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HANFORD EXTERNAL DOSIMETRY PROGRAM

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SUMMARY

This document describes the Hanford External Dosimetry Program as it is administered by Pacific Northwest Laboratory (PNL) in support of the U.S. Department of Energy (DOE) and its Hanford contractors. Program services include administering the Hanford personnel dosimeter processing program and ensuring that the related dosimeter data accurately reflect occupational dose received by Hanford personnel or visitors. Specific chapters of this report deal with the following subjects:

- personnel dosimetry organizations at Hanford and the associated DOE and contractor exposure guidelines
- types, characteristics, and procurement of personnel dosimeters used at Hanford
- personnel dosimeter identification, acceptance testing, accountability, and exchange
- dosimeter processing and data recording practices
- standard sources, calibration factors, and calibration processes (including algorithms) used for calibrating Hanford personnel dosimeters
- system operating parameters required for assurance of dosimeter processing quality control
- special dose evaluation methods applied for individuals under abnormal circumstances (i.e., lost results, etc.)
- methods for evaluating personnel doses from nuclear accidents.

This document was originally developed as a controlled manual with distribution limited to those Hanford Site personnel who routinely use the program services. The uncontrolled version of the manual was prepared for distribution to individuals who have an interest in the program services, but who do not actually use the services. The manual should not be considered applicable to facilities or circumstances other than those at Hanford and it reflects the operational practices only as they existed as of October 1989. There is no plan or intent to update the uncontrolled copies as changes are made in the Hanford program.

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SECTION 1.0

Introduction

1.0 INTRODUCTION

Several organizations are involved with Personnel Dosimetry for Hanford personnel. Pacific Northwest Laboratory (PNL) provides technical support to Hanford Contractors regarding the methods used to assign personnel dose. Assessment of personnel dose from internal depositions is conducted by the Hazard Assessment and Records Section within the Health Physics Department at PNL.

Assessment of personnel dose from external exposure is conducted by the Instrumentation and External Dosimetry Section within the Health Physics Department. Assignment, use and dose evaluation for Hanford Personnel Dosimeter systems is discussed in this report, Hanford External Dosimetry Program Manual. Maintenance and calibration of Hanford portable radiological instrumentation are also provided by the Instrumentation and External Dosimetry Section. Official dose records for Hanford Personnel are maintained by the Hazard Assessment and Records Section. They provide each contractor with individual dose information, maintain an historical radiation exposure record for each employee, and provide Contractor and Hanford Site statistical dose information.

1.1 SCOPE

The information in this manual is provided to the different Radiation Protection organizations at Hanford to serve as a guide for using and evaluating personnel dosimeter information. Information is provided herein regarding the construction of personnel dosimeters, dosimeter processing, calibration, and dose assessment. Quality Control procedures are described throughout this manual. Detailed information may be obtained from Hanford External Dosimetry Program staff.

1.2 U.S. DEPARTMENT OF ENERGY EXPOSURE GUIDELINES

The DOE exposure guidelines are described in DOE 5480.11, "Radiation Protection for Occupational Workers" (DOE 1988). Table 1.1 is a summary of the annual radiation protection standards for radiation workers. Several instructions are provided in the DOE Order with respect to radiation

TABLE 1.1. Radiation Protection Standards^(a)

<u>Stochastic Effects</u>	5 rem (annual effective dose equivalent)
<u>Nonstochastic Effects</u>	
Lens of eye	15 rem (annual dose equivalent)
Extremity	50 rem (annual dose equivalent)
Skin of the whole body	50 rem (annual dose equivalent)
Organ or tissue	50 rem (annual dose equivalent)
<u>Unborn Child</u>	
Entire gestation period	0.5 rem (annual dose equivalent)

(a) Table from DOE 5480.11 (DOE 1988).

protection practices. Some of those that pertain to external dosimetry are as follows:

1. Individuals less than 18 years of age shall neither be employed in, nor allowed to enter, controlled areas in such a manner that they will receive doses of radiation in amounts exceeding 0.1 rem (effective dose equivalent) per year.
2. Personnel monitoring is required for each individual where there is a potential to exceed in a year any one of the following from external sources:
 - 100 mrem (0.001 sievert) annual effective dose equivalent to the whole body
 - 5 rem (0.05 sievert) annual dose equivalent to the skin
 - 5 rem (0.05 sievert) annual dose equivalent to any extremity
 - 1.5 rem (0.015 sievert) annual dose equivalent to the lens of the eye.

3. Assessment of nonuniform exposure to the skin is necessary if the projected skin dose exceeds 1% of annual dose equivalent limit.

1.3 CONTRACTOR ADMINISTRATIVE EXPOSURE GUIDELINES

Hanford contractors have established administrative exposure guidelines for their personnel that are less than the exposure limits summarized in Table 1.1. These guidelines are summarized in the respective contractor policy manuals.

SECTION 2.0

Personnel Dosimeters

2.0 PERSONNEL DOSIMETERS

The thermoluminescent dosimeters (TLDs) used at the Hanford Site are of the following types: basic, multipurpose, beta/photon, ring, two-element supplemental, and area. The characteristics of each dosimeter, the associated procurement process, and acceptance testing of the dosimeters are described in this section.

2.1 THERMOLUMINESCENT DOSIMETERS

The TLDs are used to determine the dose to personnel resulting from beta, gamma, and/or neutron radiation. These dosimeters are based on the capability of specific thermoluminescent phosphors, upon controlled heating, to emit light that is proportional to the radiation exposure received by the phosphor. Using different phosphors, which have different radiation response characteristics, and using different filter materials between the phosphor and the source of radiation, an estimate of the dose to personnel can be determined. Because of the variability in the dosimeter response to different radiation types and energies, it is important that the dosimeters be calibrated to radiation types and energies encountered in the employee work environment. This will allow for accurate dose determination for personnel.

Thermoluminescent Phosphors - The phosphors used in Hanford dosimeters have the characteristic of storing energy caused by radiation exposure. Upon heating, light is emitted that is proportional to the radiation exposure received. The phosphors are procured commercially in the form of extruded ribbons (commonly referred to as chips at Hanford), measuring 0.318 cm (1/8 in.) square by 0.089 cm (0.035 in.) in thickness. Three forms of the ribbons are used in Hanford dosimeters as identified in Table 2.1. These ribbons may be used individually or mounted in dosimeter inserts. By properly calibrating and evaluating the dosimeter inserts, the radiation exposure received by the phosphors may be interpreted in terms of dose to tissue and thus to personnel.

2.2 DESCRIPTION AND CONSTRUCTION OF HANFORD DOSIMETERS

Several types of dosimeters are used at Hanford to measure the dose to personnel. The use of a specific dosimeter is administered by the respective

TABLE 2.1. Characteristics of Phosphoric Ribbons
Used in Hanford Dosimeters

	<u>TLD-200</u>	<u>TLD-600</u>	<u>TLD-700</u>
Form	CaF ₂ :Mn	⁶ LiF	⁷ LiF
Density, g/cm ³	3.18	2.64	2.64
Atomic number	16.3	8.2	8.2
Efficiency ^(a)	6.0	1.0	1.0

(a) Relative light output from readout on a Hanford automated reader for ¹³⁷Cs (normalized to TLD-700 response).

contractor organizations. For each dosimeter, there is a plastic card, called an insert, which contains the thermoluminescent (TL) chip(s). A plastic holder or pouch contains the insert. The insert and the holder, in combination, comprise the dosimeter. The dosimeter is often referred to as a TLD (thermoluminescent dosimeter). A description of each of the Hanford personnel dosimeters is provided in the following subsections.

2.2.1 Basic Dosimeter

The basic dosimeter is used to monitor dose to Hanford employees or visitors from penetrating photon radiation only. These employees are not expected to receive significant radiation exposure.

Insert - The basic dosimeter insert (illustrated in Figure 2.1) consists of a single TLD-700 chip suspended in a plastic card made of gray Noryl[®] thermoplastic resin. The chip is suspended in place through the use of two 0.002-in. Teflon[®] films on either side of the chip and a 0.005-in. Teflon film, with a hole for the chip, which fixes the chip in place. The insert measures 7.8 cm x 3.8 cm x 0.1 cm.

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- ® Noryl is a trademark of the General Electric Corporation, Selkirk, New York.
 - ® Teflon is a trademark of the E. I. du Pont de Nemours and Company, Wilmington, Delaware.

FIGURE 2.1. Hanford Basic Dosimeter Insert

Holder - The holder for the basic dosimeter insert is a plastic pouch obtained through the Hanford Plant Central Stores. This pouch holds the Hanford security credential as well as the basic dosimeter insert.

2.2.2 Multipurpose Dosimeter

The multipurpose dosimeter is used to monitor the shallow-, deep-, fast-neutron, and slow-neutron dose components potentially received by radiation workers in Hanford facilities.

Insert - The multipurpose dosimeter insert consists of three TLD-700 chips and two TLD-600 chips suspended in a black Noryl plastic card. The plastic card has the same dimensions as the basic dosimeter (7.8 cm x 3.8 cm x 0.1 cm). The TLD-700 chips are placed in insert Positions 1, 2, and 5 as shown in Figure 2.2. The TLD-600 chips are placed in Positions 3 and 4.

Holder - The multipurpose dosimeter holder, shown in Figure 2.3, is injection-molded from acrylonitrile-butadiene-styrene (ABS) plastic and is designed to hold the multipurpose dosimeter insert and the Hanford security credential. The holder measures 9.2 cm x 7.3 cm x 0.6 cm and weighs approximately 30 g. Several filters are retained in cavities in the holder with a clear adhesive. Each filter is 1.27 cm in diameter. When the insert is placed into the holder, a snug friction fit is obtained with each TLD chip centered between the appropriate filters. The insert can be placed into the holder in only one direction. An illustration of the holder is shown in Figure 2.3. The filter specifications for the material for each holder position are summarized in Table 2.2.

FIGURE 2.2. Hanford Multipurpose Dosimeter Insert, Front View

FIGURE 2.3. Hanford Multipurpose Dosimeter Holder, Front View

TABLE 2.2. Filtration Specifications for Hanford Multipurpose Dosimeters

Position	Filtration, mm					
	Teflon	Security Credential	Aluminum	Tin	Cadmium	Plastic
1	0.05	0.84				
2	0.05	0.84	0.64			1.05
3	0.05	0.84		1.02		0.70
4	0.05	0.84		0.51	0.51	0.70
5	0.05	0.84		1.02		0.70

2.2.3 Beta/Photon Dosimeter

The beta/photon dosimeter is used to monitor dose to personnel in selected Hanford facilities with a significant low-energy beta radiation component. This dosimeter, when used, is worn along with the multipurpose dosimeter. The dosimeter insert and holder is issued by the respective contractor Radiation Protection organization.

Insert - The beta/photon dosimeter insert, shown in Figure 2.4, consists of three ^7LiF (TLD-700) and two $\text{CaF}_2\text{:Dy}$ (TLD-200) chips in a red Noryl plastic card. The plastic card has the same dimensions as the multipurpose dosimeter insert (7.8 cm x 3.8 cm x 0.1 cm). The TLD-700 chips are placed in insert Positions 1, 2, and 5. The TLD-200 chips are placed in insert Positions 3 and 4 (as shown in Figure 2.4). The insert can be inserted into the holder in only one direction.

FIGURE 2.4. Hanford Beta/Photon Dosimeter Insert, Front View

Holder - The beta/photon dosimeter holder (illustrated in Figure 2.5) is injection-molded from ABS plastic and is designed to hold the beta/photon dosimeter insert. The holder measures 7.6 cm x 4.45 cm x 0.6 cm and weighs approximately 25 g. The inside of the holder is lined with aluminized Mylar to block light from entering the holder.

Filters for each dosimeter position are retained in cavities in the holder. The filtration specifications for the material for each holder position are summarized in Table 2.3.

2.2.4 Ring Dosimeter

The Hanford ring dosimeter (illustrated in Figure 2.6) consists of two ^7LiF (TLD-700) chips in a sealed plastic ring. The ring is available in two sizes, medium and large, and is red in color. The cap on each ring is heat-sealed in place to provide an airtight enclosure and is approximately 0.005 cm thick.

FIGURE 2.5. Hanford Beta/Photon Dosimeter Holder, Front View

TABLE 2.3. Filtration Specifications for Hanford Beta/Photon Dosimeters

<u>Position</u>	<u>Filtration, mm</u>				
	<u>Teflon</u>	<u>Aluminized Nylon</u>	<u>Aluminum</u>	<u>Tin</u>	<u>Plastic</u>
1	0.051	0.014			
2	0.051	0.014	0.64		1.05
3	0.051	0.014		1.02	0.70
4	0.051	0.014			
5	0.051	0.014			0.51

FIGURE 2.6. Hanford Two-Chip Ring Dosimeter

2.2.5 Two-Element Supplemental Dosimeter

A two-element supplemental dosimeter (illustrated in Figure 2.7) is used to measure the dose distribution from nonuniform sources of penetrating beta and/or gamma radiation. The dosimeter contains two ^7LiF (TLD-700) chips: one chip is placed under each of two separately filtered regions of the dosimeter. The filtration for these regions is approximately 0.003 cm of aluminized Mylar[®] and, for the other position, 0.064 cm of aluminum plus 0.105 cm of plastic. These dosimeters are obtained through the respective contractor Radiation Protection organizations.

[®] Mylar is a registered trademark of E. I. du Pont de Nemours and Company, Wilmington, Delaware.

FIGURE 2.7. Hanford Two-Element Supplemental Dosimeter

2.2.6 Area Dosimeter

The Hanford Area dosimeter (illustrated in Figure 2.8) consists of four inserts and a holder with eight filtered regions. The dosimeter is used to determine the approximate energy fluence of beta and photon radiation in the employee work environment.

Insert - Each of the four Hanford Area dosimeter inserts is identical in construction to the beta/photon dosimeter inserts. The TLD-700 chips are

FIGURE 2.8. Hanford Area Dosimeter Holder

located in Insert Positions 1, 2, and 5. TLD-200 chips are located in Positions 3 and 4. The inserts are uniquely labeled and are blue.

Holder - The Hanford Area dosimeter holder is injection-molded from ABS plastic. The inside of the holder is lined with aluminized nylon. Additional aluminum filters are used to construct the eight filtered regions of the holder. Behind each filtered region is a pair of TLD-700 and TLD-200 chips, as illustrated in the Figure 2.8. The filtration specifications for each position are shown in Table 2.4.

2.3 PROCUREMENT OF DOSIMETER MATERIAL

Significant quantities of dosimeter ribbons (chips), Teflon film, dosimeter inserts, and holders are generally procured each year. The dosimeter inserts and holders are acceptance tested before they are put into use.

2.3.1 Procuring New Ribbons (Chips)

Three distinct types of TL ribbons are used in Hanford personnel dosimeters. These ribbons include two distinct types of LiF and one type of CaF₂:Dy ribbons. The two types of LiF ribbons are commonly referred to as TLD-600 and TLD-700 ribbons or chips. Procurement of TLD-600 ribbons should state that the material is enriched to at least 95% in the ⁶LiF isotope.

TABLE 2.4. Filtration Specifications for Hanford Area Dosimeter

<u>Position</u>	<u>Filtration, mm</u>		
	<u>Teflon</u>	<u>Aluminized Nylon</u>	<u>Aluminum</u>
1	0.051	0.014	
2	0.051	0.014	0.025
3	0.051	0.014	0.051
4	0.051	0.014	0.127
5	0.051	0.014	0.254
6	0.051	0.014	0.635
7	0.051	0.014	1.27
8	0.051	0.014	2.54

Procurement of TLD-700 ribbons should state that the material is enriched to at least 99.93% in the ^7LiF isotope. The calcium fluoride ribbons are commonly referred to as TLD-200 chips. Each procurement of ribbons should state that for each respective ribbon type (i.e., TLD-200, TLD-600, or TLD-700), all ribbons shall have the same weight within 5% and should have a total sensitivity variation of less than 15% for an exposure to 200 mR of ^{137}Cs gamma radiation. It is desirable that the absolute sensitivity of the material procured be within 10% of the sensitivity of ribbons previously procured. This can be done by specifying the batch number of previously procured ribbons.

2.3.2 Procuring New Teflon

Teflon films are used to enclose the TL ribbons in the Hanford dosimeters. The films must be transparent Teflon TFE-fused plastic by the extruded sintered process only. For multipurpose and beta/photon dosimeters, films measuring 1-3/4 in. wide by 0.002 in. thick and 1-3/4 in. wide by 0.005 in. thick are needed. For basic dosimeters, similar films measuring 3/4 in. wide are needed. A tolerance of not greater than 0.0003 in. shall be stated for the width and the thickness of the films.

2.3.3 Procuring/Acceptance Testing New Dosimeter Inserts

New dosimeter inserts are procured through an established supplier using an injection mold, which identically matches the existing dosimeter inserts. Ribbons and Teflon film are provided to the supplier by PNL. Acceptance testing is conducted using established procedures to determine the physical dimensions and proper placement of TL ribbons.

2.3.4 Procuring/Acceptance Testing New Dosimeter Holders

New multipurpose and beta/photon dosimeter holders are procured through an established supplier using an injection mold that identically matches the existing holders. Filters are provided by the supplier and must meet specified tolerances. Acceptance testing of all dosimeter holders is conducted to determine proper filter placement.

SECTION 3.0

Personnel Dosimeter Identification, Acceptance Testing, Accountability, and Exchange

3.0 PERSONNEL DOSIMETER IDENTIFICATION, ACCEPTANCE TESTING, ACCOUNTABILITY, AND EXCHANGE

Hanford dosimeters are uniquely identified; barcode and optical character labels are used on the dosimeter inserts and each holder is labeled with a barcode label. Accountability of dosimeters during acceptance testing, personnel use, processing, etc., is tracked. Each Hanford contractor has established guidelines for dosimeter use, including exchange frequency.

3.1 DOSIMETER IDENTIFICATION

Each Hanford dosimeter insert has two labels: a bottom and a top label. The bottom label is a barcode label that contains the unique permanent identification (PID) number of the dosimeter insert. This identification is used to track the dosimeter throughout its entire history. The top label is an optical character label that is used to assign the dosimeter. For each permanent employee at Hanford, two dosimeters are assigned to be alternated during even and odd wear periods. If a person leaves, the dosimeters are reassigned by changing the top label.

3.1.1 Barcode Label

The bottom label is a barcode label that contains the seven-digit PID number of the insert, a single character indicator of the exchange frequency of the insert (even or odd), and a single character indicator of the type of dosimeter. The structure of the label is as follows:

aTWXXXXXXa

where a = the barcode start or stop indicator

T = a type indicator either \$ (check dosimeters, i.e., a dosimeter that has been exposed to a known dose), - (blank dosimeters), or . (all other dosimeters)

W = either a 0 (even wear period) or 1 (odd wear period)

X = the unique seven-digit PID number for the insert.

Examples of three barcodes follow:

a. 0 0 1 2 3 4 5 6 a

Non-control dosimeter (.)
Even wear period (Ø)
PID number Ø123456

a- 00 1 2 3 5 5 6 a

Blank control dosimeter (-)
Even wear period (Ø)
PID number Ø123556

a\$ 1 0 1 2 3 7 8 9 a

Check control dosimeter (\$)
Odd wear period (1)
PID number Ø123789

3.1.2 Optical Character Label

The top label used on Hanford dosimeter inserts is an optical character label that contains the name, payroll number, and wear period for personnel dosimeters. For temporary dosimeters, the contractor and a dosimeter label are shown. The optical character labels are easily read. The structure of the optical character label is as follows:

II LLLLLLLLLL
W PPPPPF

where I = initials of employee

L = last name of employee

W = code indicating either we period for dosimeters assigned to personnel (Ø for even wear period, 1 for odd wear period), or T for temporary dosimeter or C for calibration dosimeter

P = employee payroll number.

Examples of three types of optical character labels follow:

JJ JOHNSON	Dosimeter is assigned to employee JJ Johnson,
1 12345	payroll number 12345 for an odd (1) wear period.

BLANK	Dosimeter is a blank (no exposure, check dosimeter
Ø ØT123	with a dosimeter label of ØT123.

WHC Dosimeter is to be assigned, temporarily, to
T TB567 employees or visitors.

There are a few optical character labels where the two leading characters of the label have specific definitions, as follows:

00 = (e.g., 00234) open audit dosimeter.

0T = (e.g., 0T234) multipurpose, blank check dosimeter.

1T = (e.g., 1T234) multipurpose, 1-R-dosed check dosimeter.

2T = (e.g., 2T234) basic, blank check dosimeter.

7T = (e.g., 7T234) basic, 1-R-dosed check dosimeter.

The specific codes given to ring check dosimeters also are as follows:

CK = 1-R-dosed ring check dosimeters.

BK = blank ring check dosimeters.

3.2 ACCEPTANCE TESTING OF DOSIMETER INSERTS AND HOLDERS

All personnel dosimeter inserts and holders are tested before they can be used for personnel. First, physical acceptance testing is conducted for all dosimeters using a gauge to ensure that the inserts can be processed through the automated readers.

3.2.1 Dosimeter Inserts

Basic, multipurpose, and beta/photon dosimeter inserts are exposed to 50 mR of ^{137}Cs gamma and 3 mrem of D_2O -moderated ^{238}Pu neutron radiation. During processing, tolerance ranges have been established for the response of TLD-200, TLD-600, and TLD-700 chips.

3.2.2 Dosimeter Holders

Basic dosimeter holders consist of a plastic pouch procured through Central Stores. These holders are not tested. Each multipurpose and beta/photon dosimeter holder is tested by exposure to 50 mR of ^{137}Cs gamma and 3 mrem of D_2O neutron radiation. Tolerance ranges have been established for each position of each holder type.

3.3 DOSIMETER ACCOUNTABILITY

Each dosimeter is tracked by means of the unique PID number. This number is used to assign dosimeters to personnel and to track the dosimeter throughout its history. This is accomplished by means of two computer files as described here.

3.3.1 Permanent Identification File

The assignment of dosimeters to personnel is conducted by means of the PID file. The barcode label is read during dosimeter processing, dosimeter issuance, and return. The PID file maintains a record of dosimeter assignment. Any change in the assignment of a dosimeter requires an update to the PID file.

3.3.2 Dosimeter History File

A retrievable record of all reported doses is maintained for each basic, multipurpose, and beta/photon dosimeter permanently assigned to personnel. Records are maintained of the exposures used to determine chip sensitivity factors and the factors used in the calculation of dose.

3.4 GUIDELINES FOR DOSIMETER USE

Dosimeter assignment is administered by the respective contractor Radiation Protection staff. Each contractor has established guidelines for their employees and facilities.

3.4.1 Hanford Personnel

Two dosimeters are assigned to each Hanford employee: one to be worn during even wear periods and one for odd wear periods. The type of dosimeter assigned and the exchange frequency is administered by the respective contractor Radiation Protection organization.

3.4.2 New Personnel

New personnel are assigned temporary dosimeters until their permanently assigned dosimeters can be issued routinely.

3.4.3 Visitors

Visitors to Hanford are assigned temporary dosimeters, depending on the areas they are scheduled to enter.

3.4.4 Offsite Visits by Hanford Personnel

Hanford personnel should not wear their routine dosimeter while visiting offsite. This procedure is necessary to avoid recording twice in the Hanford individual dose record any exposure received offsite. Generally, the dose received at a non-Hanford facility will be monitored by the respective organization and reported to PNL. Upon receipt of the offsite dose information, it is recorded into the individual dose record.

3.5 DOSIMETER EXCHANGE PERIODS

The exchange period for Hanford dosimeters may be monthly, quarterly, or annual. The respective contractor Radiation Protection organization administers the choice of dosimeter type and exchange frequency based on the potential for radiation exposure.

3.5.1 Routine Processing

Labels on the dosimeter inserts for permanent employees on a routine exchange frequency are color coded to allow for an easy visual indicator of whether the proper insert is being worn. A summary of the colors for each exchange period may be obtained from the respective contractor Radiation Protection organizations.

3.5.2 Special Processing

At the request of the respective contractor Radiation Protection organizations, personnel dosimeter inserts may be processed at any time on a special basis.

SECTION 4.0

Dosimeter Processing and Data Recording

4.0 DOSIMETER PROCESSING AND DATA RECORDING

Dosimeter processing is conducted using automated readers for basic, multipurpose, beta/photon, and area dosimeter inserts, and using a manual system for ring and two-element supplemental dosimeter chips.

4.1 PROCESSING PERSONNEL DOSIMETERS USING AN AUTOMATED READER

The Hanford automated reader system is used to process the basic, multipurpose, and beta/photon personnel inserts, as well as the area dosimeter inserts (all described in Section 2.0). These dosimeters all use the Teflon-enclosed TL chips. The identical processing procedures used for all of these inserts are discussed in the following sections.

4.1.1 Pre-Issue Low-Temperature Annealing

All dosimeter inserts are annealed at 80°C for 16 hours prior to being issued. This procedure improves long-term consistency in sensitivity between dosimeter inserts. The annealing process also reduces the significance of signal fading by eliminating the lower-temperature peaks.

4.1.2 Pre-Read Cleaning Cycle

Prior to being processed, all dosimeter inserts are cleaned in two ultrasonic cleaning baths. The first bath contains water and the second bath contains alcohol. If necessary, a bath containing diluted acetic acid is used prior to the water and alcohol baths. This cleaning process removes oils and mineral deposits that may be present on the dosimeter inserts. After the cleaning process, the inserts are placed on a rack to dry.

4.1.3 Pre-Read Low-Temperature Annealing

After the pre-read cleaning cycle, all inserts are annealed for 30 minutes at 80°C. This annealing process ensures that the inserts are dry, assists in volatilizing any residues, and further eliminates low-temperature peaks.

4.1.4 Reader Processing

Dosimeter inserts are stacked in the input cartridge for automatic processing. Numerous quality control checks must be satisfied during the

processing of the dosimeter inserts. These are discussed further in Section 6.0, Quality Control. The reader heat cycle is Positions 1, 2, 5, 4 and 3. The reader heats Positions 1, 2, and 5 for 15 seconds and heats Positions 3 and 4 for 27 seconds. The heater is maintained at approximately 300°C.

4.1.5 Glow Curve Recording

Glow curves are recorded for all dosimeters processed through the automatic readers. The glow curves are retained for 60 business days before being discarded. The glow curves provide evidence of the rate at which the light is being received by the photomultiplier tube.

4.2 AUTOMATED READER RESULT RECORD

Inserts are automatically processed through the automated reader system. The reader is microprocessor-controlled with several conditions that must be satisfied for processing to continue. A unique sequence number is assigned to each dark current, light source, or dosimeter reading obtained by the reader. The reader sequence number is combined with information received from the dosimeter inserts to form an individual record.

4.2.1 Reader Sequence Number

A sequential five-digit number is assigned automatically to each dark current, light source, or dosimeter record provided by the Hanford automated readers. Each reader is uniquely identified to preclude any confusion of records between systems. By using the sequence numbers, the exact order of dark current, light source, audit dosimeter, check dosimeter, and personnel dosimeter results can be reconstructed for evaluation. In addition to the ability to order the data by sequence number, a continuous log of reader results is also printed during processing.

4.2.2 Dosimeter Result Record

An extensive database capability has been developed to identify the different types of information that must be entered into the dosimeter result record. An internal technical reference document, Data Processing, Volume III of a series of internal manuals, describes the many details involved. Some of the items that constitute the dosimeter record are

- sequence number - unique five-digit number assigned by the reader system
- processing date - date assigned to dosimeter processing batch that uses the same calibration code; often referred to as January monthly processing, 1st quarter processing, etc.
- personnel number - information obtained from the optical character label (i.e., top label on dosimeter), which will be the payroll number for permanently assigned dosimeters or the temporary dosimeter number for temporary dosimeters
- adjusted chip readings - chip counts for each dosimeter position that have been adjusted by applying chip sensitivity factors, position sensitivity factors and reader sensitivity factors, after subtraction of an average background reading (discussed in detail in Section 5.0)
- contractor code - unique identifier for each Hanford contractor
- note code - code that describes why the dosimeter is being processed; an example would be the routine processing of a monthly assigned multipurpose dosimeter. (There are many note codes corresponding to the different types of dosimeters, exchange periods, and processing circumstances.)
- kind code - code that identifies the type of dosimeter; examples include a "1" for basic dosimeters, "5" for multipurpose dosimeters, "B" for beta/photon dosimeters, and "R" for ring dosimeters.

4.3 PROCESSING PERSONNEL DOSIMETERS USING A MANUAL READER

A manual reader is used to process the individual TLD-700 chips used in the ring and two-element dosimeters. Chips used in these dosimeters are screened upon procurement. The entire batch of chips is carefully controlled to ensure that the sensitivity of the field, check, and audit dosimeters is nearly identical.

4.3.1 Chip Annealing

Before use, a batch of chips is annealed at 400°C for 2 hours and at 80°C for 16 hours. The annealing process removes any residual signal from previous radiation exposure and sets the sensitivity of all of the chips to a uniform level.

4.3.2 Dosimeter Fabrication

Ring and two-element dosimeters are hand-loaded with the annealed TLD-700 chips. Two chips are required for each of these dosimeters. The ring casings

are heat-sealed to minimize the entry of contaminants into the chip cavity in the ring casing. The two-element dosimeter is injection-molded and forms a relatively dust-tight system. Each dosimeter is labeled for use by the respective contractor.

4.3.3 Dosimeter Processing

Chips from ring and two-element dosimeters are manually processed using either Harshaw^(a) 2000A, 2080, or 2000D reader systems. The results from the reader are electronically transmitted to a computer system. The operator must enter the dosimeter identification, contractor code, etc. For ring dosimeters, only one of the TLD-700 chips is routinely processed. If the result for the first chip exceeds a set level, typically 750 mrem, the second chip is kept for 15 business days in case there is a need to conduct any follow-up evaluations. If the reading of the first chip exceeds a higher set level, typically 1500 mrem, then the second chip is processed immediately for confirmation of the reading following the processing of ring check dosimeters. Both chips from the two-element dosimeter are processed in order to estimate the shallow- and deep-dose components.

4.3.4 Glow Curve Recording

Glow curves are recorded for all ring dosimeters that are being specially processed. Glow curves are not recorded for dosimeters that are being routinely processed.

4.4 MANUAL READER RESULT RECORD

Data entry for the assignment of ring and two-element dosimeters to personnel must be done manually from the contractor-supplied Dosimeter Processing Acceptance form that accompanies the dosimeters.

By matching the dosimeter assignment and the dosimeter processing information, a dosimeter result record is developed.

(a) The Harshaw Chemical Company, 6801 Cochran Road, Solon, Ohio.

4.4.1 Data Recording

Information on the Dosimeter Results Acceptance form is manually entered into a computer file. This information is matched with the dosimeter result by means of the dosimeter PID number.

4.4.2 Dosimeter Result Record

A dosimeter result record is developed similarly to the record for the personnel dosimeters. The results for the ring and two-element dosimeters are combined in the same file as the results for the personnel dosimeters for a given processing batch (i.e., January monthly processing, etc.).

SECTION 5.0

Personnel Dosimeter Calibration and Dose Assessment

5.0 PERSONNEL DOSIMETER CALIBRATION AND DOSE ASSESSMENT

Personnel dosimeters undergo various calibrations using standard sources and calibration factors appropriate to the given dosimeter type and field conditions. Dosimeters are processed automatically or manually for dose assessment purposes. The calibration parameters and processes and the determination of dosimeter doses are discussed in this section.

5.1 PERSONNEL DOSIMETER CALIBRATION

Personnel dosimeter calibration at PNL is based on radiation exposures traceable to the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards, using on-phantom exposures. As necessary, Hanford-specific calibration factors are introduced to better match the response of the dosimeters to known field conditions.

5.1.1 NIST-Traceable Sources

Exposure rates for radiation sources used as a basis for calibrating Hanford personnel dosimeters are traceable to NIST standards. Primary calibration for the basic dosimeter is the deep dose from an on-phantom ^{137}Cs exposure. For the multipurpose dosimeter, primary calibration is based on

- 16 keV K-fluorescent on-phantom exposure for the shallow-dose component
- on-phantom ^{137}Cs exposure for the deep-dose component
- on-phantom ^{252}Cf exposure for the fast-neutron component
- in-core exposure in the Sigma Pile for the slow-neutron component.

For the beta/photon dosimeter, the primary calibration is based on

- ^{90}Sr on-phantom exposure for the shallow-dose component
- ^{137}Cs on-phantom exposure for the deep-dose component.

Additional exposures are made to selected K-fluorescent, filtered x-ray techniques, beta sources, and neutron energies to determine the response of the dosimeters in other radiation environments. Information pertaining to the calibration of the exposure and/or dose received from these sources is

available in the respective source documentation maintained at the 318 Building calibration facility.

5.1.2 On-Phantom Dosimeter Calibration

On-phantom calibrations are used to determine the dose response for all personnel dosimetry systems. Process control dosimeters are exposed in-air to ^{137}Cs gamma radiation and the mean results for these dosimeters are used to determine the on-phantom calibration coefficients using well-determined calibration factors.

5.1.3 Hanford Site Calibration Factors

Calibration factors determined from the NIST calibration sources are used directly without any modification for field conditions, with the exception of the fast-neutron calibration. A Hanford Site calibration factor is used to better match the response of the multipurpose dosimeter with Hanford field conditions. For the fast-neutron calibration using ^{252}Cf , the time of the exposure is modified so that the dosimeter response is similar for both the field and calibration exposures. The dose response of the multipurpose dosimeter is approximately a factor of 2 less than the actual dose for a bare ^{252}Cf -source exposure and a factor of about 8 greater than the actual dose for a 15-cm D_2O -moderated ^{252}Cf -source exposure.

5.1.4 Environmental Dose Correction

The contribution to the dosimeter signal from naturally occurring environmental radiation is determined using the following formula:

$$\text{ENV_FAC} = \frac{0.18 \times (1 - \exp^{-(0.0008 \times Y1)})}{0.0008} \quad (5.1)$$

where ENV_FAC = the dose in millirem contributed from back-ground radiation

0.18 = the expected dose in millirem per day expected from environmental radiation in the Hanford environs

Y1 = the number of days between the previous and current dosimeter processing

0.0008 = a factor to compensate for the fade of the TL signal.

5.2 DOSIMETER DOSE DETERMINATION

Dose assessments are determined similarly for all dosimeters processed with the automatic reader system and similarly for all dosimeters processed with the manual reader system. As such, the determination of dose for each personnel dosimeter is discussed separately according to whether the dosimeter is automatically or manually processed.

5.2.1 Processing Dosimeters Using an Automated Reader

Dosimeter processing with the automated reader involves the processing of several control dosimeters during one run. The results from these control dosimeters are used to normalize the dosimeter results to a predetermined level. The automated reader sensitivity is maintained to within 5% of pre-established levels using the internal light source. To further improve precision, the sensitivity of each chip in each dosimeter insert is determined and catalogued in a computer database.

Monitoring Automated Reader Sensitivity Using Internal Light Source

The sensitivity of the automated readers is monitored routinely using the readings of an internal light source. Process control procedures require that the sensitivity of the readers be within 5% of a predetermined value throughout the processing of dosimeters.

Determining Automated Reader Sensitivity Using Control Dosimeters

The relative sensitivity of the readers is also available from the results of processing control dosimeters. The control dosimeters that are processed include the following:

- 0T dosimeters - multipurpose dosimeter inserts that have received no radiation exposure
- 1T dosimeters - multipurpose dosimeter inserts exposed in-air to 1 R of ^{137}Cs gamma radiation
- 2T dosimeters - basic dosimeter inserts that have received no radiation exposure
- 7T dosimeters - basic dosimeter inserts exposed in-air to 1 R of ^{137}Cs gamma radiation.

Several of these control dosimeters are processed initially to determine the preliminary calibration constants to be used during the dosimeter processing. Control dosimeters are processed at least every 50 dosimeters. The results of each control dosimeter are checked by the microprocessor controlling the reader and must comply with predetermined limits for the processing to continue. The mean response of the control dosimeters is calculated as follows:

$$\emptyset TM(i) = \frac{\sum \emptyset T(k,i) \times CSF(k,i) + PSF(n,i)}{N} \quad (5.2)$$

$$1TM(i) = \frac{\sum 1T(k,i) \times CSF(k,i) + PSF(n,i)}{N} \quad (5.3)$$

$$2TM(i) = \frac{\sum 2T(k,1) \times CSF(k,i) + PSF(n,i)}{N} \quad (5.4)$$

$$7TM(i) = \frac{\sum 7T(k,1) \times CSF(k,i) + PSF(n,i)}{N} \quad (5.5)$$

where $\emptyset TM(i)$ = the mean of the $\emptyset T$ control multipurpose dosimeters for each dosimeter Position i

$1TM(i)$ = the mean of the $1T$ control multipurpose dosimeters for each dosimeter Position i

$2TM(1)$ = the mean response of the $2T$ control basic dosimeters for Position 1

$7TM(1)$ = the mean response of the $7T$ control basic dosimeters for Position 1

$CSF(k,i)$ = the chip sensitivity factor for Position i of the k th dosimeter

$PSF(n,i)$ = the position sensitivity factor for reader n and the i th dosimeter position.

In all cases, k refers to the identity of the individual dosimeters and N refers to the respective number of control dosimeters of each type. The mean value of the control dosimeters is used to determine the calibration factors used to calculate dose, as discussed in the following subsections.

Determining Chip Sensitivity Factors

Chip sensitivity factors are determined for each dosimeter insert using repeated exposures in-air to 1 R of ^{137}Cs gamma radiation. The chip

sensitivity factor for each chip position in each dosimeter insert is computer catalogued using the unique PID number for each insert. These factors are used to normalize the radiation response of each chip relative to a reader count of 1500. The formula used to determine chip sensitivity factors is as follows:

$$CSF(k,i) = \frac{1TM'(i)}{R(k,i)} \quad (5.6)$$

where $1TM'(i)$ = the mean value of the 1-R control dosimeters processed for each Position i . In this calculation, the count actually observed without correction for position or chip sensitivity is used

$R(k,i)$ = the mean response of Position i of dosimeter k from exposure to 1000 mR of ^{137}Cs gamma in air.

The chip sensitivity factors calculated for each position of a dosimeter are intended to be independent of the reader system and reader sensitivity used.

Determining Reader Sensitivity Factor

The average result of the many 1T control dosimeters processed is normalized to a value of 1500 reader counts before being used to determine the calibration coefficients for basic, beta/photon, and multipurpose dosimeters. A reader sensitivity factor (RSF) is calculated as follows:

$$RSF = \frac{1500}{(1TM(2) - \emptyset TM(2) * CSF(2))} \quad (5.7)$$

where 1500 = the reader counts used for normalization

$1TM(2)$ = the mean value of the 1T control dosimeters for Position 2

$CSF(2)$ = chip sensitivity factor

$\emptyset TM(2)$ = the mean value of $\emptyset T$ control dosimeters for Position 2.

This procedure provides more consistent dosimeter and calibration data between dosimeter processings and between readers. The deviation between the actual reader count for the control dosimeters dosed with 1 R of ^{137}Cs and the

observed count is routinely recorded. Generally, the deviation is very small, less than a few percent.

Using Dosimeters to Monitor Personnel Exposure

Basic, multipurpose, and beta/photon dosimeters are used to monitor personnel or site visitor exposure to radiation. These dosimeters and their associated calibration factors, dose algorithms, and other calculations are described in the following subsections.

Basic Dosimeters. Basic dosimeters are used to routinely monitor Hanford employees or visitors who are not radiation workers, but who may be exposed to small levels of radiation. The basic dosimeter responds to any significant level of penetrating photon exposure. This dosimeter has a single chip and the results are represented as a deep-dose component.

Calibration Factor - The calibration factor, C_{ϕ} , determined from the basic control dosimeters, is used to calculate the deep dose for basic dosimeters. This constant is based on the dosimeter response to a ^{137}Cs exposure with dosimeters affixed to a phantom. The calibration constant is termed C_{ϕ} and is calculated as follows:

$$C_{\phi} = \frac{1000 \times 1.03}{(7\text{TM}(1) - 2\text{TM}(1)) \times 1.10} \quad (5.8)$$

Dose Algorithm - The dose algorithm for the basic dosimeters is based on determining deep dose by comparing the response of the chip in Position 1 to the calibration response from ^{137}Cs .

Deep Dose - The deep dose for basic dosimeters is calculated as follows:

$$\text{Dose} = [C_{\phi}(R - 2\text{TM}) \times \text{RSF} \times \text{CSF}] - \text{ENV_FAC} \quad (5.9)$$

where C_{ϕ} = the calibration factor in millirem per chip signal for basic dosimeters

R = the response of the chip

2TM = the average for the basic background control dosimeters

RSF = the reader sensitivity factor

CSF = the chip sensitivity factor for this dosimeter

ENV_FAC = environmental dose based on the number of days elapsed between previous and current dosimeter processing.

Equation (5.9) provides for the calculation of deep dose for basic dosimeters using adjustments for any change in reader sensitivity, for change in reader sensitivity between positions, and for the intrinsic efficiency of the chip to radiation. For basic dosimeters, the shallow dose is set equal to the deep dose.

Multipurpose Dosimeters. Multipurpose dosimeters are used to monitor radiation workers in compliance with applicable regulations or guidelines. Each dosimeter has five chip positions, which provide an estimate of the shallow-dose, deep-dose, fast-neutron, and slow-neutron dose components. The determination of dose components is dependent upon the methods of calibration and dose calculation.

Calibration Factors - Calibration factors are based on the dosimeter response to ^{137}Cs gamma, ^{252}Cf fast-neutron, and Sigma Pile slow-neutron radiation. Several calibration factors are predicted from the 1T and ØT control dosimeters using the following formulas:

$$\underline{1000\text{-mR } ^{137}\text{Cs On-Phantom}} \quad (5.10)$$

$$\begin{aligned} P1 &= 1.10 \times (1\text{TM}(1) - \emptyset\text{TM}(1)) \\ P2 &= 1.10 \times (1\text{TM}(2) - \emptyset\text{TM}(2)) \\ P4 &= 1.10 \times (1\text{TM}(4) - \emptyset\text{TM}(4)) \\ P5 &= 1.10 \times (1\text{TM}(5) - \emptyset\text{TM}(5)) \\ C_1 &= \frac{1000 \times 1.03}{P2} \text{ (mrem/reader count)} \\ K_2 &= \frac{P1}{P2}, \quad K6 = \frac{P4}{P5} \end{aligned}$$

$$\underline{50\text{-mrem Sigma Pile}} \quad (5.11)$$

$$\begin{aligned} \text{SN3} &= 4.18 \times (1\text{TM}(3) - \emptyset\text{TM}(3)) \\ \text{SN4} &= 2.16 \times (1\text{TM}(4) - \emptyset\text{TM}(4)) \\ \text{SN5} &= 0.05 \times (1\text{TM}(5) - \emptyset\text{TM}(5)) \\ C_4 &= \frac{50}{(\text{SN3} - \text{SN4})} \\ K_5 &= \frac{\text{SN4} - K_6 \text{SN5}}{(\text{SN3} - \text{SN4})} \end{aligned}$$

$$\frac{1000\text{-mrem } ^{252}\text{Cf Exposure On-Phantom}}{(\text{NIST-Traceable})} \quad (5.12)$$

$$\begin{aligned} \text{FN3}' &= 1.075 \times (\text{1TM}(3) - \emptyset\text{TM}(3)) \\ \text{FN4}' &= 0.942 \times (\text{1TM}(4) - \emptyset\text{TM}(4)) \\ \text{FN5}' &= 0.068 \times (\text{1TM}(5) - \emptyset\text{TM}(5)) \end{aligned}$$

$$\frac{1000\text{-mrem } ^{252}\text{Cf Exposure On-Phantom}}{(\text{Hanford Site-Specific})} \quad (5.13)$$

$$\begin{aligned} \text{FN3} &= 1.73 \times \text{FN3}' \\ \text{FN4} &= 1.73 \times \text{FN4}' \\ \text{FN5} &= 1.73 \times \text{FN5}' \end{aligned}$$

$$\begin{aligned} C_5 &= \frac{1000}{(\text{FN4} - K_6\text{FN5} - K_5(\text{FN3} - \text{FN4}))} \\ C_6 &= K_6 C_5 \\ C_7 &= K_5 C_5 \end{aligned}$$

where $\emptyset\text{TM}(i)$ = the mean value of the adjusted chip counts for the multipurpose background control dosimeters for the i th chip position

$1\text{TM}(i)$ = the mean value of the adjusted chip counts for the multipurpose 1-R-dosed control dosimeters for the i th chip position

P_i = predicted chip count for i th position from 1000-mR ^{137}Cs -irradiated dosimeters on-phantom

SNI = predicted chip count for i th position from 50-mrem Sigma-Pile-irradiated dosimeters

FNI' = predicted chip count for i th position from 1000 mrem ^{252}Cf (bare irradiated dosimeters on-phantom)

FNI = predicted chip count for i th position for Hanford-specific PuF_4 -equivalent calibration

1.10 = backscatter factor for ^{137}Cs irradiation between on-phantom and in-air exposures

1.03 = Roentgen to dose conversion factor for ^{137}Cs .

Dose Algorithm - The shallow-, deep-, fast-neutron-, and slow-neutron-dose components are calculated using the following formulas:

$$\text{Shallow-Dose (SD) Component} \quad (5.14)$$

$$\begin{aligned} \text{If } R(1) < 0, \text{ then } \text{SD} &= 0 \\ \text{SD} &= C_1 * (1.1 R(1) - 0.4 R(2) + 0.3 R(5)) \\ \text{SD} &= \text{SD}/10 \\ \text{SD} &= \text{INT}(\text{SD} - \text{ENV_FAC} + 0.5) \end{aligned}$$

SD = SD x 10
 If (SD < 0.0), then SD = 0

Deep-Dose (DD) Component (5.15)

If R(2) < 0, Then DD = 0

$$XLLN = \frac{R(2)}{R(1)} + \frac{R(5)}{R(2)}$$

 XL1 = 0.76
 If(XLLN .LT. 0.5), then XL1 = 0.80
 If(XLLN .GT. 1.5), then XL1 = 0.92

$$DL1 = R(2) - R(5)$$

 If((R(2) - R(5)) < 0), DL1 = 0

$$DD = C_1 * (R(5) + XL1 * DL1)$$

$$DD = DD/10$$

$$DD = INT(DD - ENV_FAC + 0.5)$$

$$DD = DD * 10$$

 If (DD < 0.0), then DD = 0

*** SHALLOW LESS THAN DEEP-DOSE CORRECTION ***
 If (SD < DD), Then SD = DD

Fast-Neutron Dose (FN) Component (5.16)

If (R(3) or R(4) < 50, then FN = 0
 If (R(4) - 1.05 x R(5)) < 0, then FN = 0
 If (R(5)/R(3) or R(5)/R(4)) < 0.8, then FN = 0

$$XF = (R(3) - R(4))$$

 If (XF < 20 and R(3) < 100), then FN = 0
 If (R(3)/R(4) > 1.75), then FN = 0
 If XF < 0, then XF = 0

$$FN = C_5 * R(4) - C_6 * R(5) - C_7 * XF$$

$$FN = FN/10$$

$$FN = INT(FN + 0.5)$$

$$FN = FN * 10$$

 If (FN < 0.0), then FN = 0

Slow-Neutron Dose (SN) Component (5.17)

$$SN = C_4(R(3) - R(4))$$

$$SN = SN/10$$

$$SN = INT(SN + 0.5)$$

 If SN < 0, then SN = 0

where R(i) refers to the adjusted chip count for each dosimeter k. Position i calculated as follows:

$$R(i) = (XR(i) - \emptyset TM(i)) \times CSF(k, i) \times RSF + PSF(i) \quad (5.18)$$

where XR(i) = the raw chip count before any adjustments

CSF = the chip sensitivity factor for the kth dosimeter and ith position

RSF = the reader sensitivity factor

PSF = the position sensitivity factor determined by the following ratio:

$$PSF(i) = \frac{(1TM(i) - \emptyset TM(i))}{(1TM(2) - \emptyset TM(2))}$$

C₁ = calibration factor in mrem-per-reader count for deep- or shallow-dose component

C₄ = calibration factor in mrem-per-reader count for thermal-neutron dose component

C₅ = calibration factor in mrem-per-reader count for fast-neutron dose component

C₆ = calibration factor in mrem-per-reader count for photon correction to fast- neutron dose component

C₇ = calibration factor in mrem-per-reader count for thermal-neutron correction to fast-neutron dose component

ENV_FAC = environmental dose based on the number of days elapsed between previous and current dosimeter processing.

Beta/Photon Dosimeters. Beta/photon dosimeters are used to monitor radiation workers who are exposed to significant beta radiation. The significance of beta radiation to personnel dose in the work environment can be determined using the area dosimeter.

Calibration Factors - Calibration factors for the beta/photon dosimeter are based on the dosimeter response to ¹³⁷Cs gamma radiation, 16- and 59-keV K-fluorescent x-rays, and ⁹⁰Sr radiation. The coefficients used in the dose algorithm use the same factors obtained from the 1T and $\emptyset$ T multipurpose control dosimeters discussed for the multipurpose dosimeters.

Dose Algorithm - The dose algorithm for the beta/photon dosimeter is based on initially estimating a nonpenetrating radiation component. The deep dose is calculated directly. The shallow dose is equal to the sum of the nonpenetrating component and the deep dose. This is done using the following formulas:

(5.19)

```
BPC1 = 0.8 * C1
BPC2 = 0.383 * C1
BPC3 = 0.3 * C1
BPC4 = 1.16 * C1
R12 = R(1)/(R(2) + 1.0)
R13 = R(1)/(R(3) + 1.0)
R14 = R(1)/(R(4) + 1.0)
R41 = R(4)/(R(1) + 1.0)
R42 = R(4)/(R(2) + 1.0)
R43 = R(4)/(R(3) + 1.0)
R45 = R(4)/(R(5) + 1.0)
C***
C*** DEEP COMPONENT
C***

If(R(2) <= 0.0), then
    DC = 0.0
    GO TO 4000
END IF

C **** TEST TO SEE IF ANY LOW-ENERGY PHOTON PRESENT
C **** NO LOW-ENERGY PHOTONS PRESENT
If(R41 < 1.5), then
    If(R43 < 1.2), then
        C **** CS137 ONLY
        DC = C1 * R(2)
        GO TO 4000
    END IF

    If(R43 > 10.0), then
        C **** SR90 ONLY
        DC = 0.0
        GO TO 4000
    END IF

    C **** CS137 + SR90
    DC = C1 * R(3)
    GO TO 4000
    END IF

C **** LOW-ENERGY PHOTONS PRESENT
If(R43 > 15.0), then
    If(R41 > 3.4), then

        C **** 16KEV ONLY
        DC = BPC1 * R(2)
        GO TO 4000
    END IF

    C **** 16KEV + SR90
    DC = (1.9 * R(5) - R(1)) * BPC3
    GO TO 4000
```



```

END IF

If(R41 > 6.0 AND R12 < 1.1), then
C **** 59KEV AND M150 ONLY
    DC = 0.8 * C1 * R(2)
    GO TO 4000
END IF

If(R43 > 4.5 AND R12 > 1.1), then
C **** 16KEV + CS137
    DC = C1 * R(2)
    GO TO 4000
END IF
If(R43 > 2.0), then
    If(R12 < 1.1), then
        If(R43 < 3.0), then
            C **** CS137 + 59KEV
                DC = C1 * R(2)
                GO TO 4000
        END IF
    END IF

C **** 59KEV OR M150
C **** FACTOR OF 0.8 USED TO REDUCE OVER-RESPONSE ON CHIP 2
DC = 0.8 * C1 * R(2)

GO TO 4000
END IF

C **** 59KEV + SR90
    DC = BPC2 * R(3)
    GO TO 4000
END IF

C **** IF EVERYTHING FAILS
    DC = C1 * R(2)
    If (DC < 0.0), then
        DC = 0.0
    END IF

C **** SHALLOW COMPONENT
If R(1) < 0.0, then
    SC = 0.0
ELSE
    SC = BPC4 * (2.0 * R(1) - R(2) - 1.2 * R(5))
END IF

If SC < 0.0, then
    SC = 0.0
END IF

```

```

C **** CALCULATE SHALLOW DOSE
SD = SC + DC
ISD = INT(SD - ENVIRONMENTAL_FACTOR)
SD = ISD
If (SD < 0.0), then
    SD = 0.0
END IF

C **** CALCULATE DEEP DOSE
DD = DC
IDD = INT(DD - ENV_FAC)
DD = IDD
If DD < 0.0, then
    DD = 0.0
END IF

C **** SHALLOW DOSE LESS THAN DEEP DOSE CORRECTION
If (SD < DD), then
    SD = DD
END IF

```

where $R(i)$ = the adjusted chip count

C_1 = calibration factor in mrem-per-reader count determined from multipurpose control dosimeters

BPC1 = calibration factor in mrem-per-reader count for low-energy photon deep-dose component

BPC2 = calibration factor in mrem-per-reader count for mixed mid-energy photon and ^{90}Sr deep-dose component

BPC3 = calibration factor in mrem-per-reader count for mixed low-energy photon and ^{90}Sr deep-dose component

BPC4 = calibration factor in mrem-per-reader count for shallow-dose component

ENV_FAC = environmental dose based on the number of days elapsed between previous and current dosimeter processing.

5.2.2 Processing Dosimeters Using a Manual Reader

Processing individual chips from ring or two-element dosimeters with the manual readers is similar to the automated reader processing. The reader is set up according to standard procedures, and the sensitivity of the reader must be within an acceptable tolerance, using both an internal light source and the routine processing of background and dosed control chips. The reader calibration is determined for each dosimeter processing.

Manual Reader Sensitivity Using Internal Light Source

The sensitivity of the manual readers is monitored routinely using the internal light source. Process control procedures require that the sensitivity of the readers be maintained within 5% throughout the processing.

Manual Reader Sensitivity Using Control Chips

The relative sensitivity of the manual readers is available from the results of processing control chips throughout the dosimeter processing. Control chips are either 1) no-dose, background-level chips identified as BK dosimeters or 2) chips exposed in-air to 1-R ^{137}Cs gamma radiation and identified as CK dosimeters. Control chips, including both dosed and background chips, are processed at least every 50 chips.

Calibration Factor

A single calibration factor is determined for each batch of ring or two-element dosimeter chips from the results of the control dosimeters. This is done using the following formulation:

Calibration Coefficients from Control Dosimeter Readings.

$$\begin{aligned} P_1 &= (\text{CKM} - \text{BKM}) \\ \text{RC}_1 &= \frac{1030}{P_1}, \text{ mrem/reader count} \\ \text{RC}_2 &= 0.81 \times \text{C}_1, \text{ mrem/reader count} \end{aligned}$$

Dose Algorithm

Different dose algorithms are used for the ring and two-element dosimeters.

Ring Dosimeters

The formulation used to calculate a deep dose from the ring dosimeters follows:

$$\begin{aligned} \text{DD} &= \text{RC}_1(\text{R}_R - \text{BKM}) - \text{ENV_FAC})/10.0 \\ \text{If } \text{DD} < 0, &\text{ then } \text{DD} = 0 \\ \text{IDD} &= (\text{INT}(\text{DD} + 0.5)) * 10 \end{aligned}$$

where RC_1 = the ring calibration factor in millirem-per-reader unit discussed above

R_R = the raw chip reading

BKM = the average reader count for background control dosimeters
ENV_FAC = the environmental background correction based on the time between the dosimeter issue (close to chip annealing date) and dosimeter processing

DD = ring dose in centirem

IDD = ring dose reported in nearest multiple of 10 mrem.

There are two chips in each of the ring dosimeters. If both chips are processed, the chip with the highest reading is used to calculate the reported dose.

Two-Element Dosimeters.

The formulation used to calculate shallow and deep dose from the two-element dosimeters is based on first estimating a nonpenetrating component. The deep dose is calculated directly, and the shallow dose is the sum of the nonpenetrating component and the deep dose. The shallow dose is based on the dosimeter response to ^{90}Sr beta radiation and the deep dose is based on the dosimeter response to ^{137}Cs gamma radiation. The dose is calculated from the following formulation:

Nonpenetrating (NP) Component

$\text{SNP} = C_2 * (R(1) - R(2))/10.0$
If $(\text{SNP} < 0)$, then $\text{SNP} = 0$
 $\text{ISNP} = (\text{INT}(\text{SNP} + 0.5) * 10)$

Deep-Dose (DD) Component

$\text{SDD} = (C_D * (R(2) - \text{BKM}) - \text{ENV_FAC})/10.0$
If $(\text{SDD} < 0.0)$, $\text{SDD} = 0$
 $\text{ISDD} = (\text{INT}(\text{SDD} + 0.5) * 10)$
If $(\text{ISDD} < 0)$ then $\text{ISDD} = 0$

Shallow-Dose (SD) Component

$\text{ISDS} = \text{ISNP} + \text{ISDD}$

5.3 PERSONNEL DOSE ASSESSMENTS

Doses recorded in the official personnel files are assessed using the following relationships.

$$\begin{aligned} \text{Whole Body Dose} = & \text{Deep Dose} \\ & + \\ & \text{Fast-Neutron Dose} \\ & + \\ & \text{Slow-Neutron Dose} \end{aligned}$$

$$\begin{aligned} \text{Skin Dose} = & \text{Shallow Dose} \\ & + \\ & \text{Fast-Neutron Dose} \\ & + \\ & \text{Slow-Neutron Dose} \end{aligned}$$

$$\begin{aligned} \text{Extremity Dose} = & \text{Skin Dose} \\ & + \\ & \text{Finger Ring Dose} \end{aligned}$$

The two-element dosimeter results are evaluated on a case-by-case basis. The deep-dose component would correspond to a whole body dose. The shallow-dose component would correspond to a skin dose.

SECTION 6.0

Quality Control

6.0 QUALITY CONTROL

Operating parameters of the automated and manual reader systems must meet predetermined values and limits, respectively, for processing dosimeters. Open and/or field audit dosimeter results are evaluated and recorded.

6.1 AUTOMATED READER SYSTEM

The automated reader is microprocessor-controlled. Several operating parameters of the reader are monitored automatically and, for processing to continue, these parameters must meet predetermined values. If the predetermined limits are not met, the reader sounds an alarm and processing is stopped until the problem is resolved. Parameters monitored include temperature of the heater, flow of nitrogen, pneumatic pressure, reader dark current, reader sensitivity to internal light source, and reader results from processing control dosimeters exposed to 1 R of ^{137}Cs gamma radiation and background control dosimeters.

Unique sequence numbers are assigned to each dosimeter processing, reader light-source reading and reader dark-current reading. By using the sequence numbers, the sequence of results for routine, control, and audit dosimeters, as well as for reader light-source and dark-current readings, can be retrospectively examined.

6.2 MANUAL READER SYSTEM

An operating procedure is used to prepare the manual reader for processing chips. Reader dark current and internal light source readings are collected and must comply with predetermined limits before processing can be initiated. Control dosimeters consisting of no-dosed background and 1-R ^{137}Cs dosed chips are also processed. The results of these dosimeters must meet predetermined limits. If any of the limits are not met, routine processing is stopped until all quality control limits are met.

6.3 PROCESS CONTROL DOSIMETERS

Throughout the processing of dosimeters with either the automatic or manual reader systems, process control dosimeters are processed at least every 50 dosimeters. Control dosimeters consist of the following:

Multipurpose Dosimeters

ØT dosimeters - no-dosed, background control dosimeters

1T dosimeters - 1-R ¹³⁷Cs exposed dosimeters

Basic Dosimeters

2T dosimeters - no-dosed, background control dosimeters

7T dosimeters - 1-R ¹³⁷Cs exposed dosimeters

Ring and Two-element Dosimeters

BK dosimeters - no-dosed, background control dosimeters

CT dosimeters - 1-R ¹³⁷Cs exposed dosimeters

The results from processing these dosimeters are recorded, used to evaluate the quality of the dosimeter processing, and used to determine the calibration factors for multipurpose, beta/photon, and basic dosimeters.

6.4 AUDIT DOSIMETERS

Audit dosimeters, including field and/or open audit dosimeters, are processed with each routine dosimeter processing. Field audit dosimeters are similar, in all aspects, to routinely assigned personnel dosimeters. These dosimeters are identified with standard payroll numbers and are submitted for processing by respective contractors along with the rest of their dosimeters. Open audit dosimeters are distinctly marked as audit dosimeters and are processed throughout the dosimeter processing. For both field and open audit dosimeters, the type of radiation and the dose level of the exposure are unknown to the operator.

6.5 DOSIMETER PROCESSING EVALUATION

At the completion of each dosimeter processing, an evaluation is made using open and/or field audit dosimeter results to determine the acceptability of results relative to pre-established limits. Figures 6.1 through 6.6 represent test charts used to graph the difference between the calculated and given doses for the ring, multipurpose, and basic dosimeters, respectively. A minimum of 80% of the reported results must lie within the tolerance limits shown on each of the respective graphs.

FIGURE 6.1. Performance Chart of Audit Ring Dosimeters Exposed to ^{137}Cs Gamma Radiation

FIGURE 6.2. Performance Chart of Audit Basic Dosimeters Exposed to ^{137}Cs Gamma Radiation

FIGURE 6.3. Performance Chart of Audit Multipurpose Dosimeters Exposed to 16-keV X-Ray Radiation

FIGURE 6.4. Performance Chart of Audit Multipurpose Dosimeters Exposed to Slow-Neutron (Sigma Pile) Radiation

FIGURE 6.5. Performance Chart of Audit Multipurpose Dosimeters Exposed to Fast-Neutron (^{252}Cf - PuF_4 -Equivalent) Radiation

FIGURE 6.6. Performance Chart of Audit Basic Dosimeters Exposed to ^{137}Cs Gamma Radiation

6.6 PERSONNEL DOSE REPORTING

Upon completion of the processing evaluation, a form is signed by the dosimeter processing supervisor and a technical reviewer indicating any adjustment to the dosimeter dose results and their mutual agreement on the acceptability of the dosimeter processing results for official dose recording. An example of this form is shown in Exhibit 6.1.

6.7 QUALITY CONTROL REPORTING

A copy of the Dosimeter Results Acceptance form (shown in Exhibit 6.1) and copies of the audit dosimeter test charts (shown in Figures 6.1 through 6.6) are provided to the External Dosimetry historical files. In addition, a letter report summarizing any significant deviations from routine procedures occurring during each routine dosimeter processing is prepared for each Hanford contractor. A statement evaluating the audit dosimeter results is included in the letter report.

EXHIBIT 6.1.

DOSIMETER RESULTS ACCEPTANCE FORM

DOSIMETER RESULT ACCEPTANCE

PROCESSING REVIEW

RUN: _____
(Month/Year)

Annual

Quarterly

Monthly

READER # _____ SEQUENCE NUMBER: Beg. _____ End: _____

RING CALIBRATION FACTORS: BO: _____ C1: _____ C2: _____

FINAL CALIBRATION FACTORS:

C₀ _____ C₄ _____
C₁ _____ C₅ _____
C₂ _____ C₆ _____
C₃ _____ C₇ _____

BLANKS: BO: _____ B1: _____ B2: _____ B3: _____ B4: _____ B5: _____

CORRECTIONS TO BE APPLIED TO DOSE RESULTS*:

<u>Dosimeter</u>	<u>SHALLOW</u>	<u>DEEP</u>	<u>TOTAL NEUTRON</u>	<u>EYE</u>
Finger Rings		_____		
Basics	_____	_____		
Multipurpose	_____	_____	_____	_____
Beta/Photon	_____	_____		

*Reported Results X indicated factor.

COMMENTS: _____

PROCESSING ACCEPTANCE:	_____	DATE:	_____
TECHNICAL ACCEPTANCE:	_____	DATE:	_____
	_____		_____
	_____		_____

SECTION 7.0

Personnel Dose Evaluation for Abnormal Circumstances

7.0 PERSONNEL DOSE EVALUATION FOR ABNORMAL CIRCUMSTANCES

Abnormal circumstances include lost dosimeter results, abnormal dosimeter results, and dosimetry results not indicative of actual exposure conditions. The dose evaluation of these abnormal circumstances and for personnel skin or clothing contamination is reported to the respective contractor Radiation Protection staff.

7.1 LOST DOSIMETER RESULTS

The respective contractor Radiation Protection staff are contacted whenever a personnel dosimeter result is lost. An investigation is conducted regarding the circumstances of any occupational exposure received by the employee and a letter is prepared providing the best estimate of the dose received by the employee for the time period representing the lost result. The estimate may be based on an evaluation of previous exposure received by the employee when doing similar work, on a review of exposure received by other employees, or on any other pertinent information.

7.2 ABNORMAL DOSIMETER RESULTS

Abnormal dosimeter results may be identified by glow curves, atypical chip ratios, or questions from respective contractor Radiation Protection organizations regarding the appropriateness of an individual dosimeter result. For any investigation resulting in a proposed change to the dosimeter record for an employee, a letter is written to the respective contractor Radiation Protection organization identifying the apparent cause of the problem and, if sufficient information is available, a recommended dose. If necessary, an investigation is performed by the contractor to determine the appropriate dose to be assigned to the employee. The respective contractor is informed by letter of the correct dose to be recorded and a copy of the letter is placed in the individual's exposure history file.

7.3 DOSIMETER RESULTS NOT INDICATIVE OF ACTUAL EXPOSURE CONDITIONS

The accuracy of recorded personnel doses is contingent on the use of properly designed and calibrated dosimeters for employee working conditions.

The response of the Hanford dosimeters is well characterized for different beta, photon, and/or neutron radiation fields and proper use of these dosimeters is the responsibility of the employee and respective contractor Radiation Protection organization. Technical evaluation of the dosimeter response by PNL External Dosimetry Program staff to new or different radiation fields can be arranged through the respective contractor Radiation Protection organizations.

7.4 DOSE EVALUATION FOR PERSONNEL SKIN OR CLOTHING CONTAMINATION

Procedures are in effect for the respective contractor Radiation Protection organizations that identify action levels for follow-up dose evaluation for skin or clothing contamination. When an evaluation is determined to be necessary, documentation is prepared describing the various assumptions used in the dose assessment. A copy of this information is provided to the individual's exposure history file.

SECTION 8.0

Nuclear Accident Dosimetry

8.0 NUCLEAR ACCIDENT DOSIMETRY

Several methods for determining personnel dose evaluation from a nuclear accident are described in this section.

8.1 PERSONNEL DOSE EVALUATION

Several steps can be performed to identify personnel who may have received significant exposure from a nuclear event or from a very high-level radiation source. The specific steps, depending on the type of the source and the nature of the personnel exposure, are described in the following subsections.

8.1.1 Quick-Sort Evaluation

The "quick-sort" is a field measurement of ^{24}Na activity in the human body after an exposure to neutron radiation. Measurements are made quickly by placing the probe of a Geiger-Mueller (GM)-type survey instrument against the abdomen of a subject who is bent over during the measurement. An alternative approach is to place the GM probe in the armpit and have the individual hold it tightly against his/her body by exerting pressure with his/her arm. Empirical data have been developed relating the neutron dose received by the subject to the observed GM count rate.

8.1.2 Metal Object Analysis

Samples of metallic objects (coins, rings, belt buckles, eyeglass frames, etc.) carried by the person may be analyzed to determine the activity of any radionuclides produced by exposure to neutron radiation. A complex evaluation of the activity of the different radionuclides produced, the mass of the original metallic elements, and consideration of the geometry of the exposure conditions can all provide valuable information regarding the neutron spectrum and the dose received.

8.1.3 In Vivo Examination

A whole body in vivo examination can provide information on the activity of different radionuclides in the body and the spatial distribution of these

nuclides. This information can provide an evaluation of the dose received and possibly information on the orientation of the body during exposure.

8.1.4 Blood Analysis

Samples of blood can be used to estimate the concentration of ^{24}Na in blood resulting from neutron radiation or the number of chromosomal aberrations that are correlated to the whole body dose received.

8.1.5 Hair Analysis

Samples of hair can be used to estimate the dose and spatial profile of the exposure conditions to fast-neutron radiation through analysis for ^{32}P .

8.1.6 Interpretation of Multipurpose Dosimeters

Dosimeters for all personnel involved in a criticality will be collected for special processing. Normal process control features will be used and routine procedures will be used for determining radiation dose measured by each dosimeter. Additional interpretation is necessary when dose and spectrum measurements become available from personnel nuclear accident dosimeters (PNADs) and fixed nuclear accident dosimeters.

8.2 PERSONNEL NUCLEAR ACCIDENT DOSIMETERS

Personnel nuclear accident dosimeters are worn by personnel for use in determining the neutron spectrum in the event of a criticality. These dosimeters should be collected for all personnel along with the multipurpose dosimeters.

8.3 FIXED NUCLEAR ACCIDENT DOSIMETERS

Fixed nuclear accident dosimeters are located throughout Hanford facilities in locations where a nuclear accident can potentially occur. The construction and location of these units are described in PNL's internal guidelines on the location of criticality alarms and nuclear accident dosimeters at Hanford. The dosimeters, containing several metallic foils, a sulfur pellet, and TL chips, are positioned where they may be retrieved following a nuclear accident. Analysis of these materials provides information to assess the deep-tissue dose from neutron and photon radiation, as well

as the energy fluence of the neutron radiation resulting from a nuclear accident. This information can be used to characterize the nuclear accident better and to improve the accuracy of the dose estimated for any employees exposed.

SECTION 9.0

References

9.0 REFERENCES

U.S. Department of Energy (DOE). 1986. Department of Energy Standard for the Performance Testing of Personnel Dosimetry Systems. DOE/EH-0027, Washington, D.C.

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