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A STANDARD COMPLEX-WIDE CORRECTION FACTOR FOR OVERESTIMATING EXTERNAL DOSES MEASURED WITH FILM BADGE DOSIMETERS

FOREWORD

The Manhattan Engineering District, and, later, the Atomic Energy Commission (AEC) had early responsibility for processing nuclear weapons material. The AEC was superceded in this function (briefly) by the Energy Research and Development Agency (ERDA), then the Department of Energy (DOE). This document presents assumptions for the latter period, when the AEC, ERDA, and DOE were the responsible agencies. For the purposes of this document the term 'DOE' is used as a term of convenience to mean 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, followed by multi-element film dosimeter designs, gave way in the 1970's and 1980's to the use of thermoluminescent dosimeters (TLDs) for personnel dose monitoring.

This technical information bulletin (TIB) presents external radiation dose assumptions that may be applied to dose reconstructions involving cases for which dose estimates may be prepared based on recorded deep and/or shallow dose that incorporate dose monitoring information during the later film badge era. Information in this TIB supports radiation dose estimates for complex-wide cases covering the time period of 1970 and after.

It is possible to apply reasonable, overestimating complex-wide assumptions for interpreting recorded photon dose for select cases. The methodology described below will generate a reasonable overestimate of external radiation dose for cases that are likely non-compensable. In accordance with the process efficiencies discussed in 42 CFR 82, use of an overestimated dose allows the expeditious processing of likely non-compensable cases.

Due to the remoteness in time from the film era, the uncertainties inherent in applying simplifying overestimating assumptions are greater than the period of the use of TLDs. For this reason, care will be exercised in the selection of cases that are processed under the assumptions in this TIB. Case selection will be based upon the likelihood that the assumptions applied here provide a claimant-favorable overestimate of dose, once case-specific exposure conditions are taken into account. This TIB should not be used at sites where significant personnel doses may result from the presence of elevated airborne levels of environmental radioactivity (EALER) after 1970.

1.0 INTRODUCTION

The objectives of this document are: 1) to discuss the degree of standardization of late film dosimeters and 2) to develop a standard correction factor that will overestimate dose. Information in this document examines the performance of late film and TLD dosimeters, application of the standard correction factor to overestimate doses, and to address uncertainties from the following sources.

- Variation in workplace photon radiation fields
- Variation in exposure geometries
- The slight under-response of multi-element film badges to photons from about 100 keV to about 250 keV.

While accounting for these uncertainties, the method proposed here will take into account similarities among sites across the DOE complex in the following attributes.

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

A single correction factor that takes a large number of programs and features into account must admit a great deal of error into any estimate that it modifies. This error is permissible under this program, so long as the error is in the claimant's favor. Specifically, any error must overestimate rather than reduce the claimant's probability of causation. For this reason, the correction factor proposed here overestimates any given claimant's dose. To ensure overestimation in the case of the highest organ dose conversion factors, the additional step is taken to multiply the dose by the appropriate organ dose conversion factor to ensure that dose is overestimated for all cancers; as an additional claimant-favorable measure, a value of at least one is assumed for the Exposure-to-organ dose conversion factor. As the intent is to overestimate the dose to take advantage of an efficiency progress, this methodology proposed here is useful only for likely non-compensable claims.

2.0 PERSONNEL PHOTON DOSIMETRY TECHNOLOGY

The respective DOE sites followed a similar evolution in photon dosimetry technology to measure photon dose to workers. Two-element film dosimeter were used in the 1940s and early 1950s, later replaced by multi-element film dosimeters in the latter 1950s and these in turn replaced by TLDs in the 1960s and 1970s. PICs have been used in addition to these dosimeters throughout all of the years of DOE operations. Table 2-1 illustrates this pattern for several DOE sites. Basically, all of these sites, and perhaps many others, have equivalent dosimetry technology capabilities for photon radiation. The adequacy of the respective photon dosimetry methods to accurately measure radiation photon dose is determined from response characteristics of the dosimetry technology according to the radiation type, energy, exposure geometry, etc., as described in this section.

Table 2-1. Evolution in DOE site photon dosimetry capabilities.

	Year of first use			
	Photographic film dosimeter		**Thermoluminescent dosimeter**	
Site	**Two-element**	**Multi-element**	**Site-specific**	**Commercial**
Fernald	1952	1954	n.a.	1985
Hanford	1944	1957	1972	1995
INEEL	1951	1957	1966	1986
LANL	(a)	1950	1978	
Mound	1952	?	1981	?
ORNL	1944	1953	1976	1989
RFP	1951(b)	1954	1970	?
SRS	1951(c)	1959	1970	1982
Y-12	1948	1961	1980	1989

n.a. – not applicable
a. LANL used other dosimeter designs prior to 1950.
b. RFP used dosimeter capabilities from LANL until implementing their system.
c. SRS used dosimeter capabilities from ORNL until implementing their system.

A more detailed example of the evolution in dosimetry technology is shown in Table 2-2 for Hanford, INEEL, ORNL and SRS. This level of detail in the dosimetry design is an important consideration in evaluating the adequacy of the dosimetry technology. Judgment of the dosimetry technology capabilities that can be made from this information include:

- Capabilities exist to estimate the penetrating dose based on laboratory tests with these dosimeter designs.
- The respective dosimeter design ensures minimal effect on the penetrating dose component of typical beta radiation nuclides in the workplace because of the 1,000 mg/cm^2 density thickness of the metal filter. This thickness also approximates the 1 cm depth in tissue [i.e., $H_p(10)$] such that any beta contribution to the dosimeter calculated dose could be considered a true penetrating dose.

The most serious limitation of the two-element film dosimeter designs shown in Table 2-2 concern mixed beta/photon radiation fields in which the non-penetrating dose may be significantly in error because of an inability to distinguish between beta and low-energy photon radiation. This limitation is described in Section 2.1.1 and was the motivating reason for the development of the multi-element film dosimeters.

Table 2-2. Chronology of DOE site improvements to personnel dosimetry systems.

Facility	Period Start	Period End	Dosimeter material	Type	Filters	Density[a] (mg/cm^2)	Thickness (mm)
Hanford	44	44	PICs				
	44	52	Film	DuPont 552	OW,Ag	~0, Ag = 1050	0, Ag = 1
	53	56	Film	DuPont 552	OW,Ag	~0, Ag = 1050	0, Ag = 1
	57	62	Film	DuPont 552	OW,Al, Ag#1, Ag#2	~0; Al = 132; Ag#1=137; Ag#2=1050	0
	63	71	Film	DuPont 558	OW,Fe, Ta	~0; Fe=20; Ta=843	0, 0.025, 0.5
	72	95	TLD	Five/Four Chips	OW,Al, Cd, Sn, Sn	~0;379;912; 980;912	0.05
	95	-	TLD	Harshaw 8825	OW,pl, Sn, Cu	~0;1000,	0.64
INEEL	51	56	Film	DuPont 552	OW, Cd	~0; ~1000	0, 1
	57	65	Film	DuPont 552	OW,Al, Ag, Cd	~0; 175, 203, 950	
	66	85	TLD	Two Chips	OW,Al (Cd)	~0; 203 (0; 950)	
	86	-	TLD	Panasonic 814/808	Al/plastic (4)	~16; 58; 600; 600	
ORNL	43	44	PICs				
	44	52	Film	DuPont 552	OW, Cd	~0; ~1000	0; 1
	53	57	Film	DuPont 552	OW, Pb, Cd, Cu, plastic	~0; varies, ~1000;	
	58	79	Film	DuPont 552	OW, Al, Cd, plastic	~0; varies, ~1000;	
	80	88	TLD	Two Chips	OW(Plastic) , Al	~0; 430	
	89	-	TLD	Harshaw 8805	OW,Plastic, Cu, Teflon	~0; 300; 242; ~1000	
SRS	51	58	Film	DuPont type 552	OW, Cd	~0; ~1000	Cd =1
	58	70	Film	DuPont 555	OW, Al, Ag	~0; 540; 1050	Al = 2; Ag = 1
	70	82	TLD	Two chips	OW, Al	~0; 540	Al = 2
	82	-	TLD	Panasonic, UD-802	Mylar, plastic+mylar, plastic+mylar, Pb	~0; 300; 300; ~1000	Pb = 0.7

a. Density thickness of filtration in holder only. Total density thickness would also include filtration in the dosimeter card and responsive elements.

2.1 PERSONNEL PHOTON DOSIMETERS

Personnel whole body photon dosimeters implemented to measure the dose to workers from photon radiation were essentially identical at the MED Metallurgical, Clinton and Hanford laboratories in the early to mid-1940s. Parker (1945) described results of an intercomparison study of dosimeter processing and exposure calculations between these three laboratories prior to declaring the Hanford system capable of routine dosimeter processing. Ongoing comparison of dose interpretation among these MED/AEC sites, and other sites, was done through the years (Wilson et al 1990). The dosimeter exchange frequency was gradually lengthened, generally corresponding to the period of the regulatory dose controls (GE 1954).

2.1.1 Two-Element Film Dosimeters

The two-element dosimeter was based on laboratory studies that identified the preferred element and thickness for a metallic filter to flatten the dosimeter photon energy response at lower energies (Pardue et al 1944). Pardue et al (1944) recommended selection of a filter of cadmium (Z = 47) that is about 1 mm thick to minimize the film energy response and still allowed measurement of lower energy photons. The respective DOE sites used cadmium and other elements such as silver (Z = 48) or tin (Z = 50) in their designs. This dosimeter was first used at the University of Chicago (Thornton et al 1961). This dosimeter design was adopted for use at ORNL and noted as the “tin” badge (Thornton et al 1961). There appear to be some refinements in this basic design at ORNL where five basic changes in this design were used (Thornton et al 1961) and at LANL by adding filters of lead (Z=82) and brass (Cu = 29, Zn = 30) to obtain improved capabilities in beta/photon fields and in photon energy resolution. These refined dosimeter designs, using two or three metallic filters, provide improved capabilities to distinguish between beta and photon radiation, primarily, and with knowledge of the workplace radiation field, between beta, and lower and higher energy photon radiation.

An important feature of the respective DOE site photon dosimeters was the selection of the type of film to be used. The available film had similar radiation energy response characteristics but the sensitivity of the film to radiation varied (Thornton et al 1961). Many sites used film, such as the DuPont 502 type, with a sensitive (lower radiation dose response) and an insensitive (typically accident-level dose response) side to each film packet. In normal practice only the sensitive side of the film was processed for personnel dose assessment. However, for higher doses, and to confirm higher suspicious readings, the insensitive film response could also be measured.

The two-element dosimeter design had an open window (OW) to measure non-penetrating radiation in addition to the filter region with 1 mm of silver, cadmium or tin. Each of these metallic filters has a density thickness of approximately 1,000 mg/cm^2. This selection minimizes the potential for beta radiation to contribute to the interpreted penetrating dose. Certainly, only beta radiation with energy greater than about 3 MeV can penetrate the filter and contribute to the interpreted penetrating dose.

Historically, studies of film dosimeter performance, stability of latent image, etc., were performed during the 1950s (Wilson 1957, 1960). Numerous intercomparison and performance studies were done among DOE laboratories (Wilson et al 1990). The laboratory measured A-P photon energy response of the two-element dosimeter system is shown in Figure 2-1 in comparison with $H_p(10)$. As noted in this figure, the film dosimeter open window (OW) response shows a significant over-response to lower-energy photon radiation. Operationally, the over-response was so significant that some option was necessary to interpret the dosimeter response based on the anticipated radiation fields in the work environment. The ratio of the OW to the filtered film response was routinely used in dose evaluation (Larson and Roesch 1954) and there is reference to using a fraction (i.e., 0.2 at Hanford, 35% at SRS) of the open window response to add to the penetrating dose in facilities with low energy photons and no beta radiation (i.e., plutonium facilities) (Fix et al 1997b, Taylor et al 1993). The film nonpenetrating (i.e., open window) and penetrating (i.e., metallic filter) response was generally used to estimate the skin dose from beta and photon radiation.

2.1.2 Multielement Film Dosimeters

Multi-element film dosimeters were developed to provide improved capabilities to measure beta, lower-energy and higher-energy photon radiation dose components particularly in mixed beta and photon radiation fields. This was done by most of the DOE sites in several site-specific designs. Often, the basic design of the two-element dosimeter (i.e., open window and 1 mm silver, cadmium or tin shield) was incorporated by the respective sites into the design of the multielement dosimeters. The multi-element beta/photon film dosimeters generally consisted of 3 or 4 shielded areas and provided substantially improved capabilities to measure deep dose by flattening the overall response. Processing results (i.e., optical density) were recorded for the film response behind each of these filters and an algorithm was used to calculate the respective dose components.

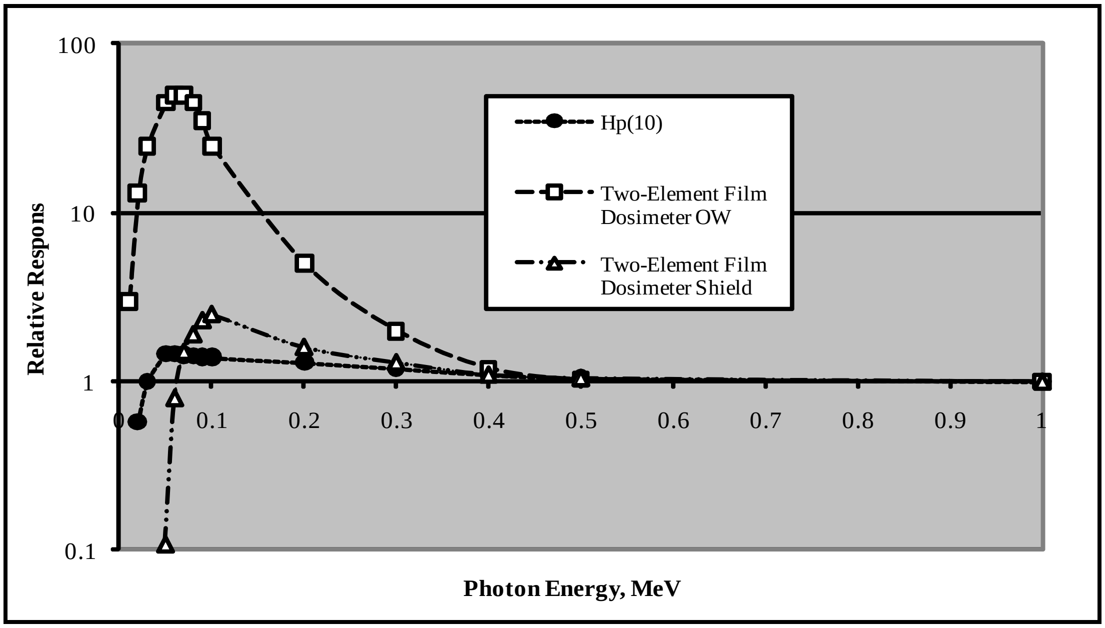

Figure 2-1. Measured two-element dosimeter photon response for anterior-to-posterior exposure geometry (Pardue et al 1944, Wilson et al 1990).

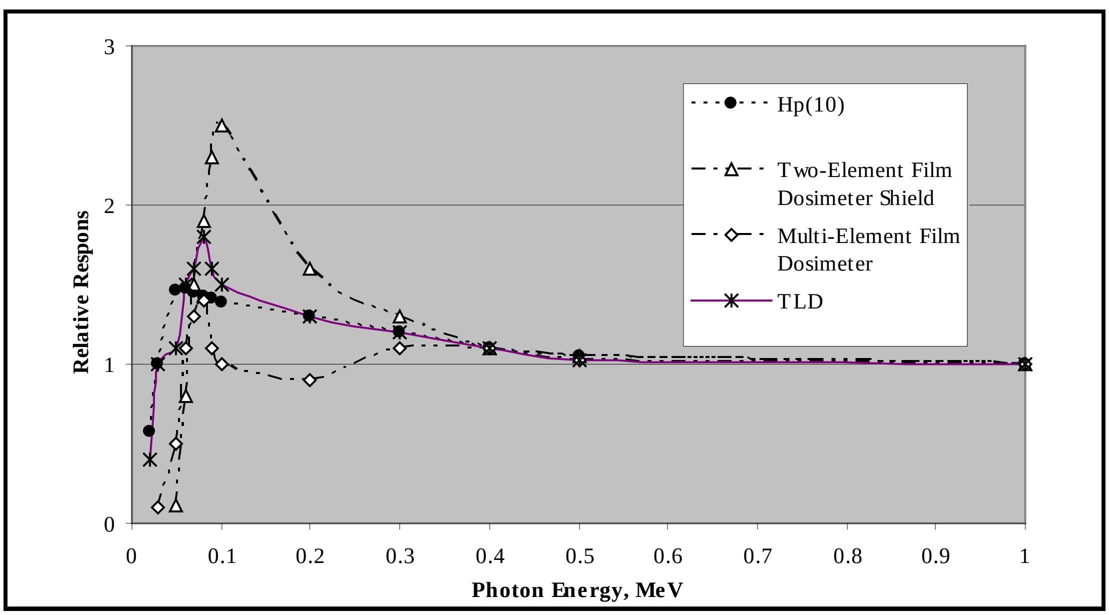

Figure 2-2. Measured deep dose response for Hanford Two-Element film, multi-element film and thermoluminescent dosimeter compared to $H_p(10)$. (Wilson et al 1990).

2.2 FILM BADGE RESPONSE IN COMPARISON WITH $H_P(10)$.

As can be seen in the foregoing figures, the comparison of TLD and film badge performance to $H_p(10)$ dose demonstrates that film dosimeters a) under-respond to photons of energies less than about 60 keV; b) over-respond to photons of energies between the response threshold up to several hundred keV; and c) conform well with respect to $H_p(10)$ beyond about 300 keV. Figure 2-1 shows that for shallow dose considerations, the open-window portion of the two-element film badges over-respond at even very low energies. This is corrected with the compensating design of the multi-element film badge as shown in Figure 2-2, though somewhat overcompensated in that these dosimeters slightly under-responded to photons between about 100 and about 250 keV.

3.0 <u>INTERPRETATION OF DOE FILM BADGE RECORDS.</u>

The predominant concern with regard to interpreting film badge results is of film dosimeters' under-response to photons of energies less than about 60 keV. For this reason, application of the dose parameters in this TIB should not be applied to workplaces with extensive exposure to low-energy photons in the workplace. Workplace radiation fields that included photons in the < 30 keV energy range are likely underestimated by film badge dosimeters, and for this reason, assumptions dealing with this dose component, such as with workers who worked directly with plutonium, should be documented specifically in the dose reconstruction report, or in an appropriate supporting document. Typical exceptions are outlined in Section 4.1.

Another inaccuracy in the film era, over-response in the open-window reading to photons of energies between the response threshold and about 300 keV, is not necessarily of concern for the purposes of dose reconstruction. The error in this case occurs on the side of the claimant, as the dose the energy employee may have received is overestimated by the film badge result. Adjustments to this overestimated dose component may be made as necessary on a case-by-case basis.

The strategy for interpretation of documented film badge results from DOE records may be summarized in accordance with the four bullets below.

- Doses from photons in the standard energy range of > 250 keV may be interpreted as exposure without modification.

- Multi-element film dosimeter doses are slightly under-predicted between about 100 keV and about 250 keV.

- Dose from photons are not reliably estimated in the lowest energy range, < 30 keV, and performance around 60 keV is questionable. Workplaces with photons from plutonium are not adequately characterized by the assumptions in this document, therefore dose reconstructions that involve exposure to plutonium and those that utilize dose from the lowest photon energy range must document assumptions on a case-by-case basis.

3.1 STANDARD EXPOSURE GEOMETRY AND ENERGY RANGES.

The review of organ dose conversion factors was limited to the Anterior-Posterior exposure geometry for photons of energies between 30 and 250 keV. The standard use of these exposure parameters has been adopted by this project as a claimant-favorable assumption.

3.2 FILM BADGE LEVEL OF DETECTION

The sensitivity of the film used determines the lowest level of dose that may be detected. A typical value of film sensitivity is 0.5 NOD units per 400 milliroentgens exposure (CETS 1989). This translates to a lower limit of detection of between 10 and 20 milliroentgens for films with this sensitivity, for photons above a few hundred keV (CETS 1989). For the purposes of this project, this sensitivity is referred to as the minimum level of detection (LOD) for a given dosimeter, and a review of this quantity reported by individual site dosimetry programs was performed as part of the research for this project. Values for early film badges were assumed to be as high as 50 mrem for photons and 60 or 80 mrem(OCAS 2003) for electrons. A review of film records captured as part of this project's research also demonstrates film badge readings recorded as '< 10;' values this low are possible, but for the purposes of this project, should be neglected without substantial site-specific information on source term and calibration techniques to corroborate such a low value. For the purposes of overestimation, the typical value of 40 mrem as listed in the CETS 1989 reference will be assumed for later film badge programs. .

3.3 STANDARD CORRECTION FACTOR

A standard correction factor is promulgated here that increases the assigned dose to claimants with the objective to overestimate the actual organ dose. The use of this factor is intended to assure claimant-favorable assigned dose by compensating for uncertainty from potential variance in site-specific exposure conditions and calibration practices that, without correction, may have resulted in an underestimated dose. This standard correction factor overestimates dose in order to take into account, and overestimate, corrections that may be required to convert the dose as measured from site to site to a standard value of $H_p(10)$, including the under-response of multi-element film dosimeters to photons between 100 and 250 keV. The value of this factor (2.0) is listed, along with the other parameters necessary for estimating doses under this TIB, in Table 4-1, below.

3.4 ORGAN DOSE CONVERSION FACTOR

The correction factor listed above incorporates uncertainty in measurements and radiation exposure characteristics in workplaces as measured with film badges, however, in contrast to the standard correction/conversion factor applied to TLDs in OTIB-0008, may not incorporate sufficient claimant favorability for some organs with high organ dose conversion factors. For this reason, the additional step is taken to multiply the dose (overestimated by a factor of 2) by the applicable organ dose conversion factor from the tables in Appendix B of the External Implementation Guideline. Specifically, dose is multiplied by the Exposure (R)-to-organ (H_T) dose conversion factor unless that value is less than unity, in which case the dose conversion factor will be assumed to have a value of 1. Appropriate dose conversion factors are selected from the tables by organ using the median value for the Anterior-to-Posterior (AP) geometry.

4.0 <u>STANDARD ASSUMPTIONS FOR OVERESTIMATING DEEP DOSES MEASURED WITH FILM BADGES.</u>

Standard values for energy distribution, missed dose, organ dose conversion factors, and exchange frequencies are given in Table 4-1 below. These may be applied to recorded doses from the late film badge era. Based on a review of the literature, the applicability date of 1970 is significantly predated by the first year of monthly exchange for most sites, however, care should be exercised by the dose reconstructor to ensure that the assumed monthly frequency is accurate in individual cases. Similarly, the routine exchange frequency may not be reflected in individual cases, for operational reasons. When an alternate frequency is indicated in the DOE record, the assumed number of zeros should be adjusted to ensure that missed dose is adequately overestimated. Assumptions in Table 4-1 support complex-wide dose overestimates from the year 1970 and later for workplaces without significant low-energy photon contributions. Examples of such workplaces are given in section 4.1, below.

Table 4-1. Standard assumptions for overestimating doses measured with film badges.

Period of applicability	Photonenergy range (keV)	Missed dose per cycle	Standard correction factor	Exposure-to- Organ (H_T) DCF	Assumed exchange frequency
1970 onward	100% 30–250	0.040 rem	2.0	≥ 1[a]	Monthly

a. From Appendix B of the OCAS-IG-001, External Dose Reconstruction Implementation Guideline: a value of 1.0 or the table value (typically assume 100% AP geometry), whichever is greater.

4.1 WORKPLACE CHARACTERISTICS THAT PRECLUDE UNSUPPORTED APPLICATION OF THE OVERESTIMATING ASSUMPTIONS IN THIS DOCUMENT.

Complex workers who had significant exposure to low-energy photons may have recorded doses that do not reliably represent their actual photon dose in the film badge era. Application of the assumptions presented here is not appropriate unless justification is specifically supported in individual dose reconstruction reports. Examples of workplaces that would typically have spectra with significant low-energy photons include.

- Weapons assembly and disassembly areas.
- Plutonium machining areas.
- Plutonium processing facilities in areas where the primary hazard is from the product.
- Laboratories performing work with plutonium or americium.

Additionally, individual dose reconstructors may encounter specific situations where workplace characterization suggests exposure to photons in the lowest energy range (< 30 keV) or lower-energy photons in the intermediate range, up to 100 keV comprise a significant proportion of the dose.

5.0 EVALUATION OF SHALLOW DOSES MEASURED WITH FILM BADGES

This TIB is not to be used for evaluation of shallow doses (Note: for breast and testicular cancer cases, this TIB can be used for calculating the deep dose component only). The External Dose Reconstruction procedure (ORAUT-PROC-0006) provides generic instructions for overestimating shallow doses and shall be used at this time, pending the development of detailed instructions in TIBs or TBDs.

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