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Subject Expert: Steven E. Merwin

Document Owner
Approval: Signature on File — Edward F. Maher, Task 5 Manager — Approval Date: 10/04/2005

Concurrence: Signature on File — Richard E. Toohey, Project Director — Concurrence Date: 10/04/2005

Approval: Signature on File — James W. Neton, Associate Director for Science — Approval Date: 10/11/2005

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
01/11/2005	00	New technical information bulletin to provide information for the interpretation of dosimetry data for assignment of shallow dose. First approved issue. Initiated by Steven E. Merwin.
10/11/2005	01	Revision to incorporate guidance on non-uniform skin exposures and exposures of the breast, testes, and other organs impacted by shallow doses. Approved issue of Revision 01. Training required: As determined by the Task Manager. Initiated by Steven E. Merwin.

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1.0 PURPOSE

Technical Information Bulletins (TIBs) are general working documents that provide guidance concerning 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 National Institute for Occupational Safety and Health 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 facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 (42 U.S.C. § 7384l(5) and (12)).

The purpose of this Technical Information Bulletin (TIB) is to provide information to allow dose reconstructors to assign shallow doses for skin cancer cases and for cases involving other organs affected by non-penetrating radiation including the breast and testes. Both general and site-specific information are provided.

2.0 BACKGROUND

Almost since the inception of operations at DOE sites, it has been known that non-penetrating (shallow) doses, notably from exposure to beta particles emitted by isotopes of uranium and their daughter products, needed to be evaluated. Consequently, dosimetry systems typically included more than one dose measurement including an uncovered, or open-window reading, allowing for the measurement of non-penetrating radiation doses. These open-window (OW) measurements form the basis for the assignment of skin doses under the dose reconstruction program conducted by NIOSH to produce radiation dose estimates that the Department of Labor uses in adjudicating certain cancer claims under the EEOICPA; they are also important for assessing doses to other organs such as the breast and testes, which can be impacted by non-penetrating radiation.

There are a number of confounding factors that complicate the assignment of skin dose based solely on open-window dosimeter measurements. Examples include:

- Insufficient information is obtained by an open-window measurement to allow partitioning of dose by radiation type and energy as required by the IREP program. Even under today's standards, dosimetry systems and radiation dose limits are designed to ensure protection against adverse health effects, not the calculation of cancer risk. This is especially true for skin dose measurements. Thus, the dosimetry systems are designed such that the doses are measured accurately in order to demonstrate compliance with established dose limits. In order to partition the measured shallow dose into radiation types and energies relevant to the IREP program, additional information must be evaluated by the dose reconstructor, such as shielded (S) dosimeter readings corresponding to penetrating doses, and source term information contained in the TBDs.

- Site reporting schemes. At some sites and during certain time periods, doses were not reported as penetrating or non-penetrating. Thus, knowledge of the reporting scheme and interpretation of the data are required.

- Over-response to low-energy photons. Although early film dosimeters were relatively accurate for measuring beta doses, they are known to have over-responded significantly to low-energy photons (such as those emitted from plutonium isotopes and daughter products). Although

attempts were made at some sites to correct for the over-response through calibration techniques or after-the-fact corrections, it is not always straightforward to reproduce the procedures adopted at the sites.

- Limit of detection issues. Limits of detection (LODs) for open window measurements vary significantly based on type of radiation and energy. This complicates the assignment of missed dose.

- Security credentials. At some sites security credentials were placed over the dosimeter badge, including the open window portion. This resulted in an attenuation of beta particles, especially those of lower energies. Even though the badges may have been calibrated to correct for this attenuation, low-energy beta emitters could not be detected if the credential was thick enough to filter out all or most of the particles prior to their reaching the dosimeter.

In addition to the factors that confound the assignment of skin dose, the assignment of shallow doses to organs other than the skin such as the breast and testes is complicated by the fact that the sensitive (cancer-inducing) depths in these organs differ from the normally accepted sensitive skin depth of 0.07 mm. Because open-window dosimeter measurements were generally designed for skin dose assessments, this requires corrections to the measured doses to account for beta particle attenuation. In addition, these organs are normally covered by clothing in the workplace which requires further consideration of beta attenuation.

Recognizing the confounding factors described above, the approach to calculating shallow dose described in this document is intended to facilitate the completion of the great majority of cases without performing extensive research on individual cases, erring on the side of claimant favorability 1) when necessary due to the lack of information, or 2) intentionally in order to address multiple confounding factors in a manner that facilitates the completion of dose reconstructions in a timely manner. Cases that involve special circumstances such as unique exposure geometries, exposure to low-energy beta particles, the presence of shielding materials, etc., may require special consideration to complete the dose reconstruction in a defensible manner.

3.0 GENERAL APPROACH

Dose to the skin (and the breast, testes, and certain other organs) can be associated with penetrating radiation (i.e., radiation that impacts tissue at a depth of 1 cm or more), non-penetrating radiation, or both. Penetrating radiation includes medium and high-energy photons and neutrons of all energies, and non-penetrating radiation consists of low-energy photons (such as X-rays emitted by plutonium isotopes) and beta particles (Note: low-energy photons and high-energy beta particles are more correctly considered weakly penetrating, since a small fraction of the energy may be deposited at depths in tissue greater than 1 cm).

As mentioned in Section 2.0, evaluation of skin doses is complicated by the fact that sites sometimes did not report doses as penetrating or non-penetrating. For example, the open-window reading from a dosimeter may have been reported directly as “OW,” but this value would include the contribution from both penetrating and non-penetrating radiation. In other cases, the sites may have reported a result as “Skin Dose,” but the value reported may have included only the non-penetrating component or both the penetrating and non-penetrating components. To further complicate matters, the values reported may or may not include contributions from neutrons, which in most cases were monitored separately but were reported under different schemes. If the TBD does not provide clear information, the reporting schemes can typically be identified by evaluating the data. For example, if the reported OW

values are always equal to or higher than the S values, this is an indication that the OW reading includes both penetrating and non-penetrating radiation.

General Approach Summary
This section discusses the general approach to determining skin dose. Site-specific considerations and procedures are provided in the attachments. At the end of this section, information is provided that allows the dose reconstructor to modify this approach to assign dose to organs other than the skin that are impacted by non-penetrating radiation, such as the breast and testes.

The general approach to determining skin dose involves only a few basic steps. These steps may be supplemented or modified for certain sites and timeframes, e.g., when additional dosimeter elements were present that provided more information. The basic steps include:

1. Translate the reported doses into non-penetrating and penetrating doses, separating out reported neutron doses, if applicable.

2. Assign the penetrating dose as photons, with the energy partitioned as 30-250 keV and/or 250 keV according to the TBD.

3. Assign the non-penetrating dose as electrons >15 keV (corrected to account for attenuation, if applicable), or photons <30 keV if the employee worked in a plutonium facility.

4. Add missed electron and/or photon dose.

5. Include measured and/or missed neutron dose, if applicable.

6. All dose conversion factors for the skin should be assumed to be 1.

In general, non-penetrating radiation doses should be assigned as <30 keV photons if the employee worked with or around Pu, otherwise, > 15 keV electrons should be assigned. If the nature of the non-penetrating dose is unknown, consider the following guidance:

a. For a likely non-compensable case, it is acceptable to assume the non-penetrating dose is associated with <30 keV photons, as this maximizes POC.

b. For a likely compensable case, it is acceptable to assume the non-penetrating dose is associated with >15 keV electrons, as this minimizes POC.

c. If the compensability decision may hinge on this issue, and if the partitioning of the non-penetrating dose cannot be decided based on the available information, additional research may be required.

Electron Attenuation
All measured and missed non-penetrating doses that are considered electrons should be corrected to account for attenuation by clothing or personal protection equipment (PPE), if applicable. No attenuation should generally be assumed if the skin cancer was diagnosed in an area not normally covered by clothing, such as the face. Information on beta attenuation factors for uranium can be found in the DOE Standard "Guide of Good Practices for Occupational Radiological Protection in Uranium Facilities," DOE-STD-1136-2000 (which is based on the DOE *Health Physics Manual of*

Good Practices for Uranium Facilities, EGG-2530). Examples from this document of transmission factors for uranium through various types of protective clothing include:

- Lab coat (65% Dacron/35% cotton) – 0.91
- Two pairs of coveralls plus paper liner – 0.80
- Two pairs of gloves plus liner – 0.60
- Face shield – 0.41

For likely non-compensable cases, an acceptable claimant-favorable approach is to assume 100% transmission (i.e., ignore attenuation). For likely compensable cases, an acceptable minimizing approach is to assume a transmission of 0.6 (unless there is evidence a face shield was used and the skin cancer was on the face, in which case 0.41 would be appropriate). For cases in which a best estimate is applied and the specific type of protective clothing is unknown, a factor of 0.855 for uranium is appropriate (equal to the average of the 0.80 and 0.91 factors listed above). Note that the transmission factors listed are claimant favorable for areas where undergarments (such as a shirt) are worn, because the factors are relevant only to the protective clothing material itself. Also, these factors are not necessarily claimant favorable for beta particles of higher energy than those from uranium, and are highly claimant favorable for low energy beta particles such as those from Tc-99 (see Attachment D). Thus, the dose reconstructor must ensure that appropriate transmission factors are applied based on the specific types of exposure.

Exposure Geometry

The nature of beta particles suggests that some recorded doses may significantly overestimate or underestimate the actual dose to the skin at the cancer diagnosis location. For example, for a 100% AP exposure geometry the actual beta dose to the back would be zero, yet a dosimeter worn on the chest would record the incident dose, and thus the shallow dose reported by the site would significantly overestimate the skin dose of concern. On the other hand, if the exposure geometry were primarily PA, the dosimeter would significantly underestimate the beta dose to the back. If there is an indication that the recorded dose significantly underestimates the actual dose at the cancer location due to exposure geometry, attenuation, or other issues, the reported results should be adjusted upward accordingly. However, if there is an indication but no definitive evidence that the recorded dose significantly overestimates the actual dose, no correction should be made. The exception to this rule is the over-response of film to low-energy photons (discussed below); site-specific instructions regarding this issue are provided in the attachments.

Non-Uniform Exposure of the Skin

The skin cancer risk factors present in the IREP program are described in the associated NIOSH-IREP technical documentation and were obtained from Land and Smith 2003. The underlying data used by Land and Smith represent the risk from uniform whole-body irradiation of the skin (Ron et al. 1998; ICRP 1991). Therefore, the actual risk of cancer induction associated with partial-body irradiation is less than is indicated by the risk factors inherent in IREP. For example, if half of the body received a certain dose, there would be approximately one-half of the risk of skin cancer induction associated with the same dose to the whole body (ICRP 1991). At the same time, however, the IREP model includes a baseline risk of cancer induction, and the baseline risk for a specific area of skin would be roughly proportional to the area of skin considered. These two considerations roughly offset each other in terms of probability of causation calculations. Therefore, if a skin cancer occurred within a known area of contamination or partial-body irradiation, it is appropriate to calculate the skin dose (in accordance with OCAS-IG-001) to the affected location without adjusting for the total

skin area of the body. Similarly, if it is known that the cancer occurred in an area not within the area of contamination or partial-body irradiation, no dose should be assigned to that cancer location.

For situations in which the precise location of a skin contamination is unknown and it is unclear whether the irradiated area included the skin cancer location, the risk distributed over the whole skin area is relevant. For example, a hot particle exposure calculated for 1 cm^2 in accordance with OCAS-IG-001 should be modified to account for the total skin area (18,000 cm^2 for males and 16,000 cm^2 for females) to most accurately represent the risk of cancer induction associated with the exposure. Specifically, the following approach is prescribed for these situations:

- the maximum skin dose calculated in accordance with OCAS-IG-001 adjusted for fraction of skin area irradiated shall be considered the geometric mean (GM) of a lognormal distribution. For example, a dose of 180 rem calculated to an area of 1 cm^2 from a single hot particle on a male shall be divided by 18,000 (i.e., the GM would be 0.01 rem).

- the maximum skin dose calculated in accordance with OCAS-IG-001 not adjusted for fraction of skin area irradiated shall be considered the upper end of a lognormal distribution. The specific percentile used to define the GSD shall be based on the divisor applied to determine the GM. For example, a divisor of 18,000 in the example above implies that the dose of 180 rem would represent a percentile of greater than 99.99%; such a percentile in turn represents a GSD of approximately 14. To simplify this approach while maintaining claimant favorability, the following guidance shall be applied.

If the ratio of the non-irradiated skin area to the irradiated skin area is:	Use a GSD of:
<1	N/A (apply calculated skin dose as constant without adjustment for area)
1 - 10	6
10 – 100	8
100 – 1000	10
1000 – 10,000	12
>10,000 (e.g., single hot particle exposure)	14

Although there is evidence that hot particle doses are less effective than whole body doses in inducing cancer (Merwin and Moeller 1989; Charles et al. 1988), the overall approach described above is considered claimant favorable.

Over-response of Film to Low-Energy Photons

Film dosimetry can over-respond to 16 keV and 59 keV X rays by factors of 8.5-12 and 14-19 respectively (Wilson, 1990). Because of this over-response to low-energy photons, a nominal multiplication factor of 0.6 is prescribed in this document for non-penetrating doses assumed to be from <30 keV photons measured with film. This factor is to be applied if it can be established that the site did not apply a correction to the reported doses to account for the over-response (see additional discussion below). The factor of 0.6 is claimant-favorable in view of the available data, and is high enough to ensure that if the open-window readings were actually attributable 100% to beta particles and not low-energy photons, the calculated probability of causation (POC) which is determined by the Department of Labor would be greater under the low-energy-photon assumption. Missed doses assigned as <30 keV photons should also include this correction factor, because missed doses are based on nominal limits of detection (LODs), which for film significantly overestimates the potential missed low-energy photon dose.

Typically, film dosimetry systems that incorporated both open-window and shielded measurements did not correct for low-energy photon over-response. However, unless it can be established that the site did not already apply a correction to the reported doses to account for film over-response (e.g., the site TBD may provide this information, or the records may provide evidence), the factor of 0.6 should not be applied by the dose reconstructor.

Assignment of Shallow Dose to Organs Other than the Skin

Deep (penetrating) doses to organs other than the skin that are impacted by shallow doses should be calculated in a manner similar to organs not impacted by shallow doses, i.e., assigned as photons (or neutrons) with energy ranges and correction factors as prescribed in the relevant site TBDs, together with the appropriate organ dose conversion factors (DCFs) as prescribed in OCAS-IG-001. Non-penetrating doses to these organs should be calculated from the dosimetry data in accordance with the instructions in this TIB, and such doses assigned as electrons (measured or missed) should be adjusted per the information in Attachment A. To summarize this information, for likely non-compensable cases, a claimant-favorable factor of 0.3 should be applied to the electron doses for the breast, testes, and penis, and a claimant-favorable factor of 3.6 should be applied to the electron doses to the lip. These factors account for the attenuation afforded by clothing (where applicable) and the different depths (compared to skin) of the sensitive cells. For likely compensable cases, the external electron dose should be ignored entirely for the breast, testes, and penis, and a factor of 1.0 should be applied for the lip. Attachment A should be consulted for cases requiring a more refined estimate or for evaluation of other organs impacted by non-penetrating radiation. No adjustments are warranted for non-penetrating radiation doses assigned as low-energy photons.

Uncertainty

In this document, approaches have been presented that represent claimant-favorable assumptions in recognition of the fact that all available information necessary to develop a true best estimate of the shallow dose partitioned in a manner consistent with the IREP input parameters is not reasonably possible. Thus, a dose reconstruction based on the guidance in this document is likely to be inherently claimant favorable. Consistent with this approach, even though there may be considerable uncertainties in the measured doses and in the appropriate partitioning by radiation type and energy, it is recommended that all measured doses be treated as a constant. An additional consideration is that treating acute doses as a distribution is not likely to have a significant impact on the calculated probability of causation (POC); for example, for some cancer types an acute 30-250 keV photon dose

treated as a constant actually results in a slightly higher POC than if the same dose were treated as a normal distribution with a standard deviation of 30%. Missed doses should be divided by 2 and treated as a lognormal distribution consistent with OCAS-IG-001.

4.0 APPLICATIONS AND LIMITATIONS

This document provides site-specific information only for the Savannah River Site (SRS), Hanford, and the Gaseous Diffusion Plants (GDPs). Subsequent revisions will provide site-specific information for other major DOE sites. However, this information may be used for other sites with similar dosimetry systems and reporting protocols, provided that adequate documentation exists to ensure that doses are not being underestimated for a likely non-compensable case or overestimated for a likely compensable case.[1]

[1] Overestimates for likely compensable cases are permissible if information to support more accurate or precise dose estimates is not available and will not be forthcoming in a timely manner (Department of Health and Human Services 2005).

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ATTACHMENT A
NON-PENETRATING DOSES TO ORGANS OTHER THAN THE SKIN

Consistent with the guidance in OCAS-IG-001, doses from non-penetrating radiation are important not only for the skin, but also for other organs with sensitive tissues near the surface of the body. In particular, this paper provides guidance on how to modify the calculated non-penetrating dose to assign dose to a) the breast, penis, and testicles, and b) the lip. The breast, penis and testicles are addressed together since these share common characteristics including the fact that they are typically covered by clothing in the workplace, and the sensitive tissues are at a greater depth than 0.07 mm (the sensitive depth in skin). The lip is treated in a separate section since it is not typically covered and because the sensitive layer is actually at a depth less than 0.07 mm. Other organs that may be affected by non-penetrating radiation must be evaluated on a case-by-case basis using the information contained herein.

General Information

As described in this TIB, non-penetrating radiation includes beta particles and low-energy X-rays. This appendix presents detailed information regarding doses from beta particles to organs other than the skin, and relates this information to doses from low-energy X-rays typically encountered in Pu facilities.

The dose from beta particles depends on the average energy of the beta spectrum and the depth of the radiosensitive tissues in the organ. The Nuclear Regulatory Commission is currently funding a contract to produce Varskin 3, a significant upgrade to the computer code Varskin Mod 2. Varskin 3 is a Windows-based code that calculates the dose to skin from beta, gamma, and monoenergetic electron radiation. The user can choose the radionuclide and skin depth at which the dose is calculated. The user can also account for the presence of clothing between the source and the skin. The calculations included in this paper were performed using an alpha version of Varskin 3; the results of the alpha version have been verified to be equivalent to those obtained using Varskin Mod 2.

Whereas the deep dose from penetrating radiation varies little over the mass of an organ and therefore organ dose conversion factors (DCFs) are used to calculate an average organ dose, the dose from beta particles varies greatly with depth and, therefore, it is necessary to calculate the dose at specific depths of concern with respect to cancer induction. Provided below is information to be used by dose reconstructors to convert non-penetrating radiation dose calculated for the skin in accordance with this TIB into a quantity to be assigned in IREP for organs other than the skin (in addition to the deep dose normally assigned).

Doses to organs other than the skin are compared to doses calculated to the skin at a depth of 70 μm to derive correction factors for the non-penetrating doses assigned in accordance with this TIB. When determining the dose to organs surrounded by skin, it is necessary to know the total thickness of the skin, including the dermis. The dermis consists of a papillary layer, a reticular layer, and a subcutaneous layer. The thickness of the epidermis and dermis varies depending on location of the skin on the body. For the purposes of this paper, two types of skin have been defined: thin skin and thick skin. Thin skin is considered to have a thickness of 1.5 mm, while thick skin has a thickness of 4 mm. In some organs, such as the breast, penis, and testicles, a 1-mm layer of thick connective tissue exists beneath the dermis. Additional details on the basis for the calculations are provided below.

Breast

The breast is an exocrine gland composed of the following parts:

- Glandular tissue that produces and transports milk,
- Connective tissue that supports the breast,
- Blood that nourishes breast tissue and provides the nutrients to the breast needed for milk production,
- Lymph that removes waste products,
- Nerves that make the breast sensitive to touch, and
- Adipose tissue (fat cells) that protects the breast from injury.

Each mammary gland forms a lobe of the breast, which consists of a single major branch of alveoli, milk ducts, and one lactiferous sinus that narrows to an opening in the nipple (nipple pore). There are fifteen to twenty-five lobes in a breast and each lobe consists of twenty to forty lobules - a smaller milk duct with its supporting alveoli. Each lobule consists of ten to 100 supporting alveoli (Figure A-1).

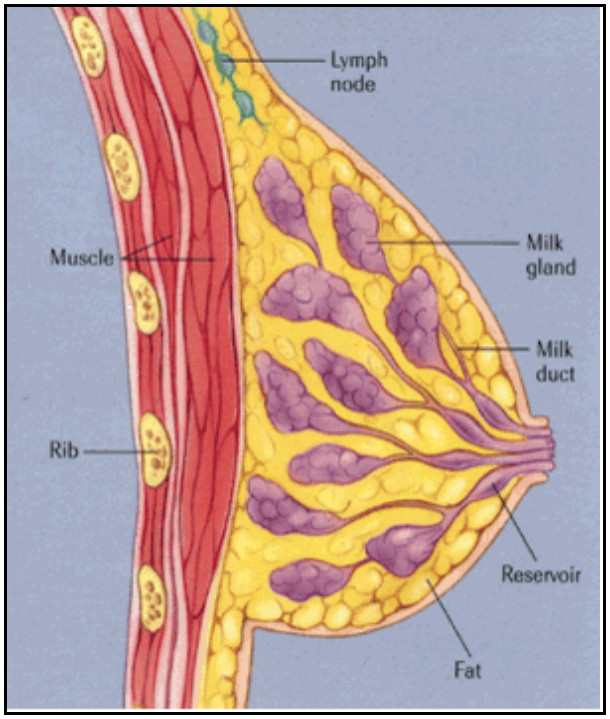

Figure A-1. Schematic diagram of the breast.

The most common type of cancer in the female breast develops in glandular tissue and is classified as adenocarcinoma. The earliest form of the disease, ductal carcinoma in situ (DCIS), develops solely in the milk ducts. The most common type of breast cancer, invasive ductal carcinoma (IDC), develops from DCIS, spreads through the duct walls, and invades the breast tissue.

Invasive lobular carcinoma originates in the milk glands and accounts for 10 – 15% of invasive breast cancers. Less common types of breast cancer include the following:

- Inflammatory (breast tissue is warm and appears red; tends to spread quickly)

- Medullary carcinoma (originates in central breast tissue)
- Mucinous carcinoma (invasive; usually occurs in postmenopausal women)
- Paget's disease of the nipple (originates in the milk ducts and spreads to the skin of the nipples or areola)
- Phyllodes tumor (tumor with a leaf-like appearance that extends into the ducts; rarely metastasizes)
- Tubular carcinoma (small tumor that is often undetectable by palpation)

Rarely, sarcomas (cancer of the connective tissue) and lymphomas (cancer of the lymph tissue) develop in the breasts.

The size of the breast depends on the amount of adipose tissue. In order to determine the contribution to breast dose from non-penetrating radiation, it was assumed that the breast had no adipose cells and that the only protection from non-penetrating radiation was the epidermis, dermis, and a layer of connective tissue. Further, the skin on the breast was assumed to be thin. Thus, the total skin thickness was assumed to be 2.5 mm (1.5 mm + 1 mm of dense connective tissue). This value is considered claimant favorable.

In addition to protection afforded by the skin itself, it is assumed that women wore both a shirt and a bra. A claimant-favorable estimate of the thickness and density of each garment is 2 mm and 0.7 g/cm^3 (total density thickness of approximately 0.28 g/cm^2).

Penis
The penis is a pendulous organ suspended from the front and sides of the pubic arch and containing the greater part of the urethra. In the flaccid condition it is cylindrical in shape. It is composed of three cylindrical masses of cavernous tissue bound together by fibrous tissue and covered with skin. Two of the masses are lateral, and are known as the corpora cavernosa penis; the third is median, and is termed the corpus cavernosum urethræ (Figures A-2 and A-3).

Cancer of the penis can occur at various locations: the surface of the glans (the head of the penis) and on the foreskin (the loose skin that covers the head of the penis); the deeper tissues of the glans; the shaft of the penis; the lymph nodes in the groin. The skin of the penis is considered to be thin and includes dense connective tissue; thus, for modeling purposes, the skin thickness is assumed to be 1.5 mm thick plus 1 mm of dense connective tissue. For modeling purposes it is assumed that male workers wore pants or shorts and one layer of undergarments. Pants were assumed to have a thickness of 2 mm and a density of 0.7 g/cm^3 while the layer of undergarment was also assumed to have a thickness of 2 mm and a density of 0.7 g/cm^3. These estimates are considered to be claimant favorable.

Testicles
The testicles (also called testes or gonads) are located behind the penis in a pouch of skin called the scrotum. The testicles produce sperm and testosterone. The germ cells inside the seminiferous tubules (sertoli cells) create sperm and are, therefore, the most radiosensitive cells of the testicles. The sperm move into the epididymis where they mature. The leydig cells distributed throughout the testicle are the body's main source of testosterone (Figure A-4).

Testicular cancer is cancer of the germ cells. It is possible to have cancer of the leydig or sertoli cells, but these tumors are not as common and are usually not malignant. Also, since testicular cancer is

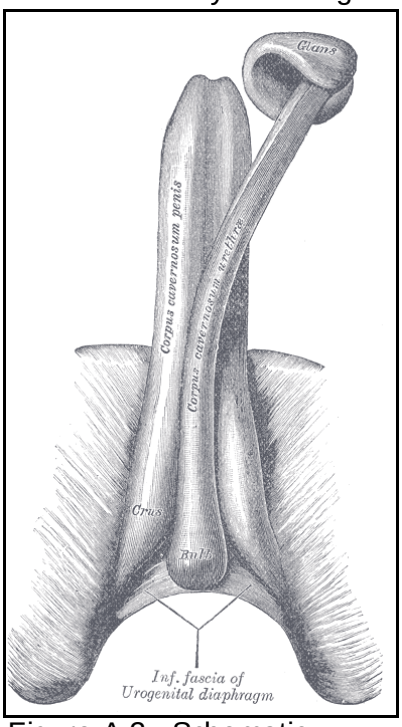

Figure A-2. Schematic diagram of the penis.

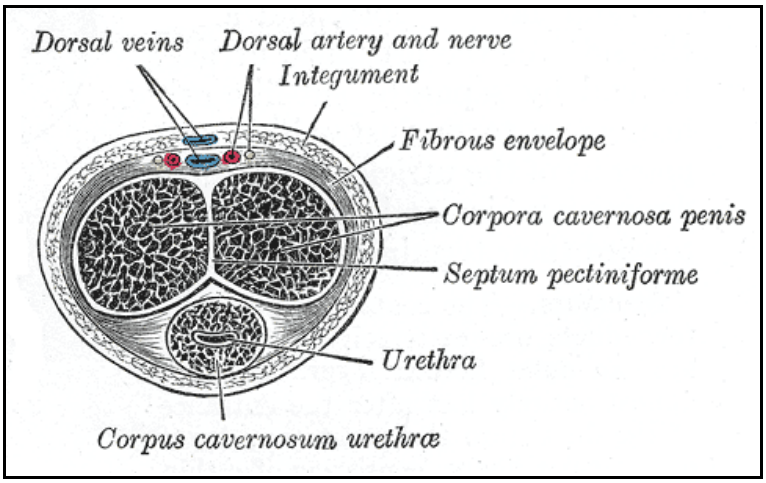

Figure A-3. Cross-sectional diagram of the penis.

associated with the germ cells, lumps or masses in the scrotum or on the epididymis, but not on the testicle, is not considered testicular cancer.

The skin surrounding the testicles is considered to be thin and includes dense connective tissue; thus, for modeling purposes, the skin thickness is assumed to be 1.5 mm thick plus 1 mm of dense connective tissue. For modeling purposes it is assumed that male workers wore pants or shorts and one layer of undergarments. Pants were assumed to have a thickness of 2 mm and a density of 0.7 g/cm^3 while the layer of undergarment was assumed to have a thickness of 2 mm and a density of 0.7 g/cm^3. These estimates are considered to be claimant favorable.

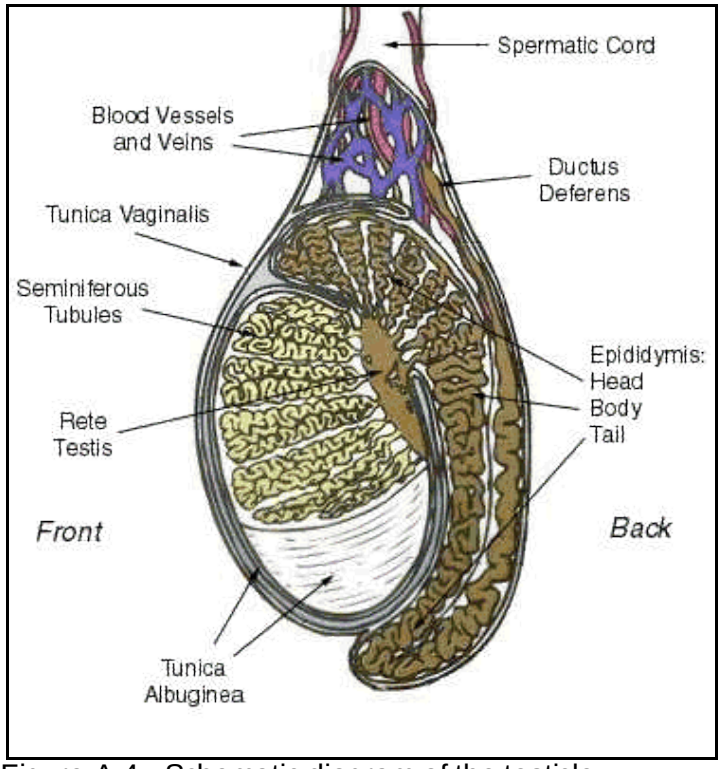

Figure A-4. Schematic diagram of the testicle.

Breast, Penis, and Testicle Dose Calculations

The following recommendations provide a correction factor that should be applied to the non-penetrating dose determined in accordance with this TIB in order to determine the dose to specific organs. The correction factor, when multiplied by the shallow dose measurement, will provide a claimant favorable reconstruction of the dose to the breast, penis and testicles.

As described above, the tissue depths for the breast, penis and testicle were nearly identical, including the layers of clothing covering these organs. Therefore, these organs were modeled identically as having a skin depth of 2.5 mm with a total covering of 5 mm of cloth with a density of 0.5 g/cm^3. The dose was calculated at a point immediately below these layers and was compared to the dose to the skin at a depth of 70 μm. The source was modeled as a 10 cm^2, infinitely thin disk source located 2 cm away from the skin. Different source geometries would not significantly change the resulting correction factors. The skin depth for the breast was set to 70 μm below the clothing and the dose was averaged over 0.01 cm^2. The results of the calculations are provided in Table A-1.

Table A-1. Correction factors for non-penetrating dose to the breast, penis, and testicles.

Radionuclide	Maximum beta energy (keV)	Correction factor for breast, penis, and testicles
Ru/Rh-106	3,540	0.29
Sr/Y-90	2,280	0.21
Y-91	1,540	0.002

The results show that the minimum beta energy required to penetrate to the target cells in the breast, penis, and testicle is 1500 keV. By comparison, ICRP Table A.43 gives this minimum energy as 1000 keV (1.0 MeV), but those calculations do not account for clothing. Thus, calculating the dose to these organs from beta radiation should only be considered for sources with maximum beta energies above

1500 keV. For these sources, Table A-1 indicates that a claimant favorable approach would be to assign 30% of the beta particle dose calculated in accordance with this TIB. This factor should be assigned to the missed dose calculated in accordance with this TIB only for the badge cycles in which the missed dose was assigned as beta particles; to ensure claimant favorability, missed dose is generally assumed to be associated with 30-250 keV photons, in which case a correction factor would not be appropriate.

Corrections associated with beta particle exposure in uranium facilities must consider the presence of uranium daughter products. Beta exposures during work involving natural uranium or uranium with enrichments below approximately 30% are typically dominated by a high energy beta particle from the U-238 daughter Pa-234m which has a maximum energy of 2.29 MeV, very similar to that of Y-90 (see Table A-1); therefore, the factor of 30% indicated above would be claimant favorable for such exposures. Although ICRP 74 Table A.43 indicates a conversion factor for the breast of 0.49 for 2 MeV beta particles, two considerations indicate that a factor of 0.3 is claimant favorable for radionuclide exposures involving such energies (e.g., uranium). First, radionuclides emit beta particles having a non-uniform energy spectrum, and thus the average beta particle energy from uranium is substantially less than 2 MeV. Second, the ICRP 74 factors do not take clothing into account. Note that for beta particle exposures above 4 MeV (i.e., as may be encountered in certain accelerator facilities) the factor of 0.3 may not be claimant favorable; ICRP 74 should be consulted for appropriate correction factors for such circumstances.

At facilities with low-energy X-rays, notably Pu facilities, the open-window dosimeter reading is often significantly higher than the shielded reading, which is largely a result of a significant fraction of the X-rays being absorbed by the 1 cm-thick shield. However, for a total shield thickness of approximately 0.5 cm for the breast, penis and testes as described above, over 50% of the 17 keV Pu X-rays and over 98% of the 60 keV Am-241 photons would reach the sensitive issues, and thus no correction is recommended for the non-penetrating component.

Lip Dose Calculations

A correction should be made when calculating dose to the lip to account for dose received at a depth of 20 μm, which is a claimant-favorable assumption based on the lip's thinner epidermis compared to that of the skin. Table A-2 provides radionuclide-specific correction factors for several radionuclides of interest. The data in Table A-2 were calculated using Varskin 3 as described previously.

The correction factor is most notable for the low-energy beta sources, especially those with maximum energies below 500 keV. These parameters are considered to be claimant favorable. Note that electrons below 100 keV do not contribute to the lip dose.

Table A-2. Correction factors for non-penetrating dose to the lip.

Radionuclide	Maximum beta energy (keV)	Correction factor for lip
Ce-141	580	1.0
Co-58	475	1.0
Co-60	318	1.2
Cs/Ba-137m	512	1.1
Eu-154	569	1.5
Eu-155	246	3.3
I-131	606	1.2
Nb-95	160	3.6
Pm-147	225	1.8
Ru/Rh-106	3,540	1.0
Sr/Y-90	2,280	1.0

Tc-99	294	1.2
Y-91	1,540	1.0
Zn-65	330	1.0

Based on the information in Table A-2, a claimant favorable approach would be to apply a correction factor of 3.6 to the non-penetrating dose component assigned as beta particles. For cases in which this factor results in a POC greater than 50%, a more appropriate correction factor should be applied based on the radionuclides of concern as documented in the site TBD and other relevant information sources. As discussed previously, beta exposures from uranium are typically dominated by the high-energy beta particle from Pa-234m, so in these cases no correction would be needed for calculating beta dose to the lip.

ATTACHMENT B
SKIN DOSE ASSIGNMENT FOR SAVANNAH RIVER SITE CASES

General Information
In the film badge era, the OW reading likely included a significant over-response to low-energy photons; therefore, prior to 1971, measured doses assigned as <30 keV photons should be multiplied by 0.6 if there is no indication in the records that the dosimeter was calibrated for low-energy photons.[2]

A. The penetrating component of skin dose (and the non-penetrating component of skin dose for Pu workers) must be multiplied by the appropriate era-specific correction factor (e.g., 1.119) per the TBD and OCAS-TIB-006.

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

- 1951 – 1970: 50 mrem for OW, 40 mrem for S
- 1971 – 1983: 25 mrem for OW, 15 mrem for S
- 1984 – present: 20 mrem for OW, 5 mrem for S

C. For 1982 and later, these instructions supersede the information in Section 3.0 (Shallow Dose Interpretation) of OCAS-TIB-006.

Procedure
Measured Dose
1. Subtract the reported S reading from the reported OW reading. This is the calculated non-penetrating dose.

2. Assign the calculated non-penetrating dose as either electrons E>15 keV, or photons E<30 keV. In the former case, a correction factor should be provided for clothing, if applicable, depending on likely clothing thickness and beta energy; in the latter case, if applicable (see General Information above) a correction factor of 0.6 should be applied prior to 1971 to account for film over-response, and the era-specific correction factor should be applied.

3. Multiply the reported S reading (separating out the neutron dose, as applicable) by the appropriate era-specific correction factor. This is the corrected penetrating photon dose.

4. Assign the corrected penetrating photon dose as photons, partitioned by energy according to the SRS TBD or OCAS-TIB-006.

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

Missed Dose
6. For any badge cycle with a zero result in either the OW or S reading, or both, assign a single missed dose as explained in Items 7-9 below.

7. If only the OW reading was reported as zero, the missed dose assigned should be the appropriate OW LOD for that era (divided by 2, treated as lognormal) and considered electrons (corrected for

[2] As discussed in OCAS-OTIB-0006, a 17-keV calibration curve in the DOE records is evidence of calibration for low-energy photons based on the employee's work with Pu.

attenuation, if applicable) or low-energy photons (multiplied by 0.6 in the film badge era, if applicable) consistent with the approach taken in Step 2.

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

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

10. During the film-badge era, if there was a potential exposure to neutrons, assign unmonitored neutron dose based on neutron-gamma ratios per the TBD (using an organ DCF of 1).

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

Examples of skin dose assignments for SRS badge readings in 1970 (assuming no clothing correction and no calibration curve in record for low-energy photons) (mrem).

OW reading	S reading	Measured dose assigned	Missed dose assigned
50	0	50 (electrons) or 50 X 0.6 X 1.119 = 33.57 (low-energy photons)	40/2 = 20 (30-250 keV photons)
0	0	None	50/2 = 25 (30-250 keV photons)
100	60	40 (electrons) or 40 X 0.6 X 1.119 = 26.856 (low-energy photons) AND 60 X 1.119 = 67.14 (photon energy per TBD or OCAS-TIB-006)	None
100	100	100 X 1.119 = 119.00 (photon energy per TBD or OCAS-TIB-006)	None
0	40	40 X 1.119 = 44.76 (photon energy per TBD or OCAS-TIB-006)	50/2 = 25 (electrons) or 50/2 X 0.6 = 15 (low-energy photons)

ATTACHMENT C
SKIN DOSE ASSIGNMENT FOR HANFORD CASES

General Information

A. In the film badge era, the OW reading likely included a significant over-response to low-energy photons; however, starting in April 1957, an additional dosimeter element was included in the badge design to facilitate an accurate measurement of X-ray dose. Therefore, prior to April 1957, measured doses assigned as <30 keV photons should be multiplied by 0.6 (only if, as described in Section 3.0, evidence exists indicating that the recorded doses were not adjusted downward by the site to account for the over-response).

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

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

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

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

E. As described in the Hanford Occupational Environmental Dose TBD, workers from the mid 1940s to the mid 1950s may have been exposed to radioactive particles emitted from facility stacks.

Procedure

Measured Dose

1944-March 1957

1. Determine the non-penetrating dose by subtracting the reported S reading from the reported OW reading.

2. Assign the non-penetrating dose as either electrons >15 keV (corrected for attenuation, if applicable), or photons <30 keV if the employee worked primarily with or near plutonium, such as in PFP. In the latter case, a correction factor of 0.6 should be applied to account for film over-response, if a correction by the site is not evident in the records as described above and in Section 3.0.

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

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

April 1957-1971

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

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

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

1972-1994

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

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

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

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

1995-Present

12. Determine the non-penetrating dose by subtracting the reported deep photon reading from the reported shallow reading.

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

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

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

Missed Dose

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

17. If only the OW (or beta, or non-penetrating) reading was reported as zero, the missed dose assigned should be the appropriate non-penetrating LOD for that era (divided by 2, treated as

lognormal) and considered electrons (corrected for attenuation, if applicable) or low-energy photons (multiplied by 0.6 prior to 1957). For the period 1957-1971, when X-ray doses were reported separately, a non-zero value reported for X-rays indicates that the missed dose should be considered electrons, and a zero value reported for X-rays indicates that the missed dose should be considered 30-250 keV photons.

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

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

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

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

Examples of skin dose assignments for Hanford badge readings in 1980 (assuming no clothing correction) (mrem).

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

Examples of skin dose assignments for Hanford badge readings in 1970 (assuming no clothing correction) (mrem).

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

ATTACHMENT D
SKIN DOSE ASSIGNMENT FOR GASEOUS DIFFUSION PLANT CASES

General Information

A. In general, the contribution to skin dose at DOE gaseous diffusion plants (GDPs) from low-energy photons is extremely small compared to the contribution from beta particles.

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

Paducah

- 1953 – 1980: 50 mrem for OW, 40 mrem for S
- 1981 – 1988: 30 mrem for OW, 20 mrem for S
- 1989 – present: 20 mrem for OW, 20 mrem for S

Note: The Paducah TBD states an OW LOD of 120 mrem for 1953-1980. However, this value appears to be speculative when compared against the LOD values for similar dosimetry systems at other sites at that time (see attachments A and B and the information for Portsmouth and K-25 below). As stated in the TBD, "In 1953, PDGP began using dosimeter and processing technical support from Oak Ridge National Laboratory…practices were similar to those used at ORNL and other major sites…ORNL has provided PGDP with dosimeters from early in the operations period through the present." Based on the information provided, it appears that the LOD value reported in the TBD is based on considerations involving low-energy beta emitters; however, this would significantly overestimate the LOD (and missed dose) when the principal source of exposure is uranium, since the dosimeters were calibrated using uranium slabs. Therefore, the value has been reduced in this TIB to 10 mrem above the reported photon LOD. The dose reconstructor should consult the TBD to address potential exposures to Tc-99.

Portsmouth

- 1954 – 1980: 30 mrem for OW, 30 mrem for S
- 1981 – 1982: Not Applicable for OW, 15 mrem for S
- 1983 – 1998: 40 mrem for OW, 10 mrem for S
- 1999 – present: 30 mrem for OW, 10 mrem for S

Note: For 1981 and 1982 there was no open window dosimeter measurement, so non-penetrating doses were not measured directly. Therefore, for this period the dose reconstructor must use judgment based on 1) extrapolation from prior and later years (if the employee's job and exposure conditions were consistent throughout the period), 2) application of shallow to deep dose ratios, or 3) co-worker studies. Additional research may be required to determine an appropriate method for the case.

K-25

- 1945 – 1987: 30 mrem for OW, 30 mrem for S
- 1988 – present: 5 mrem for OW, 5 mrem for S

Note: K-25 does not distinguish between open-window and shielded dosimeter measurements when reporting MDLs. It is implied that the MDLs should be considered the same.

C. To account for a potential exposure to Tc-99, which would not have been measured accurately by the dosimeters used at the sites, missed Tc-99 dose should be added as prescribed in the site TBD for some workers.

Procedure

Measured Dose

1. Subtract the reported S reading from the reported OW reading. This is the calculated non-penetrating dose.

2. Assign the calculated non-penetrating dose as electrons >15 keV. A correction factor should be provided for clothing, if applicable, depending on likely clothing thickness and beta energy.

3. Assign the reported S dose as photons, partitioned by energy according to the site-specific TBD.

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

Missed Dose

5. For any badge cycle with a zero result in either the OW or S reading, or both, assign a single missed dose.

6. If only the OW reading was reported as zero, the missed dose assigned should be the appropriate OW LOD for that era (divided by 2, treated as lognormal) and considered electrons (corrected for attenuation, if applicable).

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

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

9. Assign missed or unmonitored neutron dose per the TBD.

10. If applicable, assign unmonitored Tc-99 dose (as >15 keV electrons) per the TBD.

Examples of skin dose assignments for GDP badge readings in 1970 (assuming Paducah LODs, no clothing correction and no Tc-99 exposure) (mrem).

OW reading	S reading	Measured dose assigned	Missed dose assigned
50	0	50 (electrons)	40/2 = 20 (30-250 keV photons)
0	0	None	50/2 =25 (30-250 keV photons)
100	60	40 (electrons) AND 60 (photon energy per TBD)	None
100	100	100 (photon energy per TBD)	None
0	40	40 (photon energy per TBD)	50/2 = 25 (electrons)