|---|---|---|
| **Year** | **Limit (rem)** | **(yr)** | **weekly** | **semimonthly** | **monthly** | **quarterly** | **semiannually** |
| 1951 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1952 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1953 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1954 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1955 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1956 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1957 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1958 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1959 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1960 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1961 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1962 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1963 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1964 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1965 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1966 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1967 | 3 | 0.25 | 0.231 | 0.462 | 1.000 | 3.000 | |
| 1968 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1969 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1970 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1971 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1972 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1973 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1974 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1975 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1976 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1977 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1978 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1979 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1980 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1981 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1982 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1983 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1984 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1985 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1986 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1987 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1988 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | |
| 1989 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | 2.500 |
| 1990 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | 2.500 |
| 1991 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | 2.500 |
| 1992 | 5 | 1 | 0.096 | 0.192 | 0.417 | 1.250 | 2.500 |
| 1993 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 1994 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 1995 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 1996 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 1997 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 1998 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 1999 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 2000 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 2001 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 2002 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |
| 2003 | 2 | 1 | 0.038 | 0.077 | 0.167 | 0.500 | 1.000 |

### 6.5.3 Missing Entry

If the dosimetry history contains a missing entry, this probably indicates that the individual missed the dosimeter exchange and that the next dosimeter includes the dose from both exchange periods. A less likely indication is that the badge was lost and no dose was assigned for that period. The claimant-favorable assumption is that the dosimeter was lost; dose should be assigned for that period using dosimetry data preceding and following that period (consider the approach of Watson, Wood, Tankersley, and West 1994).

### 6.5.4 Exposure Geometry

Because little information is available on the exposure geometry for an individual, estimates have been made for each major job category (Attachment 6B). To estimate the exposure geometry for major job categories, engineering judgment was used and a simple calculation was performed. The fraction of the dose received via each geometry is a product of the dose rate and exposure duration that each worker experienced. Workers experienced a higher dose rate when working hands-on with radioactive material, and a lower dose rate as they performed other tasks in the radiation control area. An estimate of the fraction of hands-on time was selected for each major job category. Selection of source geometry was based on as assumed configuration of the radioactive material to which the workers were exposed. From this, a relative dose was estimated for hands-on work (1 foot away) and non-hands-on work (4 feet away), using simple rules of thumb. These were combined to estimate the fraction of the dose received via the anterior-posterior (AP) geometry (hands-on) or other geometries for the balance of the exposure (ICRP 1996). Table 6-4 presents these results. The non-AP exposure was estimated to come from either the rotational (ROT) or isotropic (ISO) geometry. The difference is that ISO considers exposure from all angles (including above and below) while ROT considers only exposure from all horizontal directions to the upright individual. Chemical operators receive doses from above and below due to pipes in the overhead and near the floor. All others were assumed to receive their non-AP doses from the ROT geometry. Table 6-5 lists these fractions, which are rounded.

Table 6-4. Exposure geometry calculation.

| Major job category | Hands-on work (time) | Source geometry | Calculated dose received | |
|---|---|---|---|---|
| | | | AP | ISO or ROT |
| Chemical operators | 25% | Line | 57% | 43% |
| Metallurgical operators | 75% | Point | 98% | 2% |
| Maintenance workers | 75% | Plane | 98% | 2% |
| Support personnel | 5% | Plane | 46% | 54% |
| Analytical laboratory tech. | 75% | Point | 98% | 2% |
| Site support personnel | 0% | Plane | 0% | 100% |
| Radiation control technicians | 10% | Plane | 64% | 36% |
| D&D workers | 75% | Plane | 98% | 2% |

Table 6-5. Exposure geometry defaults for major job categories.

| Major job category | Default selected | | |
|---|---|---|---|
| | AP | ISO | ROT |
| Chemical operators | 50% | 50% | |
| Metallurgical operators | 100% | | |
| Maintenance workers | 100% | | |
| Support personnel | 50% | | 50% |
| Analytical laboratory tech. | 100% | | |
| Site support personnel | | | 100% |
| Radiation control technicians | 60% | | 40% |
| D&D workers | 100% | | |

## 6.6 PHOTON DOSE

### 6.6.1 Energy Groups

The NIOSH IREP probability of causation program (NIOSH 2002) contains three photon energy bands:

- Below 30 keV
- 30 to 250 keV
- Above 250 keV.

Separation of the dose from each energy band is required.

#### 6.6.1.1 Exposure Spectra

Very little spectroscopy data indicating the gamma spectrum in RFP work areas have been located. To estimate the gamma spectrum to which workers were exposed, MicroShield 5.03 (Grove Engineering 1998) was used. With the use of the MicroShield decay feature, radionuclide source concentrations (DOE 1980) for weapons-grade plutonium, enriched uranium, and depleted uranium were used (freshly separated material) and then decayed for 10 and 30 years. These decay times give an understanding of the material to which workers were exposed. Depleted and enriched uranium were routinely handled in the open with no shielding. Plutonium was almost exclusively handled in glove boxes, providing shielding from the glovebox materials. This calculation assumed large pieces of material (infinitely thick with respect to the photon path length in that material) and 1/16-in. stainless steel as the shielding provided by the glovebox. Table 6-6 presents these results.

Table 6-6. Photon energy distribution for RFP materials.

| Shield | Energy | Fresh Pu | 10-yr Pu | 30-yr Pu | Fresh EU | 10yr EU | 30yr EU | Fresh DU | 10yr DU | 30yr DU |
|---|---|---|---|---|---|---|---|---|---|---|
| None | <30 keV | Not applicable | | | 0% | 0% | 0% | 0% | 0% | 0% |
| | 30-250 keV | | | | 100% | 99% | 98% | 100% | 3% | 3% |
| | >250 keV | | | | 0% | 1% | 2% | 0% | 97% | 97% |
| 1/16 inch steel | <30 keV | 0% | 0% | 0% | Not applicable | | | | | |
| | 30-250 keV | 100% | 85% | 88% | | | | | | |
| | >250 keV | 0% | 15% | 11% | | | | | | |

Plutonium processed at RFP varied in age from freshly separated to wastes that have been stored onsite for many years. Using the default assumption that the material is freshly separated, results in a claimant-favorable dose resulting from exposure to the 30 - 250 keV photon energy range.

$^{234m}$Pa is a decay product in the $^{238}$U (depleted uranium) decay chain and emits a 2.29 MeV beta particle. Thus, a significant quantity of photons resulting from bremsstrahlung radiation are produced and contribute photons of intermediate energy (30 - 250 keV). These photons are not included in Table 6-6. Bremsstrahlung radiation can contribute up to 40% of the photon dose from uranium metal (DOE 2001). This decay product grows-in fairly rapidly and is present in equilibrium quantities for most depleted uranium that was processed at RFP. It is appropriate to use the default assumption for depleted uranium that 50% of the dose is contributed by photons in the 30 - 50 keV photon energy range and 50% of the dose is a result of exposure from photons in the >250 keV photon energy range.

Although enriched uranium has significantly less in-growth of $^{234m}$Pa, $^{235}$U and it's decay products emit a 185.7 keV photon 57% of time and a 143.8 keV photon 11% of the time. These photons dominate the measured photon energy spectra. Thus, for enriched uranium, it is appropriate to use the default assumption that all the photon dose is a result of exposure in the 30 - 250 keV photon energy range. This is a claimant-favorable assumption. The default assumptions are shown in Table 6-7.

Table 6-7. Default photon energy distribution for RFP materials.

| Energy | Plutonium | Enriched uranium | Depleted uranium |
|---|---|---|---|
| <30 keV | 0% | 0% | 0% |
| 30-250 keV | 100% | 100% | 50% |
| >250 keV | 0% | 0% | 50% |

### 6.6.2 Calibration Factor

#### 6.6.2.1 Reported Dose-to-Organ-Dose Conversion Factor Units

Standard X-ray film was initially used for photon dosimetry at Rocky Flats. This film was processed by Los Alamos National Laboratory (LANL). This was followed by a period in which a subcontractor performed the processing, after which RFP took over the processing.

Little is known about the LANL-provided dosimetry, but it is reasonable to assume that the dosimeter was calibrated in roentgens (R).

When RFP provided the film dosimetry, it appears that roentgens continued as the unit of calibration (Dow Chemical 1967). It is reasonable to assume that this continued until calibration of the Panasonic TLD dosimetry system, which was performed using DOELAP sources at Pacific Northwest Laboratory (PNL). DOELAP sources have been used since that time. The Personal Dose Equivalent [Hp(10)] is the appropriate unit to use for this period.

Table 6-8 summarizes dose units to use for organ dose conversion factors.

Table 6-8. Photon dose units for use with organ dose conversion factors.

| Year | | Year | | Year | | Year | | Year | | Year | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | R | 1961 | R | 1971 | R | 1981 | R | 1991 | $H_p(10)$ | 2001 | $H_p(10)$ |
| 1952 | R | 1962 | R | 1972 | R | 1982 | R | 1992 | $H_p(10)$ | 2002 | $H_p(10)$ |
| 1953 | R | 1963 | R | 1973 | R | 1983 | $H_p(10)$ | 1993 | $H_p(10)$ | 2003 | $H_p(10)$ |
| 1954 | R | 1964 | R | 1974 | R | 1984 | $H_p(10)$ | 1994 | $H_p(10)$ | | |
| 1955 | R | 1965 | R | 1975 | R | 1985 | $H_p(10)$ | 1995 | $H_p(10)$ | | |
| 1956 | R | 1966 | R | 1976 | R | 1986 | $H_p(10)$ | 1996 | $H_p(10)$ | | |
| 1957 | R | 1967 | R | 1977 | R | 1987 | $H_p(10)$ | 1997 | $H_p(10)$ | | |
| 1958 | R | 1968 | R | 1978 | R | 1988 | $H_p(10)$ | 1998 | $H_p(10)$ | | |
| 1959 | R | 1969 | R | 1979 | R | 1989 | $H_p(10)$ | 1999 | $H_p(10)$ | | |
| 1960 | R | 1970 | R | 1980 | R | 1990 | $H_p(10)$ | 2000 | $H_p(10)$ | | |

### 6.6.3 Missed Dose

Section 2.1.2 of NIOSH (2002) recommends the use of the LOD/2 method for determining missed dose.

#### 6.6.3.1 Limit of Detection

The film badge initially used at RFP is similar to that developed at the University of Chicago and used at other U.S. Atomic Energy Commission (AEC, a DOE predecessor agency) sites. All of these badges used X-ray film surrounded with a metal badge holder. They had an open window and an area covered with 1 mm of silver, tin, or cadmium (Alvarez et al. 2003). A PNL study of this two-element dosimeter (Wilson, Fix, Baumgartner, and Nichols 1990) identified a detection level of about 40 mR at the upper 95% confidence level for radium gamma radiation. Improved film, implemented at Hanford in 1960 (Wilson, Fix, Baumgartner, and Nichols 1990), reduced this detection level to about 15 mR. Information found at RFP indicated that a DuPont 558 film packet was used in 1964 (Owen 1964). This packet contained a piece of DuPont 508 sensitive film and a piece of DuPont 1290 insensitive film. The 1290 film was not processed unless the 580 film was too exposed to read. It is not clear if RFP used the earlier 502 film or when it changed to the 508 film. Hanford changed to 508 film in 1960 (Wilson, Fix, Baumgartner, and Nichols 1990). It is claimant-favorable to assume that RFP used the less sensitive film until 1960, and then used the more sensitive 508 film. The film LOD selected is that determined by Wilson, Fix, Baumgartner, and Nichols (1990) for the Hanford badge.

In 1969, RFP started using Harshaw TLD chips to measure photon dose. Again, this dosimeter was similar to one used at Hanford. Wilson, Fix, Baumgartner, and Nichols (1990) identified an estimated detection level of 20 mR for radium gamma detection. The limit of detection information has not been identified specifically for TLD implementation at RFP, but is believed to be similar to that for the Hanford dosimeter.

The 1983 switch at RFP to the Panasonic dosimeter in 1983 achieved improved sensitivity. Information on the limit of detection during this period has not been identified, so the claimant-favorable value of 20 mrem, similar to that achieved in 1982, is recommended.

In 1992, a study was performed to reduce the variability in low-dose measurements. An uncertainty criterion incorporated in the algorithm resulted in more stable dose measurements at low doses. This resulted in an estimated limit of detection of 10 mrem. A dose-reporting threshold of 10 mrem was implemented. Any dose below this was reported as 0.

Table 6-9 lists photon limits of detection for the RFP dosimeters.

Table 6-9. Photon limit of detection for RFP dosimeters.

| Year | LOD | Year | LOD | Year | LOD | Year | LOD | Year | LOD | Year | LOD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 40 mR | 1961 | 40 mR | 1971 | 20 mR | 1981 | 20 mR | 1991 | 20 mrem | 2001 | 10mrem |
| 1952 | 40 mR | 1962 | 40 mR | 1972 | 20 mR | 1982 | 20 mR | 1992 | 20 mrem | 2002 | 10mrem |
| 1953 | 40 mR | 1963 | 40 mR | 1973 | 20 mR | 1983 | 20 mrem | 1993 | 10 mrem | 2003 | 10mrem |
| 1954 | 40 mR | 1964 | 40 mR | 1974 | 20 mR | 1984 | 20 mrem | 1994 | 10 mrem | | |
| 1955 | 40 mR | 1965 | 40 mR | 1975 | 20 mR | 1985 | 20 mrem | 1995 | 10 mrem | | |
| 1956 | 40 mR | 1966 | 40 mR | 1976 | 20 mR | 1986 | 20 mrem | 1996 | 10 mrem | | |
| 1957 | 40 mR | 1967 | 40 mR | 1977 | 20 mR | 1987 | 20 mrem | 1997 | 10 mrem | | |
| 1958 | 40 mR | 1968 | 40 mR | 1978 | 20 mR | 1988 | 20 mrem | 1998 | 10 mrem | | |
| 1959 | 40 mR | 1969 | 20 mR | 1979 | 20 mR | 1989 | 20 mrem | 1999 | 10 mrem | | |
| 1960 | 40 mR | 1970 | 20 mR | 1980 | 20 mR | 1990 | 20 mrem | 2000 | 10 mrem | | |

#### 6.6.3.2 Number of Zero Readings

Section 6.5.1 of this TBD discusses the determination of the number of zero readings.

#### 6.6.3.3 Determination of Missed Dose

Determination of missed dose is performed using LOD/2 times the number of zero readings, as discussed in Section 2.1.2.2 of NIOSH (2002). For the period from 1977 to the present, the number of zero readings can be determined directly from the dosimetry data. The missed dose is assumed to be lognormally distributed with central tendency nLOD/2, and the upper 95% dose is nLOD, where n is the number of zero readings. If the number of zero readings cannot be determined, it must be estimated assuming prorated dose limits were not exceeded. Section 6.5.1 of this TBD and Section 2.1.2.3 of the reconstruction guidance discuss this estimate. In this case, the estimate is assumed to be lognormally distributed with central tendency mLOD/2, where m is the median of minimum and maximum possible number of zero readings, and the upper 95% dose is pLOD, where p is the maximum possible number of zero readings.

#### 6.6.3.4 Unmonitored Energy Range

All dosimeter types used at RFP were calibrated and their response was corrected for photon energies resulting in worker dose in the work areas (low-energy X-rays, americium photons, and high-energy photons). No corrections for unmonitored photon energy range are appropriate.

The two-element film dosimeter used at RFP is similar to those used at other sites. The response of this dosimeter is addressed in the Savannah River Site TBD (ORAU 2003). These documents address the significant over-response of film to low photon energies. The dosimeter (open window) was calibrated with low-energy photons. To correct for this over-response, a portion of the open-window dose was added to the deep dose measured under the 1-mm cadmium filter. There is evidence (Falk 2003) that this correction was used at RFP. This indicates that the early film dosimeter was corrected for energy response. No missed photon dose correction factor is appropriate for this dosimetry system.

The multielement film dosimeter used at RFP provided better energy response to measure worker dose more accurately. Although little information is available on this dosimetry system, it appears that corrections were incorporated to prevent missed photon dose. Therefore, no missed photon dose correction factor is appropriate for this dosimetry system.

Harshaw TLD chips were used at RFP in an interim neutron film/photon TLD badge, and then in the RFP TLD badge. These dosimeter elements were shielded and of various thicknesses. Most important, the TLD elements were relatively tissue-equivalent with respect to photon response and unlikely to have missed photon dose in an energy range to which workers were exposed. No missed dose correction is appropriate for this dosimetry system.

The initial implementation of the Panasonic TLD system was based on a range of DOELAP exposure categories. The response of the dosimeter was evaluated with respect to these exposures, and the algorithm was derived from these exposures. Thus, the initial implementation of the Panasonic TLD system and the later DOELAP-accredited operation of that system are unlikely to have missed photon dose in an energy range to which workers could be exposed. No missed-dose correction is appropriate for this dosimetry system.

### 6.6.4 <u>Geometry</u>

#### 6.6.4.1 Angular Dependence

The film dosimeters used at RFP experienced varying angular response. Dosimeters were not always exposed straight-on, resulting in varying responses with respect to actual worker exposure. There is insufficient data to identify an angular dependence correction to apply to any of the dosimeters. Because any correction would reduce the dose or, in the case of the Panasonic dosimeter, increase the dose only slightly, not including this correction factor is generally claimant-favorable.

The film dosimeter experienced an apparent increase in dose when exposed from the edge because photons were able to expose the film under the filter, without passing through the filter. RFP has generated limited experimental exposure data that demonstrates this phenomenon qualitatively. Edge-on exposure with 60-keV photons indicated a factor of 4 over-response.

TLD dosimeters are likely to experience the same problem. No information on this issue in relation to the neutron film/photon TLD badge or the Harshaw TLD badge photon response has been found.

Quantitative information is available for the RFP Panasonic dosimeter (RFETS 2001). The dosimeter was tested in 1993 and 1996. For eight DOELAP exposure categories, element responses generally decreased as the angle increased. For angles of incidence from -30° to +30°, the ratio of reported dose to delivered dose ranged from 0.88 to 0.99 for photons.

#### 6.6.4.2 Exposure Geometry

Exposure geometry is common to all types of radiation exposure, as addressed in Section 6.5.4.

### 6.6.5 Uncertainty

The *External Dose Reconstruction Guideline* (NIOSH 2002) describes methods for quantification of laboratory uncertainty associated with reading film and TLDs. These methods provide a statistical treatment of the variability associated with reading dosimeters in the laboratory.

#### 6.6.5.1 Film

Rocky Flats used film to measure photons between 1951 and 1968. The DuPont 558 film packet (containing the sensitive 508 film) was used in 1964 (Owen 1964). The 508 film was the successor to 502 film and both films have a useful range from 10 - 20 mR up to approximately 10 R (NRC 1989). It is not clear if RFP used 502 film or when it changed to 508 film. Hanford changed to 508 film in 1960 (Wilson, Fix, Baumgartner, and Nichols 1990). Both film types have approximately the same reading uncertainty.

The method in the *External Dose Reconstruction Implementation Guideline* (NIOSH 2002) was used to determine the laboratory uncertainty (upper 95% confidence dose) for film readings. This method is detailed in *Film Badge Dosimetry in Atmospheric Nuclear Tests* (NRC 1989). The discussion of this method cites sensitivity parameters for 502 film. A spreadsheet was developed using these parameters to match the example provided and then modified with RFP-specific parameters. RFP densitometer readings appear to be a factor of 1,000 greater than those illustrated in the example. It is believed that these are "milli" density units. Results are consistent with the example when this assumption is used. Review of dosimetry worksheets indicate that density readings were recorded to the nearest whole number; therefore, the densitometer reading uncertainty is assumed to be ± 0.5 density unit. Reviewing RFP density-to-dose conversion charts from 1966 to 1968, it was possible to determine film sensitivity. Using this parameter, the upper 95% confidence doses for various dosimeter readings were calculated.

Although the uncertainty is reduced at higher exposures, the NRC methodology recognizes that additional uncertainty contributed by variability in calibration, film processing, and reading the calibration curve, prevents the upper 95% confidence dose from falling below 120% of the reported exposure. This limitation has been applied here and effects the estimate of the upper 95% confidence dose above 27 mR. These are listed in Table 6-10.

Table 6-10. Uncertainty for photon film dose at RFP.

| Dose (mR) | Upper 95% confidence photon dose (mR) |
|---|---|
| 1 | 6 |
| 2 | 7 |
| 5 | 10 |
| 10 | 15 |
| 20 | 25 |
| 50 | 60 |
| 100 | 120 |
| 200 | 240 |
| 500 | 600 |
| 1,000 | 1,200 |
| 2,000 | 2,400 |

#### 6.6.5.2 Thermoluminescent Dosimeter

TLDs provided improved photon dosimetry. The uncertainty associated with this type of dosimeter is estimated for the early years of use, and then measured when DOELAP performance testing began.

##### 6.6.5.2.1 Loose Chip Thermoluminescent Dosimeters

Harshaw TLD chips were used to measure photon dose at RFP from 1969 through 1982. These chips were carried in a dosimeter holder, but were removed to be read, thus the term "loose chips." A calculation was performed to estimate the uncertainty associated with reading the photon dose from these dosimeters.

Little information has been located describing the variability of chip response when these chips were in service. A chip sorting procedure was used to remove chips from service that responded outside set criteria (Link and Pennock 1983). The procedure was to expose the chips to a 1,000-mrem dose equivalent using a $^{137}$Cs source. The chips were then read and any that responded outside the mean ± 0.165 * mean were removed from use. Assuming that the chip response was normally distributed such that 5% of the chips were removed during the sorting process (a claimant-favorable assumption), the upper and lower cutoffs would have to be 1.96 standard deviations of the existing chip population. Thus the initial chip population standard deviation is (0.165 * 1,000)/1.96 = 84.18 or 8.4%. Performing a Monte Carlo simulation on this distribution, removal of the chips outside the criteria results in a truncated normal distribution with a standard deviation of 7.4%. The higher 8.4% was selected as a parameter describing the chip population routinely used to measure dose (a claimant-favorable assumption). Using the Simplified Dosimetry Uncertainty calculation recommended by NIOSH (2002), and assuming the critical level (Lc) is the LOD estimated in Section 6.3.1 of this TBD, Table 6-11 lists the upper 95% confidence dose.

Table 6-11. Uncertainty for loose chip TLD photon dose at RFP.

| Dose | Upper 95% confidence dose (mrem) 1969–1982 |
|---|---|
| 1 | 21 |
| 2 | 22 |
| 5 | 25 |
| 10 | 30 |
| 20 | 40 |
| 50 | 72 |
| 100 | 126 |
| 200 | 239 |
| 500 | 585 |
| 1,000 | 1,166 |
| 2,000 | 2,330 |

##### 6.6.5.2.2 Panasonic Thermoluminescent Dosimeter

Table 6-12 summarizes the uncertainty associated with DOELAP-accredited Panasonic dosimeter dose readings. These values were calculated using the TLD uncertainty methodology detailed in Section 2.1.1.3.2 of NIOSH (2002). This method recognizes that elements of the uncertainty are quantified in the dosimetry program documentation available for a DOELAP-accredited program. The standard deviation for null readings is from a study performed at RFP (RFETS 2001), and the relative standard deviation at high readings is the standard deviation of the DOELAP performance test results (RFETS 2001; Stanford 1990). The reasonable worst-case value was selected to provide a claimant-favorable result. No data are available for the initial algorithm implementation of the Panasonic dosimetry system (1983 to 1989). Similar performance to that after 1990 is assumed.

Table 6-12. Uncertainty for DOELAP-accredited TLD photon dose at RFP.

| | Upper 95% confidence dose (mrem) | | |
|---|---|---|---|
| | Panasonic dosimeter | DOELAP-accredited Panasonic dosimeter | |
| Dose (mrem) | 1983–1989 | 1990–1998 | 1999–present |
| 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 2 |
| 5 | 6[a] | 6[b] | 6[c] |
| 10 | 12 | 12 | 12 |
| 20 | 25 | 25 | 24 |
| 50 | 61 | 61 | 59 |
| 100 | 123 | 123 | 118 |
| 200 | 245 | 245 | 235 |
| 500 | 614 | 614 | 588 |
| 1,000 | 1,227 | 1,227 | 1,176 |
| 2,000 | 2,455 | 2,455 | 2,353 |

a. 1.23 multiplier for any dose greater than 2 mrem.
b. 1.23 multiplier for any dose greater than 2 mrem.
c. 1.18 multiplier for any dose greater than 2 mrem.

## 6.7 NEUTRON DOSE

### 6.7.1 Energy Groups

The measured neutron dose must be divided into energy groups consistent with the dose conversion factors provided in Appendix B of NIOSH (2002). These energy groups and the associated radiation weighting factors from International Commission on Radiological Protection (ICRP) Publication 60 (ICRP 1990) are:

- < 0.01 MeV (wt=5)
- 0.01–0.10 MeV (wt=10)
- 0.10–2.0 MeV (wt=20)
- 2.0–20 MeV (wt=10)
- > 20 MeV (wt=5).

The analysis in this TBD is based on neutron spectra measured at RFP (Brackenbush et al. 1989).

#### 6.7.1.1 Exposure Spectra

In August and September 1988, PNL provided technical assistance to RFP related to neutron and photon dose measurements (Brackenbush et al. 1989). This activity performed multisphere neutron measurements in representative high-neutron dose situations. The measurements included production locations, mockup situations in which plutonium parts were in a glovebox where measurements could be performed, and waste storage locations. Neutron shielding was in place, similar to that experienced by workers in that area. Relatively long (several-day) measurements were required to acquire sufficient dose to achieve accurate results.

The neutron spectra were determined from the multisphere measurements and presented in the PNL report. Dose rate was derived from neutron flux density information, flux-to-dose conversion factors from National Council on Radiation Protection and Measurements (NCRP) Report 38 (NCRP 1971). No neutron flux was identified for energies greater than 20 MeV. For this TBD, the dose rate information was divided into energy groups as required for NIOSH dose reconstruction. Table 6-13 lists this information.

Table 6-13. Neutron dose measurements divided into energy groups.

| Location | Dose rate rem/hr | Avg. energy MeV | Portion of dose from neutron energy range < 10 keV | 10–100 keV | 0.10–2 MeV | 2–20 MeV | >20 MeV |
|---|---|---|---|---|---|---|---|
| Building 771 fluorinator line | 6.07E-04 | 0.33 | 0.090 | 0.028 | 0.678 | 0.204 | 0.000 |
| Building 771 Tank 554 | 4.65E-03 | 0.91 | 0.025 | 0.014 | 0.600 | 0.361 | 0.000 |
| Building 776 molten salt glovebox | 1.71E-03 | 0.45 | 0.038 | 0.023 | 0.840 | 0.099 | 0.000 |
| Building 776 molten salt storage vault | 8.84E-03 | 0.39 | 0.085 | 0.015 | 0.711 | 0.189 | 0.000 |
| Building 776 drum storage | 2.46E-02 | 0.63 | 0.027 | 0.034 | 0.689 | 0.250 | 0.000 |
| Building 707 high dose pit | 7.35E-04 | | 0.006 | 0.006 | 0.437 | 0.552 | 0.000 |
| Building 707 low dose pit | 2.88E-04 | | 0.015 | 0.009 | 0.758 | 0.218 | 0.000 |
| Building 707 oxide can | 1.43E-03 | 0.85 | 0.018 | 0.019 | 0.676 | 0.286 | 0.000 |
| Building 707 plutonium ingot | 1.98E-03 | 1.00 | 0.014 | 0.002 | 0.791 | 0.193 | 0.000 |
| Mean | | | 0.035 | 0.017 | 0.687 | 0.261 | |
| std. dev. | | | 0.031 | 0.010 | 0.117 | 0.130 | |

### 6.7.1.2 Reported Dose to Energy Groups

This information does not show a clear pattern. Therefore, it is appropriate to apportion dose based on the mean breakdown listed in Table 6-13. Table 6-14 lists the default values selected for dose reconstruction.

Table 6-14. Default neutron energy distribution.

| Neutron energy intervals | Fraction of dose (NCRP 38) | Dose multiplier (ICRP 60) | Dose multiplier[a] |
|---|---|---|---|
| <10 keV | 0.035 | 2.40 | 0.0851 |
| 10 - 100 keV | 0.017 | 2.06 | 0.0342 |
| 0.1 - 2.0 MeV | 0.687 | 1.98 | 1.36 |
| 2.0 - 20.0 MeV | 0.261 | 2.50 | 0.654 |
| >20 MeV | 0.00 | -- | 0.00 |

a. Multiply the reported dose by these factors to determine the ICRP 60 neutron dose for each neutron energy interval

The doses and fractions discussed above are based on quality factors published in NCRP (1971). NIOSH (2002) indicates the use of radiation weighting factors from ICRP Publication 60 (ICRP 1990). To perform this correction, the neutron energy deposition values (rad) for each energy were multiplied by the ICRP radiation weighting factor to determine the corrected dose equivalent. These values were totaled for each neutron energy interval used in this dose reconstruction and compared with the value determined previously using quality factors from NCRP (1971). A multiplier, determined for each neutron energy interval, is listed in column 3 of Table 6-14. The fraction of the dose [using NCRP (1971) quality factors] and the dose multiplier [using ICRP (1990) radiation weighting factors] were combined to determine a dose multiplier. This value is listed in column 4 of Table 6-14. The neutron dose reported in the claimant's dose record is multiplied by these factors to determine the ICRP (1990) neutron dose for each neutron energy interval.

### 6.7.2 Calibration Factor

### 6.7.2.1 Dosimeter-Specific Quality Factor Conversion

The correction factor to convert from NCRP (1971) quality factors used in the neutron spectra measurements and the ICRP (1990) radiation weighting factors are discussed in Section 6.7.1.2 and listed in Table 6-14.

#### 6.7.2.2 Reported-Dose-to-Organ-Dose Conversion Factor Units

RFP initially used neutron track plates. These dosimetry elements were provided and processed by LANL. At this point, little is known about their calibration, but it is assumed that ambient dose equivalent is appropriate.

Neutron film was initially calibrated with an apparently unmoderated polonium-beryllium (PoBe) source. In 1962 or 1963, this was changed to plutonium fluoride ($PuF_4$) (Mann and Boss 1963). The dose rate assigned to the source was the total dose for an energy of 1.4 MeV, found in NBS Handbook 63 (NBS). A set of polyethylene moderators was constructed. The spectra from these moderated sources compared well with work area spectra measured with a precision Long counter and a series of paraffin moderators fitted over the counter (Mann and Boss 1963). Ambient dose equivalent is appropriate for this dosimeter.

Harshaw TLDs at Rocky Flats were initially calibrated using a 210-gram $PuF_4$ source built at RFP and calibrated at the LANL standard pile, which was established as a neutron flux standard (Mann and Boss 1963). A set of polyethylene moderators was constructed to provide various degrees of moderation. The bare $PuF_4$ source dose rate was calculated using neutron spectra from an unknown reference document and quality factors published in DOE Orders (Falk 1975). The dose rates for the moderated spectra were measured with currently available neutron dose rate instrumentation. The $PuF_4$ source was placed in storage in about 1975 and replaced with a commercially manufactured and calibrated $^{252}$Cf source. The calculation of the dose rate used a published spectrum and dose rate (AEC 1968). A set of polyethylene moderators was manufactured for this source and ambient dose equivalent rates were determined in a manner similar to that used for the $PuF_4$ source. Thus, the ambient dose equivalent [H*(10)] is the appropriate unit for this period.

Panasonic TLDs at RFP were calibrated with DOELAP exposure standards. In the early 1980s, PNL was developing the neutron standards that were used for the original DOELAP performance testing. The development of all Panasonic dosimeter algorithms used at RFP was based primarily on these exposures. Therefore, the deep dose equivalent [Hp,slab(10)] is appropriate.

Table 6-15 summarizes the dose units to use for organ dose conversion factors.

Table 6-15. Neutron dose units for use with organ dose conversion factors.

| Year | | Year | | Year | | Year | | Year | | Year | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | H*(10) | 1961 | H*(10) | 1971 | H*(10) | 1981 | H*(10) | 1991 | $H_{p,slab}(10)$ | 2001 | $H_{p,slab}(10)$ |
| 1952 | H*(10) | 1962 | H*(10) | 1972 | H*(10) | 1982 | H*(10) | 1992 | $H_{p,slab}(10)$ | 2002 | $H_{p,slab}(10)$ |
| 1953 | H*(10) | 1963 | H*(10) | 1973 | H*(10) | 1983 | $H_{p,slab}(10)$ | 1993 | $H_{p,slab}(10)$ | 2003 | $H_{p,slab}(10)$ |
| 1954 | H*(10) | 1964 | H*(10) | 1974 | H*(10) | 1984 | $H_{p,slab}(10)$ | 1994 | $H_{p,slab}(10)$ | | |
| 1955 | H*(10) | 1965 | H*(10) | 1975 | H*(10) | 1985 | $H_{p,slab}(10)$ | 1995 | $H_{p,slab}(10)$ | | |
| 1956 | H*(10) | 1966 | H*(10) | 1976 | H*(10) | 1986 | $H_{p,slab}(10)$ | 1996 | $H_{p,slab}(10)$ | | |
| 1957 | H*(10) | 1967 | H*(10) | 1977 | H*(10) | 1987 | $H_{p,slab}(10)$ | 1997 | $H_{p,slab}(10)$ | | |
| 1958 | H*(10) | 1968 | H*(10) | 1978 | H*(10) | 1988 | $H_{p,slab}(10)$ | 1998 | $H_{p,slab}(10)$ | | |
| 1959 | H*(10) | 1969 | H*(10) | 1979 | H*(10) | 1989 | $H_{p,slab}(10)$ | 1999 | $H_{p,slab}(10)$ | | |
| 1960 | H*(10) | 1970 | H*(10) | 1980 | H*(10) | 1990 | $H_{p,slab}(10)$ | 2000 | $H_{p,slab}(10)$ | | |

### 6.7.3 Missed Dose

#### 6.7.3.1 Limit of Detection

LANL processed neutron track plates for RFP from 1951 through 1956. Little is known about the performance of this system. A claimant-favorable assumption is that the minimum detectable dose is similar to that experienced by RFP with NTA film (see below). The LOD is conservatively (claimant-favorably) assumed to be 400 mrem.

In 1957, RFP switched to Nuclear Track Type A (NTA) film that was processed and read by a subcontractor. Little is known about this processing period, so again an LOD of 400 mrem is assumed.

Beginning in July 1958, RFP processed NTA film at the site. The NDRP has assembled a processing history (NDRP 2003), summarized in Table 6-16. Based on a background (blank) reading of 16 tracks per 10 $mm^2$, reported by Mann and Boss (1963) for 1962, LODs were calculated based on the most conservative calibration factor.

Table 6-16. RFP neutron film track counting detail.

| Date | Determined positive | Calibration ($mrem/track/mm^2$) | LOD |
|---|---|---|---|
| 1959 | >2x blank | 40 | 128 mrem |
| 1960 | >2x blank | 40 | 128 mrem |
| 1961 | >1.5x blank | 40 | 96 mrem |
| 1962 | >blank+1.65*sqrt(blank) | 40 or 100 | 369 mrem |
| 1963 | >blank+1.65*sqrt(blank) | 100 | 369 mrem |
| 1964 | >2x blank | 100 or 70 | 320 mrem |
| 1965 | >2 x blank or all | 70 or 40 | 224 mrem |
| 1966 | All | 110 | -- |

Mann and Boss (1963) determined that a typical background film for 2 weeks had 16 tracks/10 $mm^2$. Using three times the standard deviation of the background and a 10-mrem/track calibration factor, the minimum detectable dose is 120 mrem.

Based on the LOD, the most claimant-favorable value was selected for each year. Mann and Boss (1963) estimates were used for years when LODs were not used or not known.

In 1971, RFP started using an albedo neutron TLD. Documentation of the research performed to develop this dosimeter (Falk 1971) indicates a practical lower neutron dose limit of 10 to 20 mrem in the presence of a photon dose as high as 100 mrem. The upper limit of this estimate was selected as the LOD for this dosimeter.

In 1983, the Panasonic UD-809 dosimeter was introduced at RFP to measure neutrons. Data are not available on the LOD for this dosimeter system. Because the hardware is the same as that used in 1990, it was assumed to be similar to performance of the system at that time. The assumed LOD is 32 mrem.

In 1990, an algorithm update was incorporated in the Panasonic dosimetry system (Stanford 1990). The documentation cites a minimum detectable neutron dose of 15 to 32 mrem for a moderated $^{252}Cf$ source.

In 1993, an algorithm update was incorporated in the Panasonic dosimetry system (RFETS 2001) to include element reading uncertainty controls to reduce large dose fluctuations at low dose. This update, which has passed DOELAP performance testing, results in a stated minimum response for routine RFP neutron fields of approximately 15 mrem. Table 6-17 includes this value.

Table 6-17. Neutron limit of detection for RFP dosimeters.

| Year | LOD | Year | LOD | Year | LOD | Year | LOD | Year | LOD | Year | LOD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 400mrem | 1961 | 120mrem | 1971 | 20mrem | 1981 | 20mrem | 1991 | 32mrem | 2001 | 15mrem |
| 1952 | 400mrem | 1962 | 369mrem | 1972 | 20mrem | 1982 | 20mrem | 1992 | 32mrem | 2002 | 15mrem |
| 1953 | 400mrem | 1963 | 369mrem | 1973 | 20mrem | 1983 | 32mrem | 1993 | 15mrem | 2003 | 15mrem |
| 1954 | 400mrem | 1964 | 320mrem | 1974 | 20mrem | 1984 | 32mrem | 1994 | 15mrem | | |
| 1955 | 400mrem | 1965 | 224mrem | 1975 | 20mrem | 1985 | 32mrem | 1995 | 15mrem | | |
| 1956 | 400mrem | 1966 | 120mrem | 1976 | 20mrem | 1986 | 32mrem | 1996 | 15mrem | | |
| 1957 | 400mrem | 1967 | 120mrem | 1977 | 20mrem | 1987 | 32mrem | 1997 | 15mrem | | |
| 1958 | 400mrem | 1968 | 120mrem | 1978 | 20mrem | 1988 | 32mrem | 1998 | 15mrem | | |
| 1959 | 128mrem | 1969 | 120mrem | 1979 | 20mrem | 1989 | 32mrem | 1999 | 15mrem | | |
| 1960 | 128mrem | 1970 | 120mrem | 1980 | 20mrem | 1990 | 32mrem | 2000 | 15mrem | | |

#### 6.7.3.2 Number of Zero Readings

Section 6.5.1 of this TBD discusses the number of zero readings.

#### 6.7.3.3 Unmonitored Energy Range

NTA film is a poor detector of neutron energies below 500 to 800 keV (Griffith, Hankins, Gammage, and Tommasino 1979; Wilson, Fix, Baumgartner, and Nichols 1990). Before 1963, RFP appears to have calibrated neutron film with a variety of unmoderated neutron sources. RFP recognized that dosimetry results were not consistent with instrument measurements and initiated a project in 1962 to improve neutron film dosimeter calibration (Mann and Boss 1963).

Before 1963, neutron dose resulting from neutrons below approximately 800 keV probably was not detected. To determine how much dose was potentially missed, the neutron measurements performed in RFP work areas (Brackenbush et al. 1989) were corrected for ICRP (1990) radiation weighting factors, and the fraction of the dose resulting from neutrons less than 800 keV was determined. Table 6-18 lists these values.

Table 6-18. Potential missed neutron dose for early film dosimeters at RFP.

| Location | ICRP 60 rem/hr | below 800 keV |
|---|---|---|
| Building 771 Fluorinator Line | 1.13E-03 | 52% |
| Building 776 Molten Salt Glovebox | 3.25E-03 | 60% |
| Building 776 Molten Salt Storage Vault | 1.67E-02 | 29% |
| Building 776 Drum Storage | 4.46E-02 | 57% |
| Building 707 High Dose Pit | 1.18E-03 | 22% |
| Building 707 Low Dose Pit | 5.26E-04 | 29% |
| Building 707 Oxide Can | 2.53E-03 | 47% |
| Building 707 Plutonium Ingot | 3.70E-03 | 16% |

There appears to be no distinct pattern in these data. It is appropriate to take a claimant-favorable approach and select the largest value of 56%. Thus, the total neutron dose from RFP measurements prior to 1964 (1951 through 1963) should be multiplied by 1.79 before applying the multiplicative factors from Table 6-14.

In 1962, RFP began a project to refine neutron dosimeter calibration to match the neutron spectra experienced in the production areas more accurately. Mann and Boss (1963) documented an effort to develop a calibrated $PuF_4$ source with various moderators. The spectra from the moderator configurations of this source were compared with neutron spectra measurements taken in the plutonium production areas with a precision long counter and a series of paraffin moderators. This resulted in dosimeter calibrations that more accurately matched the exposure spectra. No missed dose correction is required for RFP neutron film dosimeters after 1963.

The RFP TLD neutron dosimeter systems (Harshaw and Panasonic) were calibrated using variously moderated spectra. There is no need for missed neutron dose corrections. After 1990, the Panasonic TLD system was DOELAP-accredited, supporting the decision to forego a missed neutron dose correction.

#### 6.7.3.4 Neutron Dose Reconstruction Project

In the early 1990s, RFP addressed the issue of neutron film processing. It had been long recognized that, in the dosimetry laboratory, human factors associated with reading large numbers of neutron films under a microscope can significantly affect neutron dosimetry results. A pilot study in 1994 reevaluated neutron doses for selected plutonium workers. This study indicated that the original evaluations of films might have contained significant errors, and that the resulting neutron doses might be significantly higher or lower than the doses actually received. The Neutron Dose Reconstruction Project was initiated to provide current and former radiation workers and assessment of the neutron exposure received in the plutonium production facilities. The scope of this project will be for the years from 1952 through 1970.

The NDRP will reread neutron films (where available) with appropriate quality controls, and will reevaluate neutron doses. In addition, it will determine notional neutron doses for plutonium workers with missing or unreadable films and for non-neutron-monitored plutonium workers.

To provide a claimant-favorable correction until NDRP data are available, it is appropriate to use the neutron correction ratio reported in *Report of Epidemiologic Analyses Performed for Rocky Flats Production Workers Employed Between 1952-1989* (Ruttenber et al. 2003). These analyses used a combination of workplace instrument measurements and Harshaw and Panasonic TLD results to estimate "correction ratios" for total penetrating doses. This ratio provides an estimate for the "total penetrating dose" (gamma + neutron), which provides an initial correction for the identified bias in the neutron film reading. This correction should be applied to personnel who worked in the noted neutron buildings from 1951 - 1967. When the NDRP is complete, a more accurate neutron dose will be available for each worker who was monitored for neutrons. An updated ratio can be generated from these data for use with unmonitored workers in this work area. Table 6-19 lists the current correction ratios.

Table 6-19. RFP correction ratios for identified neutron film reading deficiencies.

| Building | Mean | Standard deviation |
|---|---|---|
| 771 | 1.99 | 0.92 |
| Other neutron buildings[a] | 1.13 | 0.82 |

a. 123, 774, 776, 777, 779, 886, 991, and others if record suggests neutron monitoring

### 6.7.4 <u>Geometry</u>

#### 6.7.4.1 Angular Dependence

Film neutron dosimeters generally experience a slight increase with exposure from angles other than front-on. It is claimant-favorable to ignore this slight difference.

The Panasonic dosimeter was evaluated for angular dependence. For neutron fields, the element responses generally decreased as the angle between the incident radiation and the plane perpendicular to the TLD increased. For angles of incidence from -30° to +30°, the ratio of reported dose to delivered dose ranged from 0.87 to 1.00 for neutrons. The slight variability does not warrant a specific correction.

#### 6.7.4.2 Exposure Geometry

The worker exposure geometry for neutron dose is similar to that for photons, and is discussed in Section 6.5.4.

### 6.7.5 Uncertainty

#### 6.7.5.1 Film

The NDRP is evaluating film uncertainty. Until that project is complete, these data will not be available. Until then, a neutron "correction ratio" has been applied (Section 6.7.3.4). The standard deviation reported for this correction ratio (Table 6-19) reflects the variability in the data used to derive this correction ratio. This value should be used until better data is available.

#### 6.7.5.2 Thermoluminescent Dosimeter

Falk (1971) describes the Harshaw TLD system development. That document describes field tests in RFP plutonium production facilities. The results indicate "… that the survey dose range is consistently within 20 percent of the TLD neutron dose indication." Thus, for the Harshaw neutron dosimeter, a 95% confidence interval of 20% has been selected. Thus, the standard deviation is 20% ÷ 1.96 = 10.2%. The methodology for TLD uncertainty in NIOSH (2002) is used.

The initial Panasonic TLD algorithm was evaluated during development (Rocky Flats 1983). The results of the evaluation state: "A large number of (relative) biases in the range -0.100 to +0.100 and the paucity of the (relative) biases outside the ±0.200 range indicate a robust, effective algorithm." Based on this evaluation, the maximum relative bias of 0.206 was selected as the 95% confidence interval and a standard deviation of 0.206 ÷ 1.96 = 10.5% is determined.

The Stanford (1990) algorithm upgrade was tested during DOELAP performance testing. The unmoderated neutron dose category resulted in a standard deviation of 0.072. This value was selected to determine the upper 95% confidence dose during this period.

The 1993 algorithm upgrade (RFETS 2001) was tested during 1999 DOELAP performance testing. The unmoderated neutron dose category resulted in a standard deviation of 0.065. A mixture of neutrons with both low- and high-energy photons was tested. The worst-case standard deviation was 0.090. This value was selected to determine the upper 95% confidence dose for all dates after the implementation of this algorithm.

Table 6-20 lists the uncertainties for these dosimetry systems.

## 6.8 ELECTRON DOSE

Beta radiation fields are usually the dominant external radiation hazard in facilities requiring contact work with unshielded forms of uranium. This was the case at RFP for enriched and depleted uranium

Table 6-20. Uncertainty for TLD neutron dose measurements at RFP.

| Dose (mrem) | Upper 95% Confidence Dose (mrem) | | | |
|---|---|---|---|---|
| | Harshaw TLD dosimeter | Panasonic dosimeter | DOELAP accredited Panasonic dosimeter | |
| | 1971–1982 | 1983–1990 | 1991–1992 | 1993–present |
| 1 | 1.25 | 1.25 | 1.21 | 1.23 |
| 2 | 2.43 | 2.44 | 2.32 | 2.38 |
| 5 | 6.01[a] | 6.04[b] | 5.72[c] | 5.89[d] |
| 10 | 12 | 12 | 11 | 12 |
| 20 | 24 | 24 | 23 | 24 |
| 50 | 60 | 60 | 57 | 59 |
| 100 | 120 | 121 | 114 | 118 |
| 200 | 240 | 241 | 228 | 235 |
| 500 | 600 | 603 | 571 | 588 |
| 1,000 | 1,200 | 1,206 | 1,141 | 1,176 |
| 2,000 | 2,400 | 2,412 | 2,282 | 2,353 |

a. 1.20 multiplier for 5 mrem or greater.
b. 1.21 multiplier for 5 mrem or greater.
c. 1.14 multiplier for 5 mrem or greater.
d. 1.18 multiplier for 5 mrem or greater.

work. Figure 6-6 shows estimated beta dose rates from a semi-infinite slab of uranium metal at various enrichment levels. For uranium enrichments up to 30%, the beta radiation field is dominated by contributions from $^{238}U$ decay products. Thus, for depleted uranium, one is dealing essentially with 2.29-MeV (Emax) beta particles from $^{234m}Pa$, the most energetic contributor to the beta exposure.

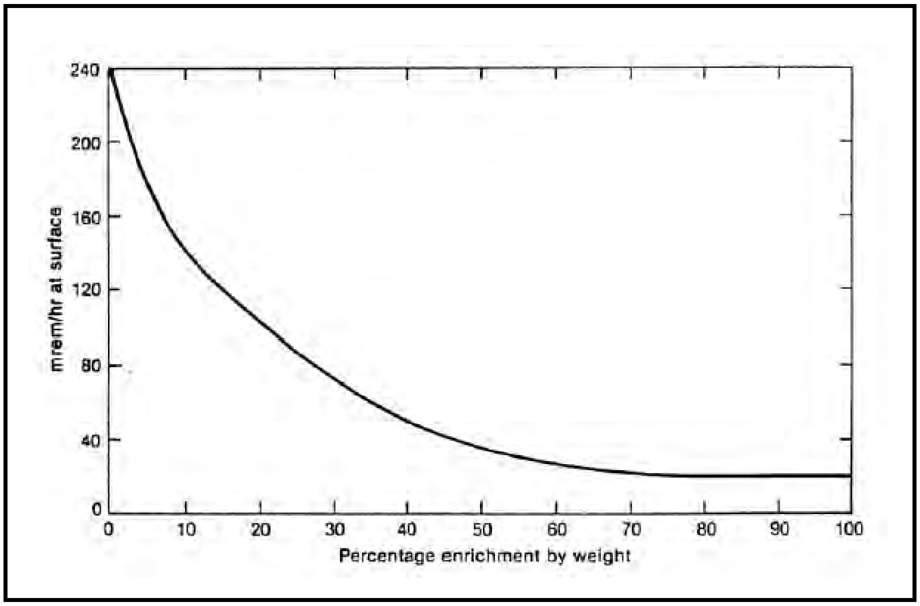


Figure 6-6. Estimated beta dose rate from uranium metal at various enrichment levels (DOE 2001).

Processes that separate and sometimes concentrate beta-emitting uranium daughters are not uncommon in DOE uranium facilities. The uranium foundry operations at RFP produced "skull" that resulted in high beta dose rates. Surface beta dose rates on the order of 1 to 20 rad per hour have been observed at some DOE facilities. Exposure control is complicated by the fact that considerable contact work takes place in facilities that process uranium metal. At RFP, large foundry ingots were generally handled by lifting devices, but machined uranium parts were handled with gloved hands. RFP did have problems with elevated beta dose rates from contamination on leather gloves worn during foundry operations.

### 6.8.1 Energy Groups

#### 6.8.1.1 Exposure Spectra

The beta spectrum from uranium is highly dependent on the quantity of daughter products in the uranium, which is, in turn, dependent on the enrichment level of the uranium. Depleted uranium daughter products grow into secular equilibrium relatively quickly (~30 days) and can be conservatively assumed to be present at these levels. Figure 6-7 shows the relative dose rate with respect to energy. Depleted uranium would be similar to the natural uranium used for this experiment.

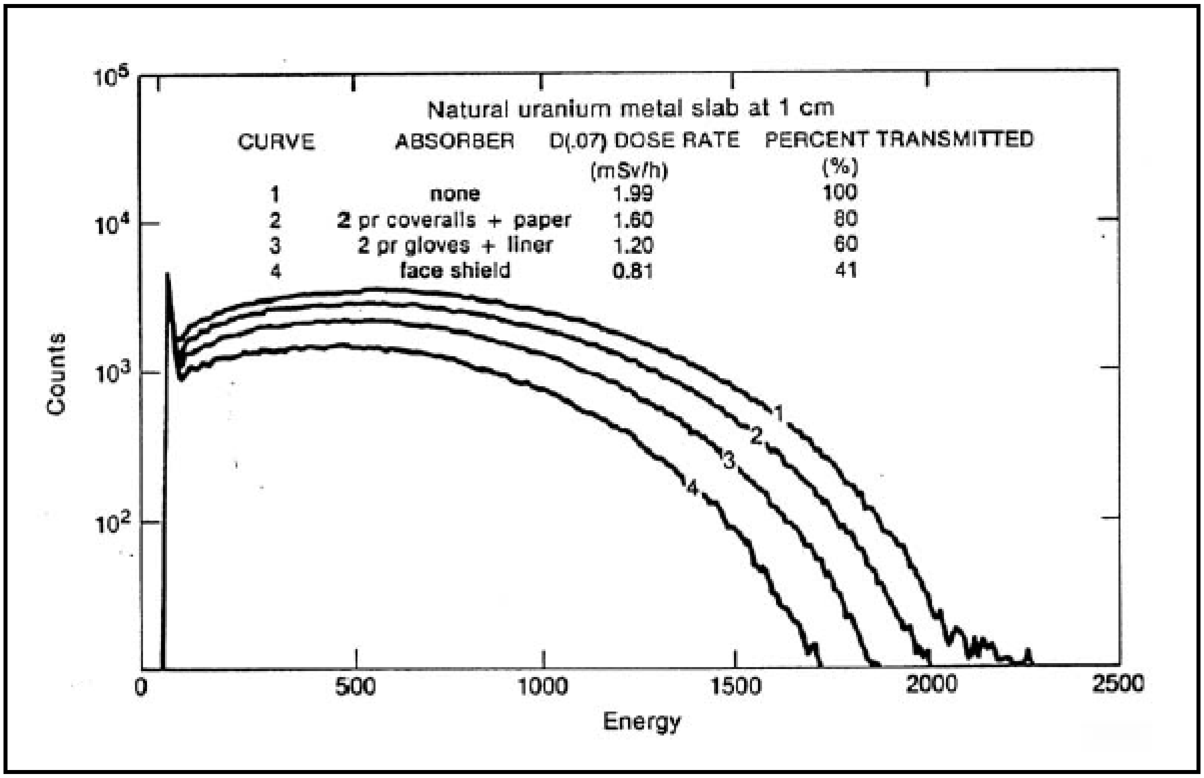


Figure 6-7. Shallow dose rate from natural uranium slab (DOE 2001).

#### 6.8.1.2 Reported Dose to Energy Groups

NIOSH (2002) indicates that because extensive research in the areas of dosimeter wear location, electron energy spectra, and film response is required to convert dose readings to shallow dose properly, "… the exposure is assumed to be equal to the shallow dose (Hp(0.07)), recognizing that this is an overestimation of the true shallow dose. Until further research is conducted, this assumption is considered reasonable." This assumption is claimant-favorable for RFP.

### 6.8.2 Calibration Factor

#### 6.8.2.1 Reported-Dose-to-Organ-Dose Conversion Factor Units

Film dosimeters at RFP appear to have been calibrated in contact with uranium slabs. Although RFP documents in the 1960s report the dose rate from a uranium slab as 240 mR, mrad, and mrem per hour at the surface, it is assumed these were inaccurate references to a dose rate in mrad/hr. The radiation weighting factor for electrons at all energies is 1 (ICRP 1990), thus, reported beta doses are equivalent to rem. This value is used directly for the Hp(0.07) dose.

### 6.8.3 Missed Dose

#### 6.8.3.1 Limit of Detection

Beta dosimetry at RFP used open-window film calibrated to a uranium slab. It is believed that the beta minimum detectable dose would have been similar to that for photons. Thus 40 mrem was selected as the minimum detectable beta dose appropriate for the film dosimetry period.

Harshaw TLDs were used for beta detection starting in 1969. It is believed that the minimum detectable dose would have been similar to that for photons. Wilson, Fix, Baumgartner, and Nichols (1990) determined that the Hanford TLD system had a 20-mR minimum detectable dose. RFP TLD measurements were similar. A minimum detectable dose of 20 mrem beta (shallow) is appropriate for RFP during this period.

The algorithm initially developed for Panasonic TLD system implementation in 1983 contains a constraint to ensure the shallow dose equivalent does not fall below 0.90 times the deep dose from photons. Thus, the shallow minimum detectable dose is 0.90 times that determined for deep dose photons (20 mrem) for this system. The minimum detectable shallow dose for this period was determined to be 20 x 0.90 = 18 mrem (shallow), as indicated in Table 6-21.

Table 6-21. Beta limit of detection for RFP dosimeters.

| Year | LOD | Year | LOD | Year | LOD | Year | LOD | Year | LOD | Year | LOD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1951 | 40mrem | 1961 | 40mrem | 1971 | 20mrem | 1981 | 20mrem | 1991 | 80mrem | 2001 | 15mrem |
| 1952 | 40mrem | 1962 | 40mrem | 1972 | 20mrem | 1982 | 20mrem | 1992 | 80mrem | 2002 | 15mrem |
| 1953 | 40mrem | 1963 | 40mrem | 1973 | 20mrem | 1983 | 18 mrem | 1993 | 15mrem | 2003 | 15mrem |
| 1954 | 40mrem | 1964 | 40mrem | 1974 | 20mrem | 1984 | 18 mrem | 1994 | 15mrem | | |
| 1955 | 40mrem | 1965 | 40mrem | 1975 | 20mrem | 1985 | 18 mrem | 1995 | 15mrem | | |
| 1956 | 40mrem | 1966 | 40mrem | 1976 | 20mrem | 1986 | 18 mrem | 1996 | 15mrem | | |
| 1957 | 40mrem | 1967 | 40mrem | 1977 | 20mrem | 1987 | 18 mrem | 1997 | 15mrem | | |
| 1958 | 40mrem | 1968 | 40mrem | 1978 | 20mrem | 1988 | 18 mrem | 1998 | 15mrem | | |
| 1959 | 40mrem | 1969 | 20mrem | 1979 | 20mrem | 1989 | 18 mrem | 1999 | 15mrem | | |
| 1960 | 40mrem | 1970 | 20mrem | 1980 | 20mrem | 1990 | 80mrem | 2000 | 15mrem | | |

In 1990, the algorithm for the Panasonic Dosimetry system was improved. The documentation for this algorithm cites "… a minimum reportable beta dose of 25% of the total shallow dose (photon plus beta) or approximately 80 mrem for DU …" (Stanford 1990). It also states that, "… beta doses delivered to radiation workers in the plant environments will likely be overestimated." A claimant-favorable decision to use the maximum 80-mrem (shallow) minimum detectable dose was made. This is a significant increase in the minimum detectable beta dose. Review of the algorithm documentation (Stanford 1990) indicates that a constraint was incorporated into the algorithm, to report beta dose only if the net open-window (element 1) value was over 25 mR ($^{137}$Cs exposure response). This net element reading is determined by subtracting the expected photon response and the expected neutron response for that element, as determined by the relationship with other dosimeter elements in the badge. These calculations would result in significant variability in the net element 1 response and it is assumed that the constraint was included to reduce the variability in the resulting beta dose estimate to an acceptable level. The result is a significantly higher minimum detectable dose, however. This constraint appears to have been removed in the next algorithm update.

In 1993, an algorithm update was incorporated in the Panasonic dosimetry system (RFETS 2001) to include element-reading uncertainty controls to reduce large dose fluctuations at low dose. This update has passed DOELAP performance testing and results in a stated minimum response for routine RFP beta fields of approximately 15 mrem (shallow) (RFETS 1993). This value has been incorporated in Table 6-21.

#### 6.8.3.2 Number of Zero Readings

The number of zero readings is determined as discussed in Section 6.5.5 of this document.

#### 6.8.3.3 Unmonitored Energy Range

Film and TLD are believed to respond to beta energies of dosimetric importance. Thus, there is no unmonitored energy range for which a correction factor is appropriate.

### 6.8.4 <u>Geometry</u>

#### 6.8.4.1 Angular Dependence

The sensitive dosimeter elements are mounted in a dosimetry badge. The assembled badge displays severe angular dependence to beta exposure. Fortunately, in most cases a worker's normal movements will tend to average out some of this dependence (DOE 2001).

For beta fields, the element responses of the Panasonic dosimeter generally decreased as the angle between the incident radiation and the plane perpendicular to the TLD increased from 0 degrees. For angles of incidence from -30° to +30°, the ratio of reported dose to delivered dose ranged from 0.36 to 0.59 for beta particles. Based on DOE (2001), no angular correction factor is proposed.

#### 6.8.4.2 Exposure Geometry

Exposure geometry is not a significant issue with skin exposure. Nonpenetrating radiations do not significantly expose tissue in other than a straight-on exposure.

### 6.8.5 <u>Uncertainty</u>

The method in NIOSH (2002) was used to determine the uncertainty (upper 95% confidence dose) for film readings. This method is based on a statistical discussion in *Film Badge Dosimetry in Atmospheric Nuclear Tests* (NRC 1989).

#### 6.8.5.1 Film

RFP used film to measure beta dose between 1951 and 1968. This is the same film described in Sections 6.3.1 and 6.5.1 of this TBD. A similar uncertainty estimation methodology was used; developing a spreadsheet matched the illustration given in NRC (1989). Review of RFP density-to-beta dose conversion charts from 1966 to 1968 determined film sensitivity. A saturation density for 502 film was assumed. Using this approach, the upper 95% confidence doses for various beta doses were calculated. A limit of 120% was applied as discussed in Section 6.6.5.1. This limit effects the upper 95% confidence dose at 77 mrad and above. Table 6-22 presents these upper 95% confidence doses.

#### 6.8.5.2 Thermoluminescent Dosimeter

TLDs provided improved beta dosimetry. Harshaw TLD chips were used to measure beta dose at RFP from 1969 through 1982. The uncertainty associated with this type of dosimeter was estimated for the early years of use, and then measured when DOELAP performance testing was initiated.

Table 6-22. Uncertainty for beta film readings at RFP.

| Dose (mrad) | Upper 95% confidence dose (mrad) |
|---|---|
| 1 | 17 |
| 2 | 18 |
| 5 | 21 |
| 10 | 26 |
| 20 | 36 |
| 50 | 66 |
| 100 | 120 |
| 200 | 240 |
| 500 | 600 |
| 1,000 | 1,200 |
| 2,000 | 2,400 |

##### 6.8.5.2.1 Loose Chip Thermoluminescent Dosimeters

Harshaw TLD chips were used to measure beta dose in parallel with photon dose. As with the photon TLD uncertainty, the chip sorting procedure was used to estimate the standard error associated with the beta TLD measurements. Using the Simplified Dosimetry Uncertainty calculation recommended by NIOSH (2002), and assuming the critical level (Lc) is the beta LOD estimated in Section 6.8.3.1 of this TBD, Table 6-23 lists the upper 95% confidence dose.

Table 6-23. Uncertainty for loose chip TLD beta dose at RFP.

| Dose (mrad) | Upper 95% confidence dose (mrad) 1969–1982 |
|---|---|
| 1 | 21 |
| 2 | 22 |
| 5 | 25 |
| 10 | 30 |
| 20 | 40 |
| 50 | 72 |
| 100 | 126 |
| 200 | 239 |
| 500 | 585 |
| 1,000 | 1,166 |
| 2,000 | 2,330 |

##### 6.8.5.2.2 Panasonic TLD Dosimeter

Table 6-24 lists the uncertainty associated with DOELAP-accredited Panasonic dosimeter dose readings. These values were calculated using the TLD uncertainty methodology described in Section 2.1.1.3.2 of NIOSH (2002). This method recognizes that the elements of the uncertainty are quantified in the dosimetry program documentation available for a DOELAP-accredited program. The standard deviation for null readings is from a study performed at RFP (RFETS 2001), and the relative standard deviation at high readings is the standard deviation of DOELAP performance test results (RFETS 2001; Stanford 1990). The reasonable worst-case value was selected to provide a claimant-favorable result.

Table 6-24. Uncertainty for DOELAP-accredited TLD beta dose at RFP.

| Dose (mrem) | Upper 95% confidence dose (mrem) | | |
|---|---|---|---|
| | Panasonic dosimeter | DOELAP-accredited Panasonic dosimeter | |
| | 1983–1989 | 1990–1998 | 1999–present |
| 1 | 1.19 | 1.19 | 1.19 |
| 2 | 2.29 | 2.29 | 2.28 |
| 5 | 6[a] | 6[b] | 6[c] |
| 10 | 11 | 11 | 11 |
| 20 | 22 | 22 | 22 |
| 50 | 56 | 56 | 56 |
| 100 | 112 | 112 | 112 |
| 200 | 224 | 224 | 223 |
| 500 | 561 | 561 | 558 |
| 1,000 | 1,122 | 1,122 | 1,116 |
| 2,000 | 2,243 | 2,243 | 2,231 |

a. 1.12 multiplier for any dose greater than 2 mrem.
b. 1.12 multiplier for any dose greater than 2 mrem.
c. 1.12 multiplier for any dose greater than 2 mrem.

### 6.8.6 Skin Contamination

Skin contamination incidents are routinely reported at RFP on a Contamination Report. Information generally indicates the location of the skin contamination and the initial count. The area of the contamination might not be available and should be estimated in the manner described in the Section 2.3.3 of NIOSH (2002).

Depleted uranium is the RFP production material that would result in the greatest skin dose from surface contamination. The daughter products potentially contained in the material would result in a beta exposure to the skin.

The contamination report will not indicate the length of time that the contamination was present on the skin. A claimant-favorable assumption is that the contamination was present for 4 hours. This is a reasonable worst-case assumption that, for example, the individual received contamination at the beginning of the shift, did not take a midmorning break, and discovered the contamination upon monitoring when leaving the production area at lunch. Once the contamination is discovered, initial decontamination would be performed in the production building, resulting in removal of most of the contamination. Prior to 1970, self-monitoring equipment was not readily available, and a claimant-favorable assumption of 8 hours is appropriate.

Contamination values in the contamination report are typically in counts per minute (cpm or c/m). RFP typically used a G-M "pancake" probe to perform uranium surveys. This instrument typically has a 33.3% ± 1% (cpm/dpm) efficiency for depleted uranium.

Depleted uranium consists of 99.8% by weight $^{238}U$. Table 6-25 lists the other isotopes.

It is client-favorable to assume that the depleted uranium is 1 year old. This allows for ingrowth of daughter products to achieve secular equilibrium. A decay calculation using MicroShield 5.03 (Grove Engineering 1998) was performed. Table 6-26 lists the full suite of decay isotopes.

Dose calculation might utilize software such as VARSKIN (recommended in NIOSH 2002) or other appropriate means.

Table 6-25. Depleted uranium at RFP (DOE 1980).

| Isotope | Mixture | | |
|---|---|---|---|
| | Ci/g(mix) | | |
| | Alpha | Beta | nCi/g(mix) |
| Th 231 | | 4.90E-09 | 4.9 |
| Th 234 | | 3.40E-07 | 340 |
| U 234 | 3.70E-08 | | 37 |
| U 235 | 4.90E-09 | | 4.9 |
| U 238 | 3.40E-07 | | 340 |
| Total | 3.82E-07 | 3.45E-07 | 726.8 |

## 6.9 UNMONITORED INDIVIDUALS

### 6.9.1 In Production Areas

In the early 1950s only groups expected to receive doses greater than 10% of the Radiation Protection Guideline (called the "threshold dose" at RFP) would receive dosimeters. During this period the Radiation Protection Guideline was 3 rem per quarter. Thus, the missed dose estimate for unbadged individuals working in radiologically controlled areas would be one-half of 10% of 3 rem per quarter, or 600 mrem per year. A lognormal distribution should be assumed, with the upper 95% dose estimate for these individuals 10% of the Radiation Protection Guideline or 1.2 rem per year (NIOSH 2002).

Table 6-26. One-year-old depleted uranium.

| | per gram of DU | |
|---|---|---|
| Nuclide | curies | becquerels |
| Ac-227 | 1.63E-15 | 6.04E-05 |
| * Bi-210 | 6.69E-19 | 2.47E-08 |
| Bi-211 | 1.28E-15 | 4.75E-05 |
| * Bi-214 | 7.00E-17 | 2.59E-06 |
| Fr-223 | 2.25E-17 | 8.34E-07 |
| Pa-231 | 1.04E-13 | 3.84E-03 |
| * Pa-234 | 5.44E-10 | 2.01E+01 |
| Pa-234m | 3.40E-07 | 1.26E+04 |
| * Pb-210 | 7.10E-19 | 2.63E-08 |
| Pb-211 | 1.28E-15 | 4.75E-05 |
| * Pb-214 | 7.00E-17 | 2.59E-06 |
| Po-210 | 2.16E-19 | 7.99E-09 |
| Po-211 | 3.50E-18 | 1.30E-07 |
| Po-214 | 6.99E-17 | 2.59E-06 |
| Po-215 | 1.28E-15 | 4.75E-05 |
| Po-218 | 7.00E-17 | 2.59E-06 |
| Ra-223 | 1.28E-15 | 4.75E-05 |
| Ra-226 | 7.21E-17 | 2.67E-06 |
| Rn-219 | 1.28E-15 | 4.75E-05 |
| Rn-222 | 7.00E-17 | 2.59E-06 |
| Th-227 | 1.39E-15 | 5.15E-05 |
| Th-230 | 3.33E-13 | 1.23E-02 |
| * Th-231 | 4.90E-09 | 1.81E+02 |
| * Th-234 | 3.40E-07 | 1.26E+04 |
| Tl-207 | 1.28E-15 | 4.74E-05 |
| U-234 | 3.70E-08 | 1.37E+03 |
| U-235 | 4.90E-09 | 1.81E+02 |
| U-238 | 3.40E-07 | 1.26E+04 |

*Indicates isotope is included in VARSKIN Mod 2.

### 6.9.2 Outside Production Areas

After about 1990, many individuals at RFP who did not work in radiological areas were not badged. The site Radiological Protection organization determined that these individuals were unlikely to exceed 100-mrem occupational exposure in a calendar year.

For individuals working outside the radiologically controlled areas, environmental exposure would be a better estimate of their exposure (see Section 4.0, Environmental Dose, of this Site Profile).

## 6.10 EXTREMITY DOSIMETRY

Extremity dosimeters were used at RFP. Between 1951 and 1970, the site used an Oak Ridge-designed film dosimeter similar to that used for the body badge. The extremity dosimeter was worn on the wrist. It was modified with a brass filter similar to the body badge. Little performance information is available on this badge, but it probably performed similarly to the body badge of that period.

In 1971, RFP switched to an in-house-designed wrist dosimeter containing four Harshaw chips. This badge contained two TLD-600 and two TLD-700 chips, enabling neutron and photon dose determination. Uranium workers received an open-window (thin Mylar) version.

In 1991, RFP switched to a Panasonic model UD-813AS11 (custom design) dosimeter in a plastic wrist holder. This dosimeter contains two $^{6}$Li-borate elements and two $^{7}$Li elements, enabling neutron dose measurement. Two of the elements are under a thin open window for beta and low-energy photon dose measurements. The dosimeter, which has undergone DOELAP performance testing, is documented in RFETS (2000).

RFP never used finger rings on a routine basis, but estimated the hand dose using the forearm dose measured by the wrist badge and the application of a hand-to-wrist ratio.

Many RFP workers did not receive extremity (wrist) dosimeters. In such cases, the wrist (forearm) dose was assigned as the measured skin (shallow) dose, and the hand dose was assigned the same value. If an extremity dosimeter was worn and the value was less than the skin dose measured by the body badge, the assumption was made that the extremity dosimeter was not worn and the skin dose was assigned as the wrist dose. If the extremity dosimeter did measure a dose greater than the body badge, the extremity measurement was assigned to the wrist and a hand-to-wrist ratio was used to estimate the dose to the hand. Several studies over the years determined the hand-to-wrist ratio; different values were used for different buildings (major job categories). Details on the ratios used are not available.

Additional information on these dosimeters will be required for dose reconstruction for shallow dose to the extremity, if necessary.

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## GLOSSARY

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

**beta dose**
A designation (i.e., beta) on some external dose records referring to the dose from less-energetic beta, X-ray, and/or gamma radiation (see *open window*, or *shallow dose*).

**beta radiation**
Radiation consisting of charged particles of very small mass (i.e., the electron) emitted spontaneously from the nuclei of certain radioactive elements. Most (if not all) of the direct fission products emit beta radiation. Physically, the beta particle is identical to an electron moving at high velocity.

**deep absorbed dose**
The absorbed dose at the depth of 1.0 cm in a material of specified geometry and composition.

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

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

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

**dosimetry**
The science of assessing absorbed dose, dose equivalent, effective dose equivalent, etc., from external or internal sources of radiation.

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

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

**exposure**
As used in the technical sense, exposure refers to a measure expressed in roentgens (R) of the ionization produced by photons (i.e., gamma and X-rays) in air.

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

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

**film**
In general, a "film packet" that contains one or more pieces of film in a light-tight wrapping. When developed, the film has an image caused by radiation that can be measured using an optical densitometer.

**film density**
See optical density.

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

**fission**
The splitting of a heavy atomic nucleus, accompanied by the release of energy.

**fissionable**
Material capable of undergoing fission.

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

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

**isotope**
Elements having the same atomic number but different atomic weights; identical chemically but having different physical and nuclear properties.

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

**neutron film dosimeter**
A film dosimeter that contains a Neutron Track Emulsion, type A, film packet.

**Nuclear Track Emulsion, Type A (NTA)**
A film that is sensitive to fast neutrons. The developed image has tracks caused by neutrons that can be seen by using an appropriate imaging capability such as oil immersion and a 1000X-power microscope or a projection capability.

**open window (OW)**
Designation on film dosimeter reports that implies the use of little (i.e., only security credential) shielding. Commonly used to label the film response corresponding to the open-window area.

**operating area**
Designation of major onsite operational work areas.

**optical density**
The quantitative measurement of photographic blackening; density defined as $D = Log_{10} (I_o/I)$.

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

**photon**
A unit or "particle" of electromagnetic radiation consisting of X- or gamma rays.

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

**pit**
Nuclear weapon core, made of fissionable material.

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

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

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

**radionuclide**
A radioactive isotope of an element, distinguished by atomic number, atomic weight, and energy state.

**rem**
A unit of dose equivalent equal to the product of the number of rad absorbed and the quality factor.

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

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

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

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

**silver shield(s)**
The 1-mm thick shields covering the film packet in early personnel film dosimeters.

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

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

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

**whole-body dose**
Commonly defined as the absorbed dose at a tissue depth of 1.0 cm (1000 $mg/cm^2$); however, also used to refer to the recorded dose.

**X-ray**
Ionizing electromagnetic radiation of external nuclear origin.

# ATTACHMENT A
# EXAMPLE EXTERNAL DOSIMETRY RECORD DOCUMENTS

## Occupational Dose Report

**Name:** [redacted] **Employee #:** [redacted]

**SSN:** [redacted] **Status:** Terminated

| Year | Deep Dose | Skin Dose | Extremity | Lens of Eye |
|---|---|---|---|---|
| 1951-1979 * | 1110 | 1045 | 15 | |
| 1980 | 23 | 23 | 23 | |
| 1981 | 0 | 0 | 0 | |
| 1982 | 2 | 2 | 2 | |
| 1983 | 24 | 39 | 39 | |
| 1984 | 0 | 0 | 0 | |
| 1985 | 0 | 0 | 0 | |
| 1986 | 53 | 69 | 69 | |
| 1987 | 0 | 0 | 0 | |
| 1988 | 0 | 0 | 0 | |
| Pre-1989 Dose | 1212 | 1178 | 146 | |
| 1989 | 21 | 25 | 25 | |
| 1990 | 0 | 0 | 0 | |
| 1991 | | | | |
| 1992 | | | | |
| 1993 | | | | |
| 1989-1993 Dose | 21 | 25 | 25 | |
| 1994 | | | | |
| 1995 | | | | |
| 1996 | | | | |
| 1997 | | | | |
| 1998 | | | | |
| 1999 | | | | |
| 2000 | | | | |
| 2001 | | | | |
| 2002 | | | | |
| 2003 | | | | |
| 2004 | | | | |
| 2005 | | | | |
| RFETS Total | 1233 | 1203 | 171 | |

**RADIOLOGICAL RECORDS**

Reviewed by: [redacted]

Date Reviewed: 6-4-02

**INTERNAL DOSIMETRY**

Reviewed by:

Date Reviewed:

**Offsite Dose Summary**

Total TEDE

| Site | TEDE |
|---|---|

*** details for this time period on page 2 (if available)**

dose by year.xls Page 1 of 2 krs

Figure A-1. Occupational Dose Report reviewed 6-4-02, page 1.

## Occupational Dose Report

**Name:** ______________________ **Employee #:** ______________

**SSN:** ______________

| Year | Deep Dose | Skin Dose | Extremity | Lens of Eye |
|---|---|---|---|---|
| 1951 | | | | [redacted] |
| 1952 | | | | |
| 1953 | 30 | | | |
| 1954 | | | | |
| 1955 | | | | |
| 1956 | | | | |
| 1957 | | | | |
| 1958 | | | | |
| 1959 | | | | |
| 1960 | | | | |
| 1961 | | | | |
| 1962 | | | | |
| 1963 | | | | |
| 1964 | 84 | 84 | 0 | |
| 1965 | 50 | 50 | | |
| 1966 | 232 | 234 | | |
| 1967 | 0 | 0 | 0 | |
| 1968 | 47 | 55 | | |
| 1969 | 3 | 3 | | |
| 1970 | 47 | 0 | 0 | |
| 1971 | 98 | 98 | 0 | |
| 1972 | 75 | 75 | 0 | |
| 1973 | 44 | 46 | 0 | |
| 1974 | 209 | 209 | 0 | |
| 1975 | 165 | 165 | 0 | |
| 1976 | 11 | 11 | 0 | |
| 1977 | 0 | 0 | 0 | |
| 1978 | 0 | 0 | 0 | |
| 1979 | 15 | 15 | 15 | |
| RFETS Total | 1110 | 1045 | 15 | |

**RADIOLOGICAL RECORDS**

Reviewed by: ______________

Date Reviewed: 6-4-02

**INTERNAL DOSIMETRY**

Reviewed by: ______________

Date Reviewed: ______________

**Offsite Dose Summary (continued)**

| Site | TEDE |
|---|---|
| | |

dose by year.xls Page 2 of 2 krs

Figure A-2. Occupational Dose Report reviewed 6-4-02, page 2.

Submitted ( KSAVITZ
Sorted by: Plant ID

Dosimetry His ry by Individual

Date: 10-MAR-2003 ..00
Page: 1

Criteria Selected

Plant ID: [redacted]

Plant ID: [redacted] Name: [redacted] [redacted] [redacted]

| Begin Date | End Date | Dosimeter Category | Process ID | Dosimeter Type | Wear Location | Record Type | DDE* | SDE-SK | LDE | SDE-EX | Neut. | PSE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 07-MAR-1955 00:00 | 31-DEC-1955 00:00 | CALCULATED | | | | OFFICIAL | 0 | 0 | | | 0 | |
| 01-JAN-1956 00:00 | 31-DEC-1956 00:00 | CALCULATED | | | | OFFICIAL | 18 | 35 | | | 0 | |
| 01-JAN-1957 00:00 | 31-DEC-1957 00:00 | CALCULATED | | | | OFFICIAL | 166 | 307 | | | 0 | |
| 01-JAN-1958 00:00 | 31-DEC-1958 00:00 | CALCULATED | | | | OFFICIAL | 1041 | 1813 | | | 0 | |
| 01-JAN-1959 00:00 | 31-DEC-1959 00:00 | CALCULATED | | | | OFFICIAL | 642 | 912 | | | 0 | |
| 01-JAN-1960 00:00 | 31-DEC-1960 00:00 | CALCULATED | | | | OFFICIAL | 610 | 760 | | 157 | 0 | |
| 01-JAN-1961 00:00 | 31-DEC-1961 00:00 | CALCULATED | | | | OFFICIAL | 1330 | 1619 | | | 0 | |
| 01-JAN-1962 00:00 | 31-DEC-1962 00:00 | CALCULATED | | | | OFFICIAL | 1509 | 1610 | | | 0 | |
| 01-JAN-1963 00:00 | 31-DEC-1963 00:00 | CALCULATED | | | | OFFICIAL | 1671 | 1941 | | | 0 | |
| 01-JAN-1964 00:00 | 31-DEC-1964 00:00 | CALCULATED | | | | OFFICIAL | 1490 | 1689 | | | 0 | |
| 01-JAN-1965 00:00 | 31-DEC-1965 00:00 | CALCULATED | | | | OFFICIAL | 1300 | 1390 | | 321 | 0 | |
| 01-JAN-1966 00:00 | 31-DEC-1966 00:00 | CALCULATED | | | | OFFICIAL | 2881 | 3160 | | 3385 | 0 | |
| 01-JAN-1967 00:00 | 31-DEC-1967 00:00 | CALCULATED | | | | OFFICIAL | 1558 | 2069 | | 3922 | 0 | |
| 01-JAN-1968 00:00 | 31-DEC-1968 00:00 | CALCULATED | | | | OFFICIAL | 1715 | 2392 | | 4664 | 0 | |
| 01-JAN-1969 00:00 | 31-DEC-1969 00:00 | CALCULATED | | | | OFFICIAL | 1262 | 1757 | | 2935 | 0 | |
| 01-JAN-1970 00:00 | 31-DEC-1970 00:00 | CALCULATED | | | | OFFICIAL | 1229 | 1263 | | 1659 | 0 | |
| 01-JAN-1971 00:00 | 31-DEC-1971 00:00 | CALCULATED | | | | OFFICIAL | 456 | 475 | | 1092 | 0 | |
| 01-JAN-1972 00:00 | 31-DEC-1972 00:00 | CALCULATED | | | | OFFICIAL | 559 | 603 | | 3843 | 0 | |

All dose equivalents are expressed in millirem.
* - indicates deep dose equivalent only. Neutron dose is not added.

Figure A-3. Dosimetry History by Individual dated 3-10-03, page 1.

Submitted by: KSAVITZ
Sorted by: Plant ID

Dosimetry History by Individual

Date: 10-MAR-2003 [illegible]:00
Page: 2

Plant ID: [redacted] Name: [redacted] [redacted] [redacted]

| Begin Date | End Date | Dosimeter Category | Process ID | Dosimeter Type | Wear Location | Record Type | DDE* | SDE-SK | LDE | SDE-EX | Neut. | PSE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-JAN-1973 00:00 | 31-DEC-1973 00:00 | CALCULATED | | | | OFFICIAL | 987 | 1093 | | 3838 | 0 | |
| 01-JAN-1974 00:00 | 31-DEC-1974 00:00 | CALCULATED | | | | OFFICIAL | 1131 | 1253 | | 3250 | 0 | |
| 01-JAN-1975 00:00 | 31-DEC-1975 00:00 | CALCULATED | | | | OFFICIAL | 620 | 688 | | 1483 | 0 | |
| 01-JAN-1976 00:00 | 31-DEC-1976 00:00 | CALCULATED | | | | OFFICIAL | 179 | 233 | | 656 | 0 | |
| 30-JAN-1977 00:00 | 31-JAN-1977 00:00 | CALCULATED | | | | OFFICIAL | 19 | 28 | | 73 | 4 | |
| 27-FEB-1977 00:00 | 28-FEB-1977 00:00 | CALCULATED | | | | OFFICIAL | 0 | 0 | | 49 | 0 | |
| 30-MAR-1977 00:00 | 31-MAR-1977 00:00 | CALCULATED | | | | OFFICIAL | 7 | 15 | | 69 | 6 | |
| 29-APR-1977 00:00 | 30-APR-1977 00:00 | CALCULATED | | | | OFFICIAL | 14 | 44 | | 72 | 30 | |
| 30-MAY-1977 00:00 | 31-MAY-1977 00:00 | CALCULATED | | | | OFFICIAL | 40 | 48 | | 83 | 8 | |
| 29-JUN-1977 00:00 | 30-JUN-1977 00:00 | CALCULATED | | | | OFFICIAL | 10 | 36 | | 38 | 5 | |
| 30-JUL-1977 00:00 | 31-JUL-1977 00:00 | CALCULATED | | | | OFFICIAL | 3 | 26 | | | 23 | |
| 30-AUG-1977 00:00 | 31-AUG-1977 00:00 | CALCULATED | | | | OFFICIAL | 19 | 43 | | 129 | 20 | |
| 29-SEP-1977 00:00 | 30-SEP-1977 00:00 | CALCULATED | | | | OFFICIAL | 82 | 97 | | | 6 | |
| 30-OCT-1977 00:00 | 31-OCT-1977 00:00 | CALCULATED | | | | OFFICIAL | 21 | 38 | | 84 | 5 | |
| 29-NOV-1977 00:00 | 30-NOV-1977 00:00 | CALCULATED | | | | OFFICIAL | 16 | 17 | | 94 | 1 | |
| 30-DEC-1977 00:00 | 31-DEC-1977 00:00 | CALCULATED | | | | OFFICIAL | 69 | 134 | | 267 | 46 | |
| 30-JAN-1978 00:00 | 31-JAN-1978 00:00 | CALCULATED | | | | OFFICIAL | 81 | 211 | | 239 | 31 | |
| 27-FEB-1978 00:00 | 28-FEB-1978 00:00 | CALCULATED | | | | OFFICIAL | 20 | 23 | | 114 | 3 | |
| 30-MAR-1978 00:00 | 31-MAR-1978 00:00 | CALCULATED | | | | OFFICIAL | 44 | 73 | | 228 | 5 | |
| 29-APR-1978 00:00 | 30-APR-1978 00:00 | CALCULATED | | | | OFFICIAL | 69 | 75 | | 202 | 6 | |
| 30-MAY-1978 00:00 | 31-MAY-1978 00:00 | CALCULATED | | | | OFFICIAL | 43 | 58 | | | 14 | |
| 30-JUL-1978 00:00 | 31-JUL-1978 00:00 | CALCULATED | | | | OFFICIAL | 121 | 139 | | 273 | 11 | |

All dose equivalents are expressed in millirem.
* - indicates deep dose equivalent only. Neutron dose is not added.

Figure A-4. Dosimetry History by Individual dated 3-10-03, page 2.

Submitted ... KSAVITZ
Sorted by: Plant ID

Dosimetry Hi...ry by Individual

Date: 10-MAR-2003 ...:00
Page: 3

Plant ID: [redacted] Name: [redacted] [redacted] [redacted]

| Begin Date | End Date | Dosimeter Category | Process ID | Dosimeter Type | Wear Location | Record Type | DDE* | SDE-SK | LDE | SDE-EX | Neut. | PSE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30-AUG-1978 00:00 | 31-AUG-1978 00:00 | CALCULATED | | | | OFFICIAL | 100 | 189 | | | 15 | |
| 29-SEP-1978 00:00 | 30-SEP-1978 00:00 | CALCULATED | | | | OFFICIAL | 162 | 209 | | 320 | 47 | |
| 30-OCT-1978 00:00 | 31-OCT-1978 00:00 | CALCULATED | | | | OFFICIAL | 127 | 131 | | 159 | 4 | |
| 29-NOV-1978 00:00 | 30-NOV-1978 00:00 | CALCULATED | | | | OFFICIAL | 34 | 38 | | 76 | 4 | |
| 30-DEC-1978 00:00 | 31-DEC-1978 00:00 | CALCULATED | | | | OFFICIAL | 20 | 27 | | 56 | 5 | |
| 30-JAN-1979 00:00 | 31-JAN-1979 00:00 | CALCULATED | | | | OFFICIAL | 42 | 64 | | 80 | 12 | |
| 27-FEB-1979 00:00 | 28-FEB-1979 00:00 | CALCULATED | | | | OFFICIAL | 26 | 39 | | 126 | 6 | |
| 30-MAR-1979 00:00 | 31-MAR-1979 00:00 | CALCULATED | | | | OFFICIAL | 37 | 44 | | 96 | 6 | |
| 29-APR-1979 00:00 | 30-APR-1979 00:00 | CALCULATED | | | | OFFICIAL | 42 | 156 | | 200 | 96 | |
| 30-MAY-1979 00:00 | 31-MAY-1979 00:00 | CALCULATED | | | | OFFICIAL | 28 | 68 | | 71 | 25 | |
| 29-JUN-1979 00:00 | 30-JUN-1979 00:00 | CALCULATED | | | | OFFICIAL | 35 | 52 | | 101 | 16 | |
| 30-JUL-1979 00:00 | 31-JUL-1979 00:00 | CALCULATED | | | | OFFICIAL | 28 | 44 | | 114 | 8 | |
| 30-AUG-1979 00:00 | 31-AUG-1979 00:00 | CALCULATED | | | | OFFICIAL | 61 | 67 | | 310 | 6 | |
| 29-SEP-1979 00:00 | 30-SEP-1979 00:00 | CALCULATED | | | | OFFICIAL | 45 | 65 | | 179 | 20 | |
| 30-OCT-1979 00:00 | 31-OCT-1979 00:00 | CALCULATED | | | | OFFICIAL | 86 | 117 | | 197 | 27 | |
| 29-NOV-1979 00:00 | 30-NOV-1979 00:00 | CALCULATED | | | | OFFICIAL | 49 | 74 | | | 8 | |
| 30-DEC-1979 00:00 | 31-DEC-1979 00:00 | CALCULATED | | | | OFFICIAL | 9 | 18 | | 123 | 9 | |
| 30-JAN-1980 00:00 | 31-JAN-1980 00:00 | CALCULATED | | | | OFFICIAL | 50 | 62 | | 204 | 12 | |
| 28-FEB-1980 00:00 | 29-FEB-1980 00:00 | CALCULATED | | | | OFFICIAL | 43 | 56 | | 293 | 7 | |
| 30-MAR-1980 00:00 | 31-MAR-1980 00:00 | CALCULATED | | | | OFFICIAL | 43 | 51 | | 162 | 6 | |
| 29-APR-1980 00:00 | 30-APR-1980 00:00 | CALCULATED | | | | OFFICIAL | 50 | 54 | | 227 | 4 | |
| 30-MAY-1980 00:00 | 31-MAY-1980 00:00 | CALCULATED | | | | OFFICIAL | 37 | 44 | | 106 | 7 | |

All dose equivalents are expressed in millirem.
* - indicates deep dose equivalent only. Neutron dose is not added.

Figure A-5. Dosimetry History by Individual dated 3-10-03, page 3.

( .LTH PHYSICS EXTERNAL EXPOSURE ACTIVITY RUN Y( ILY DOSES IN MREM (

| YR. | MAN # | NAME | | QUARTERLY ACCUMULATED SKIN | QUARTERLY ACCUMULATED PEN | QUARTERLY ACCUMULATED HAND | CURRENT YEAR ACCUMULATED SKIN | CURRENT YEAR ACCUMULATED PEN | CURRENT YEAR ACCUMULATED HAND |
|---|---|---|---|---|---|---|---|---|---|
| 58 | [redacted] | | 1ST QUARTER | 448 | 263 | 10 | | | |
| | | | 2ND QUARTER | 239 | 150 | 560 | | | |
| | | | 3RD QUARTER | 165 | 115 | 216 | | | |
| | | | 4TH QUARTER | 316 | 229 | 541 | | | |
| | | | | | | | 1168 | 757 | 1327 |
| 57 | | | 1ST QUARTER | 120 | 103 | | | | |
| | | | 2ND QUARTER | 75 | 62 | 94 | | | |
| | | | 3RD QUARTER | 427 | 382 | 145 | | | |
| | | | 4TH QUARTER | 138 | 93 | | | | |
| | | | | | | | 760 | 640 | 239 |
| 56 | | | 1ST QUARTER | 420 | 210 | 290 | | | |
| | | | 2ND QUARTER | 130 | 25 | 185 | | | |
| | | | 3RD QUARTER | 25 | 10 | 155 | | | |
| | | | 4TH QUARTER | 120 | 30 | 215 | | | |
| | | | | | | | 695 | 275 | 845 |
| 55 | | | 1ST QUARTER | 130 | 80 | 195 | | | |
| | | | 2ND QUARTER | 405 | 230 | 320 | | | |
| | | | 3RD QUARTER | 165 | 95 | 170 | | | |
| | | | 4TH QUARTER | 115 | 10 | 385 | | | |
| | | | | | | | 815 | 415 | 1070 |
| 54 | | | 1ST QUARTER | 215 | 45 | | | | |
| | | | 2ND QUARTER | 140 | 0 | | | | |
| | | | 3RD QUARTER | 120 | 0 | | | | |
| | | | 4TH QUARTER | 1015 | 415 | 1110 | | | |
| | | | | | | | 1490 | 460 | 1110 |
| 53 | | | 1ST QUARTER | | | | | | |
| | | | 2ND QUARTER | 210 | 210 | | | | |
| | | | 3RD QUARTER | 110 | 110 | 77 | | | |
| | | | 4TH QUARTER | 305 | 80 | | | | |
| | | | | | | | 625 | 400 | 77 |

A zero indicates a "O" dose received.
A blank indicates that no film badge was worn.

Figure A-6. Health Physics Yearly External Exposure Activity Run, 1953 through 1958.

RUN 73013 HEALTH PHYSICS YEARLY EXTERNAL EXPOSURE RUN PAGE 244

59-63

| YR | WK | DEPT | BLDG | CODE | TYPE | NAME | MAN/# | B/CD | B/BR | B/OW | W/CD | W/BR | W/OW | SKIN | PENET | WRIST |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 62 | 02 | | 71 | 2 | | [redacted] | [redacted] | 100 | 33 | 5 | 125 | 40 | 13 | 138 | 135 | 178 |
| 2 | 02 | | 71 | 3 | | [redacted] | [redacted] | | | | | | | | | |
| 2 | 04 | | 71 | 2 | | [redacted] | [redacted] | 85 | 23 | 2 | 70 | 19 | 21 | 110 | 109 | 110 |
| 2 | 04 | | 71 | 3 | 0 | [redacted] | [redacted] | | | | | | | | | |
| 2 | 06 | | 71 | 2 | | [redacted] | [redacted] | 100 | 52 | 8 | 125 | 62 | 18 | 160 | 155 | 205 |
| 2 | 06 | | 71 | 3 | | [redacted] | [redacted] | | | | | | | | | |
| 2 | 08 | | 71 | 2 | | [redacted] | [redacted] | 115 | 52 | | 190 | 92 | 40 | 167 | 167 | 322 |
| 2 | 08 | | 71 | 3 | | [redacted] | [redacted] | | | | | | | | | |
| 2 | 10 | | 71 | 3 | 0 | [redacted] | [redacted] | | | | | | | | | |
| 2 | 10 | | 71 | 2 | | [redacted] | [redacted] | 25 | 16 | 8 | 80 | 44 | 2 | 49 | 44 | 126 |
| 2 | 12 | | 71 | 3 | | [redacted] | [redacted] | 80 | | | | | | 60 | 80 | |
| 2 | 12 | | 71 | 2 | | [redacted] | [redacted] | 150 | 38 | 10 | 270 | 122 | 22 | 198 | 192 | 415 |
| 2 | 14 | | 71 | 2 | | [redacted] | [redacted] | 130 | 27 | 6 | 260 | 99 | 1 | 163 | 159 | 360 |
| 2 | 14 | | 71 | 3 | | [redacted] | [redacted] | 280 | | | | | | 280 | 280 | |
| 2 | 16 | | 71 | 3 | | [redacted] | [redacted] | 120 | | | | | | 120 | 120 | |
| 2 | 16 | | 71 | 2 | | [redacted] | [redacted] | 45 | 17 | 18 | 60 | 31 | 6 | 80 | 68 | 97 |
| 2 | 18 | | 71 | 3 | | [redacted] | [redacted] | 227 | | | | | | 227 | 227 | |
| 2 | 18 | | 71 | 2 | | [redacted] | [redacted] | 110 | 22 | 2 | 200 | 86 | 13 | 134 | 173 | 299 |
| 2 | 20 | | 71 | 3 | | [redacted] | [redacted] | | | | | | | | | |
| 2 | 20 | | 71 | 2 | | [redacted] | [redacted] | 100 | 44 | 8 | 130 | 65 | 18 | 152 | 147 | 213 |
| 2 | 22 | | 71 | 2 | | [redacted] | [redacted] | 90 | 21 | 26 | 130 | 32 | 30 | 137 | 120 | 192 |
| 2 | 22 | | 71 | 3 | | [redacted] | [redacted] | 75 | | | | | | 75 | 75 | |
| 2 | 24 | | 71 | 2 | | [redacted] | [redacted] | 90 | 25 | 11 | 130 | 44 | 1 | 126 | 119 | 175 |
| 2 | 24 | | 71 | 3 | | [redacted] | [redacted] | 136 | | | | | | 136 | 136 | |
| 2 | 26 | | 71 | 3 | | [redacted] | [redacted] | 730 | | | | | | 730 | 730 | |
| 2 | 26 | | 71 | 2 | | [redacted] | [redacted] | 55 | 13 | 16 | 40 | 21 | 6 | 84 | 74 | 67 |
| 2 | 28 | | 71 | 2 | | [redacted] | [redacted] | 60 | 15 | 14 | 40 | 16 | 2 | 89 | 80 | 58 |
| 2 | 28 | | 71 | 3 | | [redacted] | [redacted] | 230 | | | | | | 230 | 230 | |
| 2 | 30 | | 71 | 3 | | [redacted] | [redacted] | | | | | | | | | |
| 2 | 30 | | 71 | 2 | | [redacted] | [redacted] | 35 | 17 | 4 | 35 | 17 | 4 | 56 | 53 | 56 |
| 2 | 32 | | 71 | 3 | 0 | [redacted] | [redacted] | | | | | | | | | |
| 2 | 32 | | 71 | 2 | | [redacted] | [redacted] | 60 | 26 | | 45 | 26 | | 86 | 86 | 71 |
| 2 | 36 | | 71 | 2 | | [redacted] | [redacted] | 15 | | 1 | 10 | 1 | | 16 | 15 | 11 |
| 2 | 38 | | 71 | 2 | | [redacted] | [redacted] | 40 | 26 | 4 | 55 | 24 | 4 | 70 | 67 | 83 |
| 2 | 38 | | 71 | 3 | | [redacted] | [redacted] | 120 | | | | | | 120 | 120 | |
| 2 | 40 | | 71 | 3 | | [redacted] | [redacted] | 140 | | | | | | 140 | 140 | |
| 2 | 40 | | 71 | 2 | | [redacted] | [redacted] | 65 | 20 | 11 | 65 | 32 | | 96 | 89 | 97 |
| 2 | 42 | | 71 | 2 | | [redacted] | [redacted] | 35 | 20 | 2 | 40 | 22 | | 57 | 56 | 62 |
| 2 | 42 | | 71 | 3 | | [redacted] | [redacted] | 340 | | | | | | 340 | 340 | |
| 2 | 44 | | 71 | 3 | | [redacted] | [redacted] | | | | | | | | | |
| 2 | 44 | | 71 | 2 | | [redacted] | [redacted] | 35 | 20 | 8 | 40 | 21 | 6 | 63 | 58 | 67 |
| 2 | 46 | | 71 | 3 | | [redacted] | [redacted] | | | | | | | | | |
| 2 | 46 | | 71 | 2 | | [redacted] | [redacted] | 25 | 21 | 6 | 40 | 20 | 8 | 52 | 48 | 69 |
| 2 | 48 | | 71 | 3 | | [redacted] | [redacted] | 90 | | | | | | 90 | 90 | |
| 2 | 48 | | 71 | 2 | | [redacted] | [redacted] | 55 | 24 | 6 | 60 | 26 | 4 | 85 | 81 | 90 |
| 2 | 50 | | 71 | 3 | | [redacted] | [redacted] | | | | | | | | | |
| 2 | 50 | | 71 | 2 | | [redacted] | [redacted] | 60 | 15 | 14 | 65 | 25 | 2 | 87 | 80 | 92 |
| 2 | 52 | | 71 | 3 | | [redacted] | [redacted] | 100 | | | | | | 100 | 100 | |
| 2 | 52 | | 71 | 2 | | [redacted] | [redacted] | 60 | 26 | | 65 | 13 | 18 | 86 | 86 | 96 |
| | | | | | | | | | | | | | | 5211 | 5069 | 5609 TOTAL YEAR |

6574

3 = neutron
2 = gamma/xray
1 = gamma/beta

Figure A-7. Health Physics Yearly External Exposure Run, 1962.

RUN 72-303-8 HEALTH PHYSICS EXTERNAL EXPOSURE ACTIVITY RUN YEARLY DATE OF RUN 02-02-65 DOSES IN MREM PAGE 1224

| | | | | QUARTERLY ACCUMULATED | | | QUARTERLY ALLOWED | | | CURRENT YEAR ACCUMULATED | | | CURRENT YEAR ALLOWED | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YR | MAN# - | NAME | | SKIN | PEN | HAND | SKIN | PEN | HAND | SKIN | PEN | HAND | SKIN | PEN | HAND |
| 64 | | | 1ST QUARTER | 190 | 182 | 1021 | 8400 | 1400 | 21000 | | | | | | |
| | | | 2ND QUARTER | 200 | 194 | 1326 | 2400 | 400 | 6000 | | | | | | |
| | | | 3RD QUARTER | 110 | 110 | 599 | 8400 | 1400 | 21000 | | | | | | |
| | | | 4TH QUARTER | 102 | 93 | 243 | 7200 | 1200 | 18000 | | | | | | |
| | | | | | | | | | | 602 | 579 | 3189 | 31200 | 11960 | 78000 |

Figure A-8. Health Physics Yearly External Exposure Activity Run, 1964.

ROCKWELL INTERNATIONAL - ROCKY FLATS PLANT
EXTERNAL DOSIMETRY (TLD) DETAIL
COMPUTERIZED INFORMATION THROUGH 12-31-86
DOSES IN MILLIREM

10:26 THURSDAY, MARCH 12, 1987

EMPNO=[redacted] NAME=[redacted] YEAR=1981

| ACTIVITY DATE | TIME CODE | CURRENT NEUTRON | CURRENT GAMMA | CURRENT PEN | CURRENT SKIN | CURRENT HAND | CURRENT FOREARM | BK 1 | TYPE |
|---|---|---|---|---|---|---|---|---|---|
| 01/31/81 | 2 | 3 | 2 | 5 | 5 | 5 | 5 | 15 | |
| 02/28/81 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | |
| 03/31/81 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | |
| 06/30/81 | 2 | 20 | 9 | 29 | 29 | 29 | 29 | 17 | |
| 07/31/81 | 2 | 2 | 2 | 4 | 9 | 9 | 9 | 16 | |
| 08/31/81 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | |
| 09/30/81 | 2 | 11 | 1 | 12 | 12 | 12 | 12 | 16 | |
| 10/31/81 | 2 | 3 | 1 | 4 | 4 | 4 | 4 | 15 | |
| 11/30/81 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | |
| 12/31/81 | 2 | 5 | 7 | 12 | 26 | 26 | 26 | 17 | |
| YEAR | | 44 | 22 | 66 | 85 | 85 | 85 | | |

EMPNO=[redacted] NAME=[redacted] YEAR=1982

| ACTIVITY DATE | TIME CODE | CURRENT NEUTRON | CURRENT GAMMA | CURRENT PEN | CURRENT SKIN | CURRENT HAND | CURRENT FOREARM | BK 1 | TYPE |
|---|---|---|---|---|---|---|---|---|---|
| 01/31/82 | 2 | 1 | 24 | 25 | 25 | 25 | 25 | 15 | |
| 02/28/82 | 2 | 4 | 26 | 30 | 30 | 30 | 30 | 11 | |
| 03/31/82 | 2 | 3 | 8 | 11 | 11 | 11 | 11 | 17 | |
| 04/30/82 | 2 | 2 | 4 | 6 | 8 | 8 | 8 | 16 | |
| 05/31/82 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | |
| 06/30/82 | 2 | 26 | 6 | 32 | 32 | 32 | 32 | 16 | |
| 07/31/82 | 2 | 0 | 27 | 27 | 27 | 27 | 27 | 19 | |
| 09/30/82 | 2 | 3 | 3 | 6 | 6 | 6 | 6 | 26 | |
| 10/31/82 | 2 | 10 | 7 | 17 | 17 | 17 | 17 | 13 | |
| 12/31/82 | 2 | 45 | 3 | 48 | 55 | 55 | 55 | 32 | |
| YEAR | | 94 | 108 | 202 | 211 | 211 | 211 | | |

EMPNO=[redacted] NAME=[redacted] YEAR=1983

| ACTIVITY DATE | TIME CODE | CURRENT NEUTRON | CURRENT GAMMA | CURRENT PEN | CURRENT SKIN | CURRENT HAND | CURRENT FOREARM | BK 1 | TYPE |
|---|---|---|---|---|---|---|---|---|---|
| 01/31/83 | 2 | 55 | 24 | 79 | 84 | 84 | 84 | 15 | |
| 03/31/83 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 33 | |
| 06/30/83 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 43 | |
| 09/30/83 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 41 | |
| 12/31/83 | 4 | 12 | 13 | 25 | 25 | 25 | 25 | 31 | |
| YEAR | | 67 | 37 | 104 | 109 | 109 | 109 | | |

Figure A-9. External Dosimetry Detail, 1981 through 1983.

HEALTH PHYSICS EXTERNAL RADIATION EXPOSURE REPORT FOR YEAR 67
DOSES IN MREM

| MAN | NAME | | PEN | SKIN | HAND |
|---|---|---|---|---|---|
| [redacted] | [redacted] | 1ST QUARTER | 1439 | 1524 | 1725 |
| | | 2ND QUARTER | 960 | 1007 | 139 |
| | | 3RD QUARTER | 1199 | 1238 | 754 |
| | | 4TH QUARTER | 1214 | 1279 | 0 |
| | | YEAR TOTAL | 4812 | 5048 | 2618 |
| | | YEAR ALLOW | 12000 | 30000 | 75000 |

| | |
|---|---|
| LIFETIME ACC DOW | 26727 |
| LIFETIME ACC OTHER | |
| TOTAL | 26727 |
| LIFETIME ALLOW | 95000 |

Figure A-10. Health Physics External Radiation Exposure Report, 1967.

**Rocky Flats Environmental Technology Site**
**Radiological Health**
**Radiation Dosimetry Detail Report**
**Individual Lifetime Report**

**Doses Reported in millirem** — **Report Date:** 04-Jun-02

**SSN:** — **Badge:** — **Name:**

**Company:** EG&G INC. ROCKY FLATS — **Department:** ORGAN

**Exposure From Other Facilities for 2002**

| Deep | CEDE | TEDE | Organ | CDE |
|---|---|---|---|---|

**Internal Dose From Rocky Flats for 2002**

| Date | Nuclide | CEDE | Total |
|---|---|---|---|

**Total Dose Equivalents for 2002***

| Total Effective Dose Equivalents | TEDE | Organ Dose Equivalent | CDE | TODE |
|---|---|---|---|---|
| | NR | Bone Surfaces | NR | NR |
| | | Lungs | NR | NR |
| | | Liver | NR | NR |
| | | Red Bone Marrow | NR | NR |
| | | Gonads | NR | NR |
| | | Kidney | NR | NR |

* Includes doses from Rocky Flats and Off-site for Year of Report

**Cumulative TEDE Reported Since 1/1/1989****

| External | 21 | Internal | NR | Total | 21 |
|---|---|---|---|---|---|

(Deep dose + CEDEs from reported intakes since 1/1/1989)

**Reported Lifetime Dose****

| External | 1233 | Internal | 2220 | Total | 3453 |
|---|---|---|---|---|---|

(Deep dose + CEDEs from reported intakes)

** Doses include Off-site doses Reported to Rocky Flats

Figure A-11. Radiation Dosimetry Individual Lifetime Report dated 6-4-02.

```
*********************************************************************************
* RADIATION HEALTH RECORDS SYSTEM - View TLD Data          Page 1        V93013*
*********************************************************************************
* H&S ID          SSN                  Last Name                               *
* First Name            Middle       Last Name                From      To     *
*                                                                              *
*                                                                              *
* Activity  Time Curr Curr Curr Curr Curr Curr                                 *
* Date      Code Neut Gamm Pen  Skin Hand Farm Bk-1 Bk-2 Gpen Gskn Beta Type   *
* 16-DEC-91  2    0   16   16   20   20   20   0    0    16   20   0    C      *
* 30-SEP-91  2    0   12   12   12   12   12   0    0    12   12   0    C      *
* 31-MAR-91  2    0   6    6 34 6 44 10 50 6 44 31  0    6    6    0    H      *
* 02-MAR-91  2    0   0    0    8    8    8    0    0    0    8    0    C      *
* 29-DEC-90  3    0   1    1    1    1    1    0    0    1    1    0    C      *
*                     1    1    1    1                                         *
*                                                                              *
*                                                                              *
*                                                                              *
*                                                                              *
*                                                                              *
* Press <PF3> next page       <Ctrl/F4> select (Clear, Print, Exit) screen     *
*********************************************************************************

Count: *5                                                          <Replace>
```

Figure A-12. Radiation Health Records System – TLD Data.

Page 1

Rocky Flats Environmental Technology Site
Radiological Health
Radiation Dosimetry Detail Report
Termination Report

All Doses Reported in millirem (mrem) — Report Date: 17-SEP-96

Company Name: KAISER-HILL ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
Employee Number: [redacted] Name: [redacted] SSN: [redacted] Org Code: 81740

EXTERNAL DOSIMETRY DATA FOR 1996

Dosimeter Results

| | | Effective Dose Equivalents | | | Dose Equivalents | | | |
|---|---|---|---|---|---|---|---|---|
| Begin | Ending | Neutron | Gamma | Deep | Skin | Ext | Hand | LOE |
| --------- | --------- | ------- | ------ | ------ | ------ | ------ | ------ | ------ |
| | | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| Sum | | | | | | | | |

INTERNAL DOSIMETRY DATA
From Intakes Occurring in 1996

| Committed Effective Dose Equivalents | | | Committed Dose Equivalent | | | | | |
|---|---|---|---|---|---|---|---|---|
| Intake Date | Radionuclide | CEDE | Gonads | Breast | Marrow | Lung | Thyroid | Bone |
| ----------- | ----------------- | ------ | ------ | ------ | ------ | ------- | ------- | ------- |

Figure A-13. Radiation Dosimetry Termination Report dated 9-17-96, page 1.

Page 2

Rocky Flats Environmental Technology Site
Radiological Health
Radiation Dosimetry Detail Report
Termination Report

All Doses Reported in millirem (mrem)

Report Date: 17-SEP-96

Company Name: KAISER-HILL ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
Employee Number: [redacted] Name: [redacted] SSN: [redacted] Org Code: 81740

EXPOSURE FROM OTHER FACILITIES FOR 1996

| Name | From | To | DDE | LDE | SDEWB | SDEME | CEDE | CDE | TEDE | TODE | F | R | E | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sum | | | | | | | | | | | | | | |

TOTAL DOSE EQUIVALENTS FOR 1996

| Total Effective Dose Equivalents | TEDE* |
|---|---|
| | 0 |

| Total Organ Dose Equivalent | TODE* |
|---|---|
| Gonads | 0 |
| Breasts | 0 |
| Red Bone Marrow | 0 |
| Lungs | 0 |
| Thyroid | 0 |
| Bone Surfaces | 0 |

* Includes Previous Exposure from other Facilities if applicable.

CUMULATIVE TEDE AT ROCKY FLATS SINCE 1/1/89

| External | Internal | Total |
|---|---|---|
| 0 | 0 | 0 |

(Deep dose + CEDEs from intakes since 1/1/89)

ROCKY FLATS LIFETIME DOSE

| External | Internal | Total |
|---|---|---|
| 11,072 | 15,410 | 26,482 |

(Deep dose + CEDEs from intakes since hire date)

Figure A-14. Radiation Dosimetry Termination Report dated 9-17-96, page 2.

ROCKWELL INTERNATIONAL - ROCKY FLATS PLANT
EXTERNAL DOSIMETRY (TLD) DETAIL
COMPUTERIZED INFORMATION THROUGH 12-31-86
DOSES IN MILLIREM

10:26 THURSDAY, MARCH 12, 1987

EMPNO=[redacted] NAME=[redacted] YEAR-1985

| ACTIVITY DATE | TIME CODE | CURRENT NEUTRON | CURRENT GAMMA | CURRENT PEN | CURRENT SKIN | CURRENT HAND | CURRENT FOREARM | BK 1 | TYPE |
|---|---|---|---|---|---|---|---|---|---|
| 09/30/85 | 2 | 66 | 29 | 95 | 95 | 95 | 95 | 0 | |
| 10/31/85 | 2 | 34 | 17 | 51 | 51 | 51 | 51 | 0 | |
| 11/30/85 | 2 | 53 | 24 | 77 | 77 | 77 | 77 | 0 | |
| 12/31/85 | 2 | 51 | 21 | 72 | 72 | 72 | 72 | 0 | |
| YEAR | | 567 | 273 | 840 | 840 | 840 | 840 | | |

EMPNO=[redacted] NAME=[redacted] YEAR=1986

| ACTIVITY DATE | TIME CODE | CURRENT NEUTRON | CURRENT GAMMA | CURRENT PEN | CURRENT SKIN | CURRENT HAND | CURRENT FOREARM | BK 1 | TYPE |
|---|---|---|---|---|---|---|---|---|---|
| 01/31/86 | 2 | 17 | 16 | 33 | 33 | 33 | 33 | 0 | C |
| 02/28/86 | 2 | 62 | 24 | 86 | 86 | 86 | 86 | 0 | C |
| 03/31/86 | 2 | 23 | 13 | 36 | 35 | 35 | 35 | 0 | C |
| 04/30/86 | 2 | 53 | 21 | 74 | 74 | 74 | 74 | 0 | C |
| 05/31/86 | 2 | 15 | 66 | 81 | 81 | 81 | 81 | 0 | C |
| 06/30/86 | 2 | 23 | 10 | 33 | 33 | 33 | 33 | 0 | C |
| 07/31/86 | 2 | 24 | 14 | 38 | 37 | 37 | 37 | 0 | C |
| 08/31/86 | 2 | 29 | 16 | 45 | 45 | 45 | 45 | 0 | C |
| 09/30/86 | 2 | 31 | 16 | 47 | 47 | 47 | 47 | 0 | C |
| 10/31/86 | 2 | 25 | 15 | 40 | 40 | 40 | 40 | 0 | C |
| 11/30/86 | 2 | 34 | 22 | 56 | 56 | 56 | 56 | 0 | C |
| YEAR | | 336 | 233 | 569 | 567 | 567 | 567 | | |
| NAME | | 3300 | 2861 | 6154 | 6476 | 15415 | 11326 | | |
| EMPNO | | 3300 | 2861 | 6154 | 6476 | 15415 | 11326 | | |

Figure A-15. External Dosimetry Detail, 1985 and 1986.

## ATTACHMENT B
## MAJOR JOB CATEGORIES

**Chemical Operators**
Primary job duties included highly enriched uranium (HEU; B881 and plutonium (B771/371) metal reprocessing using dissolution, fluorination, calcine, and other wet chemistry methods to purify metal in preparation for foundry casting operations. Molten salt processing (B776) was an exceptionally high neutron process. Other typical job duties included waste treatment (B774/374) for waste solutions generated across RFP.

**Metallurgical Operators**
Primary job duties included casting (B881), rolling and pressing HEU (B883), Pu (B776/ 707), and DU (B444/447 and 883). Exposures tended to be less than those to Chemical Operators. Machinists, Assemblers, Material Analysts and Welders had similar exposures.

Non-Destructive Testing (NDT) Technicians had similar, but probably lower exposures because work was often done on completed pits that inherently shielded fissile materials. Experimental Operators had similar, but probably higher, exposures because they often worked with prototype systems or processes that lacked shielding and other radiological controls as the regular production processes.

**Maintenance Workers**
Typical trades (i.e., machinists, pipefitters, welders, carpenters, painters, electricians) had varied exposures because they often did more intrusive work on contaminated systems than production personnel. Examples of intrusive work include repairing leaks on process lines (pipefitters), refractory replacement in casting and heat treat furnaces (carpenters), repair of mechanical systems (machinists) and repair of instruments and controllers inside gloveboxes and other systems (electricians), painting over contamination (painters).

**Support Personnel**
This category includes Clerk Packers, Metrology Technicians, Janitors, and Handymen, who worked in process areas but did little or no hands-on work with radioactive materials. Exposures would be incidental to working in rooms with process equipment (metallurgical and chemical operations).

**Analytical Laboratory Technicians**
These individuals worked primarily in B559 (Pu samples) or B881 (HEU/DU samples) and probably had lower exposures than operators performing hands-on work with significantly higher material quantities.

**Site Support Personnel**
Stationary Operating Engineers (SOEs, also known as Boiler Vent Operators, BVOs), Security Guards, Shift Managers and Configuration Control Authority personnel performed little if any hands-on work, but had routine access to process areas. SOEs monitored exhaust systems, waste tanks, and process waste lines. Exposures would be incidental to working in rooms with process equipment (metallurgical and chemical operations).

**Radiation Control Technicians**
Radiation Control Technicians (RCTs) probably had exposures from supporting production chemical and metallurgical processes. Some exposures probably occurred during decontamination activities, surveys of contaminated areas, upset conditions. They generally performed no hands-on work, but generally worked side-by-side with production operators.

**Decontamination and Decommissioning Workers**

Decontamination and decommissioning (D&D) work includes draining actinide systems, decontamination, size reduction and removal of contaminated equipment, gloveboxes, piping, ductwork, exhaust systems, waste packaging of removed equipment, low-level and TRU wastes. Work is often in high (>2,000 dpm removable) airborne contamination areas with Derived Air Concentration (DAC) levels from >0.1 to 106. Personal Protection Equipment (PPE) includes Air Purifying Respirator, Powered Air Purifying Respirator, or PremAir supplied air. There were some high exposures due to direct work with highly radioactive equipment and contamination events.