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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AP	anterior-posterior
CFR	Code of Federal Regulations
DCF	Dose Conversion Factor
DOE	U.S. Department of Energy
DOELAP	DOE Laboratory Accreditation Program
INEEL	Idaho National Environmental and Engineering Laboratory
$H_p(d)$	Personal Dose Equivalent
keV	kilovolt-electron
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
MDL	minimum detection level
MED	Manhattan Engineer District
mm	millimeter
NTS	Nevada Test Site
NVLAP	National Voluntary Laboratory Accreditation Program
ORNL	Oak Ridge National Laboratory
ORAUT	Oak Ridge Associated Universities Team
RFP	Rocky Flats Plant
ROT	rotational
SRS	Savannah River Site
TIB	technical information bulletin
TLD	thermoluminescent dosimeter
U.S.C.	United States Code

1.0 INTRODUCTION

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

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

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

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

- Radiation from naturally occurring radon present in conventional structures

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

- Radiation from diagnostic X-rays received in the treatment of work-related injuries

The Manhattan Engineer District (MED) and later the U.S. Atomic Energy Commission (AEC) had early responsibility for processing nuclear weapons material. The AEC was superseded in this function briefly by the Energy Research and Development Agency, and then by DOE. In this document, "DOE" is a term of convenience meaning the Department of Energy and its predecessor agencies.

Essentially all DOE sites followed a similar evolution in external dosimetry technology. Early two-element film dosimeters were followed by multielement film dosimeters, and thermoluminescent dosimeters (TLDs) replaced film dosimeters from the late 1960s through the early 1980s. Since the late 1980s, DOE has required accreditation of personnel dosimetry programs under the DOE Laboratory Accreditation Program (DOELAP; DOE 1986a,b) or, for smaller programs, under the National Voluntary Laboratory Accreditation Program (NVLAP; Torres 2005). Both of these programs (DOE 1986b, Torres 2005) involve biennial performance testing based on guidance in American National Standards Institute (ANSI) Standard N13.11 (HPS 2001 or an earlier version). Under the Energy Employees Occupational Illness Compensation Program Act, dose reconstructors are to use personnel doses measured with DOELAP-accredited dosimetry programs (NIOSH 2002).

This Oak Ridge Associated Universities Team (ORAUT) TIB is based on the feasibility for the dose reconstructor to apply reasonable, overestimating, complex-wide assumptions for interpreting recorded photon dose for monitored workers due to the high degree of standardization of DOE TLD-based programs. In accordance with the process efficiencies discussed in 42 CFR Part 82, the TIB analysis selected a reasonable overestimate of external radiation dose for cases that are judged to be likely-noncompensable. This overestimate of the actual dose enables the expeditious processing of likely-noncompensable claims.

1.1 OBJECTIVES

The objectives of this document are to (1) evaluate the degree of standardization of DOE TLD measurements and (2) develop a standard methodology that the dose reconstructor will use to assign a dose, based on the recorded dose, resulting in a reasonable overestimate of the organ dose. This document examines the performance of TLDs and proposes the application of the standard methodology to overestimate doses and address uncertainties from the following sources.

- Variation in workplace photon radiation fields
- Variation in workplace exposure geometries
- Variation in worker orientation in the workplace, the organ of concern, and the range of values for organ dose conversion factors presented in *External Dose Reconstruction Implementation Guidelines* (NIOSH 2002)

While accounting for these uncertainties, the methodology proposed here takes into account similarities among sites throughout the DOE complex in the following attributes:

- Similar dose response performance by photon energies among the TLDs used
- Similar minimum detection levels (MDL)
- A standard exchange frequency

The proposed methodology considers variability associated with a large number of program features. The methodology must admit a greater degree of error into any estimate that it modifies. This error is permissible as long as it is in the claimant's favor. Specifically, any error must tend to assuredly overestimate rather than reduce the claimant's probability of causation.

Because the intent is to overestimate the dose for a quick evaluation of the potential for compensability, the proposed methodology is useful only for probable noncompensable claims.

The use of this methodology will be inappropriate for certain organs outside the considered range of organ dose conversion factors. For this reason, dose reconstructions for cancers of skin and eye and to the bone surface are not to use the claimant-favorable overestimates resulting from the analyses in this document. These assumptions also exclude assignment of shallow doses, which precludes dose reconstruction for cancers to the skin, testes, or breast.

2.0 COMPLEX-WIDE STANDARD OVERESTIMATING METHODOLOGY

Three components of the standard methodology to overestimate the organ dose assigned to a claimant for a likely-noncompensable claim are:

- Recorded dose
- Dose Conversion Factor (DCF)
- Missed dose

Recommendations are provided in the following with supporting information presented in Appendix A.

2.1 OVERESTIMATING APPLIED TO RECORDED DOSE

This TIB recommends a standard overestimating approach that, with a single modifying value applied to the recorded dose, increases the assigned dose to claimants to overestimate the actual $H_p(10)$ dose. The purpose of this modifying factor is to ensure claimant-favorable assigned organ dose for potential site-specific exposure conditions and calibration practices that, without correction, could result in an underestimated dose.

This modifying factor provides a simple option for evaluation of likely-noncompensable claims. The dose reconstructor multiplies the recorded dose by the standard modifying factor to overestimate the actual dose. This factor must be sufficiently high to compensate for variance in dosimeter performance among sites and to take into account corrections that might be required to convert the dose as measured from site to site to a standard value of $H_p(10)$. Table 2-1 lists values of factors that would correct for variations in calibration and site-specific workplace conditions.

Correction of each of these values would require application of factors with a value over the range of 0.87 to 1.22. The highest 95% uncertainty factor in Fix, Gilbert, and Baumgartner (1994) was 1.3, or for the range in reported dose for the beams examined compared to $H_p(10)$ of 0.7 (0.87/1.3) to 1.6 (1.22 × 1.3). Greater uncertainty is expected at lower photon energies. However, for most workplaces and longer term workers, the measured dose at levels sufficiently greater than the MDL will probably closely estimate $H_p(10)$ without modification and reasonably estimate exposure to the worker.

Table 2-1. Consolidated results for geometry and calibration method (from Tables A-3 and A-4).

Irradiation	Geometry/phantom	Ratio of reported dose to given

		$H_p(10)$ by photon energy (keV)[a]			
		70	118,[b] 120[c]	208	662
AP	Slab		1.1	1.1	1.1
AP, 72-83	Anthropomorphic	1.05	0.96		1.1
AP, 84-94	Anthropomorphic	0.95	0.87		1.0
Rotational	Anthropomorphic		1.1	1.2	1.0
Rot, 72-83	Anthropomorphic	1.17	1.14		1.22
Rot, 84-94	Anthropomorphic	1.06	1.03		1.11
Isotropic	Anthropomorphic		0.9	1.0	0.9
Average		1.06	1.01	1.1	1.06

a. Values have been modified from response ratios (in parentheses) to multiplicative correction factors.
b. Thierry-Chef et al. (2002)
c. Wilson et al. (1990)

2.2 OVERESTIMATING APPLIED TO ORGAN DOSE CONVERSION FACTOR

This TIB recommends a standard overestimating organ DCF. Use the DCF to calculate the organ dose by multiplying the recorded deep dose value by the DCF. The value of the DCF represents an additional source of variation.

For organ dose reconstruction, photon doses are divided into three groups of energies: less than 30-keV photons, photons with energies between 30 and 250 keV, and photons with energies greater than 250 keV. The maximum values of the photon DCFs (DCF_{max}) listed in NIOSH (2002) were evaluated for these three energy ranges for all organs except the eye, skin, testes, breast, and bone surface. The value of the maximum DCF varies from a low of 0.154 (photons of energies less than 30 keV to the red bone marrow) to a maximum of 1.066 (photons of energies greater than 250 keV to the thyroid). A value of 1.100, rounded for simplicity, captures the few values greater than unity while overestimating the organ dose in relation to the majority of the listed DCFs.

2.3 OVERESTIMATING APPLIED TO MISSED DOSE

This TIB recommends a standard overestimating approach to determining the missed dose. The consistency of intersite comparison of levels of detection suggests a standard value for missed dose of 0.020 rem per dosimeter reading (see Appendix A). This factor is based on laboratory testing, and it is not known how this might be reflected in MDLs for dosimeters in operational use in the workplace. To ensure a claimant-favorable approach, increase the assumed value for missed dose to 0.030 rem in the absence of site-specific information. This value is twice the value for missed dose for TLDs in use at the SRS, and six times the missed dose for DOELAP-approved TLDs; the value is 50% greater than the missed dose for Hanford site-specific TLDs, and three times the value for missed dose with Hanford DOELAP-approved TLDs. The claimant favorability in this overestimate is intended to offset the uncertainty in missed dose for early TLDs when the DOELAP testing protocol was not in place. Personnel dosimeter performance testing was conducted for many years prior to DOELAP (Roberson et al. 1983; Unruh et al. 1967; Gorson, Suntharalingam, and Thomas 1965) and was the subject of an AEC notice in 1963 (AEC 1963). Assume an exchange period of monthly (see Appendix A) and calculate an overestimate of the missed dose by applying the MDL to all badge cycles (i.e., 360 mrem).

Standard assumption for dosimeter exchange frequency: The transition of the early film badge exchange frequency to at least a monthly exchange frequency is described in the Site Profiles. Most sites had changed to a standard monthly and/or quarterly exchange frequency by the time TLD use began. Thus, for the period of applicability of the assumptions in this TIB, badge exchange

frequencies are assumed to be monthly although the actual exchange period should be considered from the Site Profile.

2.4 APPLICATION OF STANDARD OVERESTIMATING ASSUMPTIONS

Table 2-2 summarizes standard values for the correction factors recommended in Sections 2.1 through 2.3. A combined standard overestimating approach of 2 is obtained for the combined effects of the recorded dose modifying factor and the maximum DCF (i.e., 1.6 × 1.1 = 1.76 for the 95% uncertainty or, to account for greater than 95% uncertainty and simplicity, a factor of 2.00). This single value can be applied to all deep doses reported by DOE sites to arrive at a claimant-favorable estimate of the dose to any organ except the eye, skin, testes, breast and bone surface. In addition, it is not appropriate to apply estimates of uncertainty after the application of overestimating assumptions. Additional doses from reported shallow dose would need to be evaluated separately, as applicable, depending on the organ of interest.

Table 2-2. Standard overestimating approach.

Parameter	Analysis	Standard overestimating approach
Recorded dose	Multiply by 1.6	Multiply recorded deep dose by factor of two and enter as constant value in IREP
DCF	DCF = 1.1	
Missed dose	Zero recorded dose	Lognormal distribution, IREP parameter #1 = MDL/2 = 0.18[a] rem IREP parameter #2 = 1.52

a. Use TBD identified value, if available. Otherwise use this value based on n*LOD, where n = 12.

Dose reconstructors should apply the values in Table 2-2 based on the period of applicability for the site in question from the date of first use of TLDs through the DOELAP-accredited periods, when $H_p(10)$ equivalency is expected. The dates listed in Table 2-3 reflect the dates after which dose reconstructors can apply the assumptions in this TIB. The entries for INEEL and RFP are later than the date of TLD first use due to the potential unreliability of correction factors prior to 1970. Most sites implemented TLDs in the 1970s, as noted in Appendix A. The response characteristics of early TLDs (prior to 1970 unless specified in Table 2-3) require further evaluation and are therefore excluded.

Table 2-3. Periods of applicability for assumptions, by site.

Site	Apply assumptions from listed year (year of first use of TLDs)
Fernald	1985
Hanford	1972
INEEL	1970
K-25	1980
LANL	1980
LLNL	1969
Mound	1977
NTS	1979
ORNL	1974
Pantex	1973
Portsmouth	1981
RFP	1971
SRS	1970
Y-12	1980

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A.1 DOSIMETRY DEVELOPMENT AND BASIS OF COMPARISON

A.1.1 Dosimetry Development

Radiation response characteristics of dosimetry technology used by the DOE sites are highly similar. Most MED sites followed a similar evolution in dosimetry technology from the two-element film dosimeter design developed in 1944 (Pardue, Goldstein, and Wollan 1944), the use of multielement film dosimeter designs and, later, thermoluminescent dosimetry methods because of the ease of automation and nearly tissue-equivalent radiation response to photon radiation. The judgment in this TIB is that equivalent performance in dose estimation is achieved with the thermoluminescent dosimetry technology used by DOE sites as evaluated in this analysis. This conclusion is based on a survey of the Site Profiles listed in Table A-1.

A.1.2 Basis of Comparison

Since the initiation of the MED in the early 1940s, various radiation dose concepts and quantities have been used to measure and record occupational dose. A basis of comparison for reconstruction of dose is the *Personal Dose Equivalent*, $H_p(d)$, where d identifies the depth (in millimeters) and represents the point of reference for dose in tissue. For weakly penetrating radiation of significance to skin dose, d = 0.07 mm and is noted as $H_p(0.07)$. For penetrating radiation of significance to "whole-body" dose, d = 10 mm and is noted as $H_p(10)$. Both $H_p(0.07)$ and $H_p(10)$ are the radiation quantities recommended for use as the operational quantities to be recorded for radiological protection purposes by the International Commission on Radiological Units and Measurements (ICRU 1993). In addition, $H_p(0.07)$ and Hp(10) are the radiation quantities used in DOELAP and NVLAP dosimeter performance testing.

Table A-1. MED/AEC/DOE sites with equivalent beta/photon dosimetry capabilities.

Site	Site profile reference	Thermoluminescent dosimeter year of first use	
		Site-specific	Commercial
Fernald	ORAUT-TKBS-0017-6	N.A.	1985
Hanford	ORAUT-TKBS-0006-6	1972	1995
Idaho National Environmental and Engineering Laboratory (INEEL)	ORAUT-TKBS-0007-6	1966	1986
K-25	ORAUT-TKBS-0009-6	1980	1988
Lawrence Livermore National Laboratory (LLNL)	ORAUT-TKBS-0035-6	1969	1985
Los Alamos National Laboratory (LANL)	ORAUT-TKBS-0010-6	1978	1999
Mound	ORAUT-TKBS-0016-6	N.A.	1977
Nevada Test Site (NTS)	ORAUT-TKBS-0008-6	1970	1987
Oak Ridge National Laboratory (ORNL)	ORAUT-TKBS-0012-6	1974	1988
Pantex Gaseous Diffusion Plant	ORAUT-TKBS-0013-6	1973	1980
Portsmouth Gaseous Diffusion Plant	ORAUT-TKBS-0015-6	1981	1999
Rocky Flats Plant (RFP)	ORAUT-TKBS-0011-6	1969	1983
Savannah River Site (SRS)	ORAUT-TKBS-0003	1970	1982
Y-12	ORAUT-TKBS-0014-6	1980	1988

N.A. – not applicable.

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A.2 DOSE RECONSTRUCTION PARAMETERS

Examinations of the beta and photon (X-ray, gamma ray) radiation type, energy, and geometry of exposure in the workplace, and the characteristics of the respective dosimeter response are relevant to the assessment of bias and uncertainty, respectively, of the original recorded dose in relation to the radiation quantity $H_p(10)$. The bias and uncertainty for current DOE dosimetry systems is well documented for $H_p(0.07)$ and $H_p(10)$ under the DOELAP. The performance of current dosimeters can be compared with performance characteristics of historical dosimetry systems in the same, or highly similar, facilities or workplaces.

Overall, the accuracy and precision of original recorded individual worker doses and their comparability dose reconstructors should consider in using NIOSH (2002) guidelines depend on the following (Fix, Wilson, and Baumgartner 1997):

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

- **Calibration** of the respective monitoring systems and similarity of the methods of calibration to sources of exposure in the workplace

- **Workplace radiation fields** at each site/facility, which can include mixed types of radiation, variations in exposure geometries, and environmental conditions

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

Each of these dependent factors must be evaluated. For cases requiring a detailed dose estimate, the evaluations must be based on an analysis of site-specific information, which is applied to formulate a realistic best dose estimate. For likely noncompensable cases, overestimating dose is appropriate, so dose reconstructors can use a modifying factor that increases the recorded deep dose to account sufficiently for variance in site practices. Identifying an appropriate value for this modifying factor is the goal of this document.

A.2.1 Dosimetry Technology

Table A-2 lists the history of implementation of TLD-based external dosimetry programs at DOE sites. TLDs have technical advantages over earlier film systems because of their near tissue-equivalent response and, with proper handling, general insensitivity to many environmental parameters. The adequacy of TLD methods to measure radiation dose accurately is determined from response characteristics of the dosimetry technology according to the radiation type, energy, exposure geometry, etc., as described in later sections. By the time TLDs had become widely used, the dosimeter exchange frequency at the sites had become generally standardized to either a monthly or quarterly exchange. A monthly exchange cycle for more highly exposed radiation workers was typical. Dose reconstructors should use case- or site-specific data when available.

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Table A-2. Chronology of DOE site implementation of TLD-based personnel dosimetry systems.

Facility	Period		Type	DOELAP accredited[a]
	Start	End		
Fernald	1985	Present	Commercial Panasonic TLD system	1990
Hanford	1972	1994	Hanford TLD system	1988
	1995	Present	Commercial Harshaw TLD system	
LANL	1978	1998	LANL TLD system	1987
	1999	Present	Commercial Harshaw TLD system	
Mound	1978	Present	Commercial Harshaw TLD system	1996
NTS	1979	1986	NTS TLD system	~1987
	1987	Present	Commercial Panasonic TLD system	
ORNL	1975	1980	ORNL TLD system	1989
	1981	1988	ORNL TLD system	
	1989	Present	Commercial Harshaw TLD system	
Pantex Plant	1973	1979	Pantex TLD system	1993
	1980	Present	Commercial Panasonic TLD system	
RFP	1969	1982	RFP TLD system	1991
	1983	Present	Commercial Panasonic TLD system	
SRS	1970	1981	SRS TLD system	1987
	1981	Present	Commercial Panasonic TLD system	
Y-12	1980	1988	ORNL TLD system	1989
	1989	Present	Commercial Harshaw TLD system	

a. Year of first successful DOELAP performance testing.

Table A-3. Maximum annual potential missed dose.

Dosimeter type	Exchange frequency	Laboratory MDL (rem)[a]	Max. annual missed dose (rem)[b]
Site-specific TLDs	Monthly (n = 12)	0.02	0.24
	Quarterly (n = 4)	0.02	0.08
Commercial TLDs	Monthly (n = 12)	0.01	0.12
	Quarterly (n = 4)	0.01	0.04

a. Estimated MDL based on site practice. Dose values less than the MDL are often recorded.
b. Maximum annual missed dose based on NIOSH (2002).

A.2.1.1 Potential Missed Dose

A consideration in the analysis of this TIB concerns the estimation of missed dose based on NIOSH (2002). Table A-3 summarizes information concerning the estimated maximum potential missed dose for personnel thermoluminescent beta/photon dosimeter estimated reasonable MDLs for monthly and quarterly exchange frequencies. MDLs for DOE site TLD systems are identified in the respective site external dosimetry documentation using the DOELAP laboratory testing protocol (DOE 1986b).

A.2.1.2 Site-Specific Thermoluminescent Dosimeter

TLD systems replaced the multielement film dosimeters at essentially all DOE sites. These systems had nearly tissue-equivalent response characteristics. This is particularly evident when compared to earlier film dosimeter response characteristics. Figure A-1 shows the energy dependence of the

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widely used lithium fluoride-based (i.e., Harshaw) and lithium borate-based (i.e., Panasonic) TLDs in comparison with $H_p(10)$. The relatively close tissue-equivalent response is representative of the site TLD systems.

A.2.1.3 Commercial TLD

As listed in Table A-1, the DOE sites proceeded to implement commercial dosimetry systems that were generally highly comparable in performance with the site-specific TLD systems and with each other. DOE site-specific and commercial TLD systems became accredited under DOELAP and

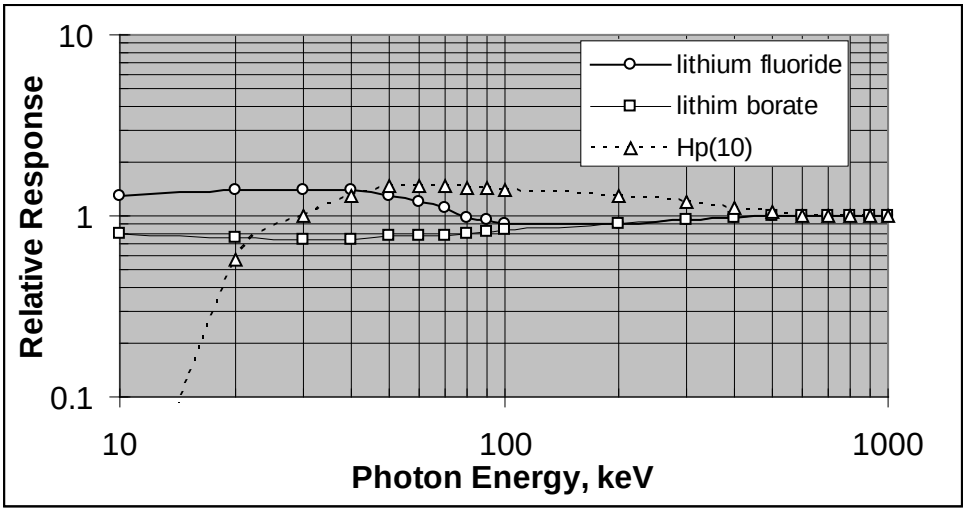

Figure A-1. Photon energy dependence in comparison with $H_p(10)$ (adopted from Becker 1973).

NVLAP, respectively, beginning in the mid- to late 1980s. These systems have been routinely reaccredited during subsequent, typically 2-year, accreditation cycles.

A.2.2 Calibration

The international adoption of the roentgen as a measure of the radiation quantity *exposure* in 1928 provided a means to compare national standards laboratory capabilities to measure *exposure* from photon radiation and a means to standardize a dosimeter response to beta radiation (i.e., in reference to the response from radium or X-rays). Agreement between the standard ionization chambers of several national laboratories to selected photon beams within ±1% was established in 1931 (Hine and Brownell 1956, p. 506). MED site calibration capabilities were based on the national standards laboratories, and these capabilities were used to calibrate dosimetry systems, beginning with ^{226}Ra and later with ^{137}Cs and ^{60}Co gamma radiation. The basic calibration of DOE dosimetry systems to higher energy photons is probably within a variance of a few percent. Parker (1945) demonstrated the basic capability for the Metallurgical Laboratory, ORNL, and Hanford sites to calibrate their dosimetry systems in 1944 to ^{226}Ra; this is indicative of the basic capability of sites to calibrate their dosimetry systems to higher energy photon radiation.

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The potential error in recorded dose depends not only on the higher energy photon response of the dosimetry technology but also on exposure characteristics for each radiation type, energy, and geometry present in the workplace. The similarity between the radiation fields used for calibration and those in the workplace is a significant issue. A significant advantage of TLDs over earlier film dosimeters is the near tissue-equivalent response of thermoluminescent materials in DOE TLD systems.

A.2.3 Dosimeter Performance Studies

Performance testing of personnel dosimetry systems is typically an ongoing activity of the dosimetry service provider and a routine component of dosimeter processing quality control. Well-documented independent performance studies of personnel dosimeters have been conducted by the AEC (1955), Brodsky and Kathren (1963), Unruh et al. (1967), the U.S. Public Health Service (Barber 1967), Chabot, Jimenez, and Skrable (1978), the NVLAP, DOELAP, Cummings (2003), and Thierry-Chef et al. (2002). The earlier studies were specific to film dosimeter performance; the later studies involved TLD systems. The combination of these studies involved many laboratories and dosimetry systems. For example, the Public Health Service study involved approximately 2,000 film badges from 25 organizations (Barber 1967). The DOELAP and NVLAP dosimeter performance testing programs initiated in the mid-1980s involve essentially all dosimeter service organizations in the United States. Performance testing is typically repeated every 2 years to maintain DOELAP or NVLAP accreditation.

A simple representation of the measured performance in these studies of dosimeter systems, in the categories of testing, is probably not possible. In addition, it is not possible to represent generally the improved performance associated with the ongoing evolution in dosimetry technology. National Sanitation Foundation Standard No. 16 (Barber 1967) presented upper and lower error factor limits that ranged from about 30% low to about 100% high (i.e., an asymmetric interval that is biased high) for beta and photon (X-ray and gamma) fields, and mixtures of beta and photon radiation. NVLAP and DOELAP testing protocols have varied somewhat, but fundamentally contain a tolerance criterion of bias plus one standard deviation between 0.3 and 0.5 (relative error) in routine beta, photon, and mixed beta/photon test and accident categories determined for 15 test dosimeters submitted in monthly exchanges of 5 dosimeters per test category for a 3-month period.

In addition to the independent performance testing studies for which the identity and performance of a laboratory are not available, many sites conducted intercomparison studies of dosimeter capabilities using laboratory and workplace irradiations. Wilson et al. (1990) summarized several such studies involving Hanford and other site (ORNL, LANL, SRS) dosimeters in laboratory and workplace exposures. In addition, many sites processed extensive internal control (i.e., blank or background and irradiated), calibration, and audit dosimeters with the personnel dosimeters. The results were routinely used to assess the acceptability of overall performance. In addition, several sites routinely evaluated worker measured doses using pocket ionization chambers, portable radiation detection instruments, and dosimeters. If there were inconsistencies, written evaluations were performed.

In recent years, further studies of early dosimeter performance compared to Hp(10) have been made because of the use of recorded dose in worker health effect studies. The International Agency for Research on Cancer (IARC) conducted a dosimeter intercomparison study to higher energy (i.e., greater than 100 keV) photons of 10 historical dosimetry systems commonly used throughout the world (Thierry-Chef et al. 2002). The IARC study considered that exposure to dosimeters worn by

workers could be characterized as anterior-posterior (AP), rotational (ROT), and isotropic irradiation geometries, or a combination thereof. Dosimeter response to selected photon energies was measured using two phantoms, which simulated the effect of the worker's body on the measured dosimeter response. The first was the International Standards Organization water-filled slab phantom, which is used for dosimeter calibration and performance testing. The second was an anthropomorphic Alderson Rando Phantom, which is constructed from a natural human skeleton cast inside material that has a tissue-equivalent response. Table A-4 lists results for the SRS commercial TLD that participated in IARC testing. The results for the SRS system are likely to be representative of other DOE TLD systems. Table A-5 summarizes results for the Hanford TLD system during 1972–1983 and 1984–1994 based on information in Fix, Gilbert, and Baumgartner (1994).

A.3 SITE-SPECIFIC INFORMATION

Site-specific information is necessary to develop detailed dose estimates. This is done to evaluate the performance of the dosimetry technology in the actual workplace radiation fields and the site-specific administrative practices regarding use of the dosimeters and practices. This establishes a basis to calculate and record occupational dose for individual workers. For likely noncompensable cases, however, dose reconstructors can apply a standard overestimating methodology that

Table A-4. IARC testing results for U.S. beta/photon dosimeters.[a]

Geometry	Phantom	118 keV		208 keV		662 keV	
		Mean	SD/mean	Mean	SD/mean	Mean	SD/mean
US-22 (SRS multielement thermoluminescent dosimeter)							
AP	Slab	0.9	4.4	0.9	3.9	0.9	3.5
AP	Anthropomorphic	0.8	3.1	0.9	2.1	0.9	3.9
Rotational	Anthropomorphic	1.1	3.1	1.2	1.5	1.0	4.1
Isotropic	Anthropomorphic	0.9	0.3	1.0	2.5	0.9	1.6

a. Ratio of recorded dose to $H_p(10)$.

Table A-5. Testing results for TLDs for energy and angular response.[a,b]

Beam energy (keV)	1972–1983		1984–1994	
	AP	Rotational	AP	Rotational
70 (M150 X-ray)	1.05 (1.3)	1.17 (1.5)	0.95 (1.3)	1.06 (1.5)
120 (H150 X-ray)	0.96 (1.2)	1.14 (1.3)	0.87 (1.2)	1.03 (1.3)
662 (Cs-137)	1.1 (1.2)	1.22 (1.3)	1.0 (1.2)	1.11 (1.3)

a. Judgment based on common dosimeter response characteristics and workplace radiation fields.
b. Fix, Gilbert, and Baumgartner (1994) TLD data only listed. Bias factor listed with estimated 95% uncertainty factor in parenthesis. Summary data for M150 calculated in the same manner as presented in Fix, Gilbert, and Baumgartner for H150 and Cs-137 with an increased 95% uncertainty factor as listed in the table.

overestimates dose to account for site-specific variations. Such a methodology is developed in Section 5.0.

A.3.1 Workplace Radiation Fields

Table A-6 summarizes common beta/photon personnel dosimeter parameters important to $H_p(10)$ performance in the workplace. Based on energy response characteristics, DOE TLDs are expected to

reasonably measure $H_p(10)$ doses in workplace radiation fields particularly for long-term workers with many dosimeter results, which tends to improve the accuracy of dose estimation because potential effects from extremes in workplace exposure geometries and radiation fields are minimized. Adjustments to dose measured by TLDs is not recommended; however, the biases listed in Table A-6 are of sufficient magnitude that the modifying factor must be sufficiently high to ensure claimant-favorable dose assignment.

Table A-6. Common workplace photon dosimeter $H_p(10)$ performance.[a]

Parameter	Description	Workplace bias[b]
Exposure geometry	Dosimeter systems commonly calibrated using AP laboratory irradiations	Recorded dose of record probably **too low** because dosimeter response is often lower at angles other than AP in comparison with Hp(10) for AP exposure geometry for common practice to use AP dosimeter calibrations. Effect is highly dependent on radiation type and energy.
Missed dose	Doses less than MDL recorded as zero dose	Recorded dose of record probably **too low.**
Environmental effects	Workplace heat, humidity, etc., fade dosimeter signal	Recorded dose of record probably **too low.**

a. Judgment based on common dosimeter response characteristics and workplace radiation fields.
b. Recorded dose compared to Hp(10).

A.4 SUMMARY OF OVERESTIMATION IMPLICIT IN THE STANDARD OVERESTIMATING ASSUMPTIONS

Site-specific correction factor: TLD photon energy response typically shows a near tissue equivalence. For most workplace conditions, a value of a modification factor at or near unity would be appropriate. By correcting to the most limiting case (a rotational geometry at a low energy of 70 keV), $H_p(10)$ is overestimated by as much as approximately 80%.

Standard organ dose conversion factor: For the organs considered under this set of assumptions, DCFs from the Implementation Guide are somewhat less than 1 with two exceptions, the testes and the thyroid. An assumed organ DCF of 1.100 would overestimate dose received by the organ by a very small amount for these two organs, but by a larger factor for most organs. The standard overestimating organ DCF of 2.0 further increases the margin of claimant favorability.

Standard level of missed dose: For all cases processed in accordance with this TIB, the assumed value for missed dose is 0.030 rem. This value is high for DOELAP-accredited dosimetry programs. For example, the level-of-detection value for ORNL is 0.010 rem for 1981 to the present. Application of the standard value here results in an overestimate of 200%, or an annual value of 0.360 rem in a year when *no* dose is recorded for ORNL cases.

Standard badge exchange frequency: DOE sites began in the early to mid-1950s using less frequent dosimeter exchanges, lowering missed doses. Personnel who typically received little dose would normally be assigned quarterly or even, at some sites, annual TLD exchange frequencies. Applying a standard badge monthly exchange frequency overestimates missed dose for workers at these sites by assigning them, in the example for ORNL above, 0.360 rem in missed dose, when a more accurate missed-dose value based on actual exchange frequencies is 0.120 or 0.030 rem, respectively, for the assumed MDL.