6.0 Operational Basis

The operational practices involved in the day-to-day administration of an external dosimetry program described in this chapter were originally developed for use at Hanford. As such, they were reviewed and concurred to by Hanford radiological control organizations through the HPDAC (described in Chapter 2). Non-Hanford users can subscribe to the Hanford practices as documented here or document their own practices in a site-specific document. To ensure accurate measurement of dose, the practices described here regarding how the dosimeters need to be worn, are strongly recommended for non-Hanford users as well. Other practices such as selection of persons to be monitored, are documented here to meet documentation requirements for Hanford. Such practices should be documented by the non-Hanford user to comply with their own regulatory and other requirements.

The technical basis of HEDP dosimetry technology and practices based primarily on laboratory measurements, as described in Chapter 5.0, is used to determine dosimetry practices. For some of these practices, detailed instrument and dosimeter measurements are necessary in the work environment to ensure that the dosimeter-measured dose reasonably estimates the "true" dose. User radiation protection organizations are responsible for field dosimetry practices, including monitoring exposure conditions in the work environment, controlling worker dose, and properly using dosimetry support provided by HEDP. HEDP staff work closely with user radiation protection organizations regarding several operational aspects of the dosimetry program. User select the personnel to be monitored, the choice of dosimeter, and the exchange frequency. User radiation protection organizations maintain portable instrument survey data of the work environments, and they are responsible for conducting evaluations of any lost or missing dosimeter results for their personnel. They are also responsible for the contractor-specific ALARA programs and Area Monitoring programs. HEDP staff are responsible for detailed records of dosimeter processing and dose assessment to include QA, QC, training, staff qualifications, equipment maintenance and calibration, and record keeping.

6.1 Nonoccupational Dose

DOE requires the dosimetry program to assess only personnel dose resulting from occupational exposure. Dose from medical procedures or from natural background radiation is not to be included in the recorded dose. To achieve this objective, Hanford staff training includes the statement that personnel are to contact their respective radiation protection organization representative whenever there is a possibility of dose from nonoccupational circumstances, such as medical procedures. In these cases, the radiation protection representative with the person's supervisor, will develop an approach to ensure that nonoccupational dose is not recorded. Within the external dosimetry system, procedures are used in the collection of dosimetry data and the calculation of dose to compensate for the dosimeter response from naturally

occurring environmental radiation. For offsite customers, this includes the use of transit control dosimeters in offsite dosimeter shipments.

6.2 Selection of Persons to be Monitored

At Hanford, personnel dosimeters are required for any one of the following:

- individuals entering a high or very high radiation area or entering a radiation area unescorted

- personnel who, under typical conditions, are likely to receive an external dose equivalent greater than any of the following in one year

Whole body (EDE)	100 mrem
Lens of eye	1500 mrem
Extremity	5000 mrem
Skin	5000 mrem

- individuals likely to receive a deep dose equivalent from external exposure to any organ or tissue other than the lens of the eye of 5000 mrems or more

- any declared pregnant worker who is expected to receive 50 mrem or more to the embryo/fetus during the gestation period

- minors and students, visitors, and members of the public expected to receive 50 mrem or more in a year.

User contractor organizations are responsible for assigning and exchanging dosimeters and determining the criteria for the type of dosimeter to be assigned.

6.3 Dosimeter Wearing Practices

The Hanford Standard Dosimeter (HSD) and Hanford Combination Neutron Dosimeter (HCND) are used to measure the shallow, eye, deep, and neutron dose equivalent. For routine use, (i.e. uniform radiation fields), these dosimeters should be worn on the front of the torso, between the neck and waist. If a work task requires orientation of the individual facing away from the source for a significant amount of exposure, then the dosimeter should be relocated to the back, or two dosimeters (one front and one back) used for these jobs. When protective clothing is used, and the radiation field is primarily penetrating radiation, the dosimeter may generally be worn under the protective clothing such as on a lanyard or in a pocket. When a substantial non-penetrating component (beta or low energy photon radiation) is likely to be present, and the eyes or substantial areas of skin are unprotected (e.g., the face and neck), then the dosimeter should be placed on the outside of the protective clothing. When wearing dosimetry outside protective clothing, it will be necessary to ensure that the dosimeter does not become contaminated while preserving the shallow dose response of the dosimeter (e.g., by using a thin plastic bag). When a single dosimeter must be used in conjunction with lead filled aprons or bullet proof

protective vests, it should be worn on the outside of the apron or vest. For bullet proof protective vests, HEDP staff should be consulted regarding the potential effects of vest composition on dosimeter response. Credit may be taken for dose reduction achieved with lead aprons by using multiple dosimeters and compartment weighting factors to calculate an effective dose equivalent for use as the whole body dose of record (see Section 6.8.3). For example, a dosimeter could be worn on neck/collar, outside the apron, and one on the chest under the apron. If the radiation field is well characterized, and the relationship between dosimeter readings under the apron and outside the apron are known, then a single dosimeter outside the apron in conjunction with weighting factors to calculate EDE may be used. Guidance on calculating EDE when protective lead apron are used, is given in NCRP Report No 122 (NCRP 1995).

For the HCND, Hanford practice is to wear the dosimeter within 1.27 cm of the body at all times. Studies using a bare ^{252}Cf neutron source irradiation have shown a significant decrease in the TLD response of the HCND when the dosimeter is located more than 1.27 cm from the surface of a phantom (see Chapter 5). For lower-energy neutron fields, such as those typical of Hanford's Plutonium Finishing Plant (PFP), an even greater reduction in measured dose would be expected. However, the angular response characteristics described in Chapter 5 may tend to minimize the under-response under these conditions. It is also important to understand the dependency of the TLD response on the geometry of the backscattering material. The TLD requires a large volume of tissue-equivalent material (i.e., 10 cm of material beyond the edge of the dosimeter) before the response of the dosimeter becomes insensitive to further increases in the size of the backscattering material. This is a particular concern if attempts are made to measure the neutron dose by placing the HCND on different parts of the body (i.e., arms, legs, head, etc.). In these situations allowances should be made for the fact that the measured dose will under estimate the true dose.

General guidance on wearing extremity dosimeters includes the requirement for the dosimeter to be worn in a manner to maximize the recorded dose. For example, a ring dosimeter should be worn facing the palm of the hand if vials containing radioactive material are being handled. Because of the wide variety of possible circumstances, facility radiation protection staff are directly involved in determining how and where to wear the dosimeters.

6.4 Dosimeter Exchange

There are four categories of dosimeter assignment at Hanford:

- temporary
- monthly
- quarterly
- annually.

Hanford contractor dosimetry organizations are responsible for determining the dosimeter exchange frequency for each assigned dosimeter. The basis for the assignment is primarily the anticipated dose to be received.

6.5 Dose Reporting Threshold

The dosimeter dose reporting thresholds are shown in Table 6.1 below. These levels are less than 1% of the respective DOE dose limits. Doses are reported to the nearest mrem (i.e., 11, 12, 111, 1112, etc.). In the case of the HCND, the shallow, eye, and deep doses are reported for the 8825 component and the neutron dose is reported independently (i.e., a separate record) for the 8816 component. For the 8816 record, a flag indicates whether the dose was from a TLD or TED result.

Table 6.1. Dose Reporting Thresholds (mrem)

	HSD	**8825 HCND**	**8816 HCND**	**Ring**
Shallow	10[(a)]	10[(a)]	n/a	10
Eye	10	10	n/a	n/a
Deep Photon	10	10	n/a	n/a
Neutron	20	n/a	MMD[(b)]	n/a

(a) 50 mrem for pure beta radiation.
(b) Minimum Measurable Dose corresponds to net chip readings > 10 mR equivalent.

It should be noted that the calculated LLDs for a given dosimeter type vary with radiation type, depth dose of interest, and wear period (see Chapter 5). Typically, radiation types for which the dosimeter is less sensitive, produce larger LLDs. Longer wear periods generally correspond to larger LLDs. The issue of detection thresholds and reporting thresholds was discussed in the HPDAC.[(a)] The basic issue centered around whether to use multiple reporting thresholds corresponding to detection thresholds, or use a simple threshold corresponding to practice at other DOE sites and past practice at Hanford, or use no thresholds at all. The question of which statistical concept (L_C, L_D, minimum *measurable* dose MMD, or other) would be appropriate to use for a reporting threshold was considered. Questions of what probability for type I and type II errors would be acceptable were discussed. Questions of "unreported dose" were considered. Potential impacts of changes in threshold on collective dose

(a) D. E. Bihl, "Minutes of the Hanford Personnel Dosimetry Advisory Committee Meeting Held on February 23, 1999.
D. E. Bihl, "Minutes of the Hanford Personnel Dosimetry Advisory Committee Meeting Held on March 23, 1999.
D. E. Bihl, "Minutes of the Hanford Personnel Dosimetry Advisory Committee Meeting Held on July 13, 1999.
D. E. Bihl, "Minutes of the Hanford Personnel Dosimetry Advisory Committee Meeting Held on August 17, 1999.
Copies of HPDAC minutes are retained in the Hanford Radiation Records Historical File.

reported for Hanford contractors were evaluated. A policy decision was made by DOE RL (Radiological Control Steering Committee) to continue using the simplified scheme of thresholds already in place, with the exception of neutron dose on 8816 TLDs, for which the only threshold now used is the detection threshold applied by the dose algorithm. Given the fact that the calculated LLDs are for the most part within 10 mrem of the flat thresholds above, regardless of exchange frequency or radiation type, the added complexity of applying multiple thresholds was not considered necessary. Therefore, in the interest of simplicity and consistency with past Hanford practice, a single reporting threshold has been adopted for each dose quantity and dosimeter type regardless of exchange period as shown above.

6.6 Hanford Recorded Dose

The HEDP practice of calculating the shallow and deep dose to be recorded was adopted decades ago as a conservative compromise among several alternatives. The dose recorded is calculated as:

Whole body dose	= deep dose + neutron dose
Skin dose	= shallow dose + neutron dose
Extremity dose	= skin dose + ring dose
Eye dose	= 300 mg/cm^2 dose + neutron dose

This practice is typically conservative (i.e., doses measured by reference dosimeter and rings are both recorded as extremity dose). Generally, staff do not wear ring dosimeters continuously and the adopted practice eliminates the tedious paperwork that would be necessary to base dose only on the ring (or other) extremity dosimeter measurements. Also, the adopted practice compensates to some degree for uncertainty in neutron dose received at the extremities that might be under-reported by the ring dosimeter. This practice is necessitated to some extent by the fact that there are no readily available extremity dosimeter designs which accurately measure neutron dose to the extremities. For multi-packs where the whole body and ring dosimeters were always worn together, the conservatism in recorded extremity dose can be corrected by reducing the recorded ring dose by the amount of shallow dose assessed from the whole body dosimeters in the packet. This can be accomplished after the dosimeters have been processed by means of the IODR form.

6.7 Lens of Eye Dose

The 300-mg/cm^2-depth dose due to beta and/or photon radiation is routinely calculated for the HSD and HCND. It is commonly referred to as Aeye dose@ but is not the same as the protection quantity Alens of eye dose@ calculated by REX. Based on the assumption that irradiation occurs in a uniform field, the REX recorded lens of the eye dose is calculated as follows:

$$\text{lens of eye dose} = 300\ \text{mg/cm}^2\ \text{dose} + \text{neutron dose}$$

This equation applies to dose for a given wear period corresponding to a routine chest dosimeter reporting period.

6.8 Multiple Dosimetry

Multiple dosimetry as discussed in this section, includes whole body and extremity dosimetry. Multiple dosimeters should be used when a dose to a portion of the whole body or to the extremities may significantly exceed the dose measured with the reference (i.e., chest) dosimeter. In particular, when the anticipated external EDE is significantly greater than the anticipated deep dose equivalent measured by the chest dosimeter, multiple whole body dosimeters should be worn. The need for assignment of multiple dosimeters is determined by the responsible contractor radiation control organization and should be documented in the applicable Radiation Work Permit.

NOTE: 10 CFR 835 and the *External Dosimetry Program Guide* (DOE199b) define deep dose equivalent to include both photon and neutron dose equivalent, whereas historically the two quantities have been recorded separately at Hanford. For consistency with other sections of this manual, the individual photon and neutron components will continue to be identified separately by the terms Adeep dose@ and Aneutron dose@ even though they are both implied by the term Adeep dose equivalent@ in the guidance documents used as the basis for this section. It should also be noted that, although 10 CFR 835 and the *External Dosimetry Program Guide* define EDE to include radiation from both external and internal sources, only EDE from external sources is implied in this Technical Basis Manual and in HPS N13.41, *Criteria for Performing Multiple Dosimetry,* (HPS 1997).

Extremity dosimetry should be worn for specific jobs in non-uniform fields with large dose gradients in which the extremities may receive a shallow dose more than 10 times greater than the deep + neutron dose received by the chest, <u>and</u> the extremities may receive a shallow dose greater than 500 mrem. The rationale for the ratio of 10 is the fact that the 10 CFR 835 limits for extremity dose (shallow) and whole body dose (deep +neutron) differ by a factor of 10. By ensuring compliance with the whole body limit, compliance with the extremity limit will be ensured by adherence to the above criteria. Extremity dosimetry should also be considered for jobs with potentially large dose gradients and <u>unpredictable</u> dose rates. The above criteria are minimum criteria and should be considered as guidelines. They do not preclude the use of extremity dosimetry under any circumstances where sound health physics judgment would warrant their use.

Eye dosimetry should be worn near the eyes for a specific job when the dose equivalent to the lens of the eye (at a depth of 300 mg/cm^2) may exceed the deep dose + neutron dose recorded by the chest dosimeter by 300% and also exceed 100 mrem. This guidance is based on the fact the limit for eye dose in 10 CFR 835 is a factor of 3 greater than the limit for whole body dose (deep + neutron).

Multiple whole body dosimetry should be worn when either of the following two criteria are met.

1. The calculated EDE is expected to exceed the deep + neutron dose equivalent measured by the reference dosimeter by more than 30%, and is expected to exceed 100 mrem.

2. The calculated EDE is expected to exceed the deep + neutron dose equivalent measured by reference dosimeter by more than 100 mrem.

The above criteria should be considered as an acceptable alternative to the Article 512.4 criteria (DOE 1999c). They do not preclude the use of multiple dosimetry if deemed appropriate (e.g., because of uncertainties in worker movement or radiation field strength). The 30% difference criteria was chosen based on the approximate percentages by which an actual EDE could exceed a chest dosimeter result under worst-case conditions, before multibadging would be required under current guidance in Article 512.4 of the DOE *Radiological Control* standard (DOE 1999c).

Guidance on when to multibadge is normally applied to a particular job episode, typically lasting not more than one month. For jobs that exceed one month in duration and involve multiple whole body dosimetry, the dosimetry should be processed at the end of each calendar month. For jobs that exceed one month in duration and involve routine chest and extremity dosimetry only (i.e., not a multipack), the dosimetry may be worn until the end of the calendar quarter before processing, if appropriate (i.e., if doses are expected to be low).

6.8.1 Evaluation of Dose of Record from Multiple Dosimetry Used on Non-Routine Jobs

Multiple whole body dosimeters should be issued as a packet for each individual. The packet must include a temporary chest dosimeter to replace the routine chest dosimeter as the person's primary (reference) dosimeter. Records must be maintained of the actual placement location for each dosimeter. Codes have been prepared for use by the Hanford dosimetry organizations to identify the location of the respective multiple dosimeters as shown in Table 6.2.

If the individual's routine chest dosimeter is believed to have significant dose (e.g., greater than 100 mrem) or the individual=s year-to-date dose is near an administrative control level (ACL), then it should be processed before or in conjunction with the multiple dosimeter packet to establish the individual=s current exposure status at the end of the job episode. After completion of the job, a temporary chest dosimeter would then need to be issued to the individual to be used as the primary (reference) dosimeter until the end of the normal dosimeter exchange period. However, if the routine chest dosimeter is known to have low dose, then it may be temporarily stored during multipack use, and worn as the primary (reference) dosimeter at times when the multipack is not being used, (including the remainder of the dosimeter=s exchange period after the routine job has ended).

The external dose of record in REX is stored as shallow, eye, deep, and neutron components of external dose equivalent measured at various body locations. It is from these data that protection quantities such as EDE (or whole body dose), skin dose, lens of eye dose, and extremity dose are calculated by REX for use in

exposure status reports and screens. The compliance quantities are calculated using the general relationships shown in Section 6.6 with the following caveat: on REX screens and reports, Awhole body dose@ refers to TEDE, and includes both the CEDE and external EDE contributions as well as the historical quantities called Atritium dose@ and A35% of x-ray.@

The methodology used to evaluate the dose of record for multiple dosimetry is actually a methodology for determining the amounts of the basic shallow, eye, deep, and neutron quantities to be added to (or subtracted from) the individual=s record where appropriate. When a dosimeter is processed as a supplemental dosimeter under REX note code 85 (supplemental dosimeter-normal processing) or 86, (supplemental dosimeter-special processing), its results are not automatically entered into the individual=s record. When a dosimeter is processed under any note codes other than 85 or 86, its results are automatically entered into the record unless a reject flag has been previously set for the dosimeter in REX. In those cases where REX has automatically entered the results into the individual=s record, an evaluation of any needed changes to the record will require a detailed knowledge of how results were interpreted by REX. For this reason, the recommended method for processing multiple dosimetry is to submit all dosimeters (including chest dosimeter) under note code 85 or 86. For the sake of simplicity, the following discussion assumes that all dosimeters in the multipack were processed under note code 85 or 86 and that results have not been automatically entered into the record by REX.

Table 6.2. Multiple Dosimeter Location Codes

Body Location	Code		Description
Hand	left right	= A, = B	The hand includes the area from below the wrist to the end of the fingers.
Eye	left right	= C, = D	The eye includes only the eye; the rest of the face is included in the head.
Head		= E	The head includes the complete head and the neck, both front and back, except for the eyes.
Abdomen		= F	The abdomen includes the frontal area below the bottom of the rib cage and above the groin.
Wrist	left right	= G, = H	The wrist includes the wrist and lower arm below the elbow.
Thigh	left right	= I, = J	The thigh includes the leg area below the groin and above the knee.
Knee	left right	= K, = L	The knee includes only the knee area.
Lower Leg	left right	= M, = N	The lower leg includes the leg area below the knee and above the ankle.
Foot	left right	= O, = P	The foot includes the ankle and the foot to the end of the toes.
Groin		= Q	The groin is the frontal area of the body at the junction of the thighs and the trunk of the body.
Chest		= R	The chest includes the frontal area below the neck and above the bottom of the rib cage. However, if the primary dosimeter is placed at the belt line or above and below the neck, it will be considered as the chest.
Back		= S	The back includes the area of the back of the body trunk below the neck and above the thighs.
Upper Arms	left right	= T, = U	The upper arm includes the elbow and the arm above the elbow and below the shoulder.

$ **Deep Dose + Neutron Dose.** The deep dose and neutron dose of record are summed by REX together with any internal dose commitment committed effective dose equivalent (CEDE) to obtain Awhole body dose@ total effective dose equivalent (TEDE) and printed on REX reports or screens. The external EDE for the job needs to be calculated from the multipack dosimeter results using the methods and weighting factors described in Section 6.8.3. Where both photon and neutron radiations were measured, individual Adeep@ and Aneutron@ EDEs need to be calculated. The photon and neutron external EDEs thus calculated need to be documented on a multiple dosimetry evaluation form to be submitted to the HRRP for inclusion in the individual=s radiological records. The EDE numbers are entered on the multiple dosimetry evaluation form as the Adeep@ and Aneutron@ dose to be added to the individual=s record. Assessed EDEs of less than 10 mrem are not added to the record.

- **Shallow Dose.** For compliance purposes, the shallow dose + neutron EDE assessed for the multipack, when added to the individual's record, is used by REX in calculating "skin" dose as needed for reports and screens. (The necessary adjustments to neutron dose in REX based on neutron EDE are addressed in the preceding bulleted text.) However, the shallow dose measured by all dosimeters placed on the "whole body" must be evaluated using non-compartmental (i.e., highest location) methods to determine the amount of shallow dose to add to the REX record. Special consideration should be given to the shielding of skin and/or dosimeter from beta radiation. Normally, the highest shallow dose on a whole body dosimeter would serve as the basis for the shallow dose of record. In some cases, however, this may not be appropriate. For example, the highest shallow dose reported by a dosimeter worn outside protective clothing may not be the best estimate of actual skin dose received if beta radiation is involved and a lower reading was obtained near the only bare exposed skin. Conversely, the shallow dose reported by a shielded dosimeter at any location would underestimate the true skin dose received if the person had bare, exposed skin nearby. The shallow dose to be added to the REX record will be the assessed shallow dose from the multipack. The shallow dose to be added to the record will need to be documented on a multiple dosimeter evaluation form and submitted to the HRRP.

- **300 mg/cm^2 Dose (Eye dose).** The 10 CFR 835 compliance quantity Alens of the eye dose equivalent@ is calculated in REX as the sum of the 300-mg/cm^2 dose of record (commonly referred to as Aeye dose@) and the neutron dose of record. The 300-mg/cm^2 dose of record is referred to as Aeye dose@ on IODR and multiple dosimetry forms but does not normally include neutron dose. The 300-mg/cm^2 dose + neutron dose measured by the dosimeter worn nearest the eyes should be indicated on the multiple dosimetry form as Aeye dose@ to be added to the individual=s record in REX. Even though a neutron EDE has already been assessed for the multipack, it may be significantly less than the neutron dose measured by a dosimeter worn on or near the head. Therefore, the inclusion of neutron dose (if measured) in the 300-mg/cm^2 dose adjustment to REX is necessary to ensure that Alens of the eye dose@ appearing on REX reports and screens is not under-reported because of an EDE-based neutron dose of record determined as indicated in the first bulleted test.

- **Shallow Dose to the Extremity.** AExtremity@ dose is calculated in REX as the sum of shallow dose + neutron dose + ring dose. The highest measured shallow dose + neutron dose result for all dosimeters placed on the extremities needs to be determined. This value should be indicated on the multiple dosimetry evaluation form as the dose to be added to the Aextremity@ record in REX.

NOTE: On multiple dosimetry forms, any dose assessed as Aextremity dose@ will be entered into REX as Aring dose@, i.e., shallow dose to the extremities.

A documented evaluation by the respective contractor dosimetry representative is necessary for assignment of dose from a multiple dosimetry packet, even if the dose assigned is zero.

6.8.2 Evaluation of Dose of Record for Continuing Routine Jobs

There may be instances of a recurring job where some portion of the whole body (e.g., the elbow) may be exposed to levels higher than measured with the reference dosimeter. In these cases, an evaluation should be performed to see if the criteria for use of multipacks stated at the beginning of Section 6.8 are met for a one-month period. If the criteria are met, then multipacks including multiple whole body dosimetry should be issued for periods up to one month and the results evaluated for each packet as described in Section 6.8.1 above at the end of each month. (Rings may be used in conjunction with a routine chest dosimeter for up to three months). However, multiple dosimetry may be appropriate even when the criteria of Section 6.8.1 are not met. Multipacks may be issued under any circumstances when deemed appropriate by the field health physicist, or specified by the RWP, and certainly should be considered for monthly use on long-term jobs where large dose gradients may exist and/or the dose rates are unstable over time. Otherwise, under stable conditions, consideration should be given to alternatives such as the use of correction factors applied to chest dosimeter results or relocation of the chest dosimeter.

6.8.3 Calculation of EDE

The deep or neutron external effective dose equivalent is calculated based on the product of the dosimeter-measured deep or neutron dose equivalent and a body compartmentalization factor applicable to each of the dosimeter-wearing locations consistent with the recommendations included in the DOE *External Dosimetry Program Guide* (DOE 1999b). Based on information in HPS N13.41 *Criteria for Performing Multiple Dosimetry* (HPS 1997), the whole body compartmentalization factors shown in Table 6.3 should be used. The basis for these factors is presented in Appendix A of the standard and describes the derivation of these factors from the 10 CFR 835 tissue-weighting factors.

Table 6.3. Whole Body Compartmentalization Factors

COMPARTMENT	COMPARTMENT FACTOR
Head and Neck	0.10
Thorax, above the diaphragm	0.38
Abdomen, including pelvis	0.50
Upper Right Arm	0.005
Upper Left Arm	0.005
Right Thigh	0.005
Left Thigh	0.005

From Health Physics Society Standards Committee (HPSSC). 1997. "Criteria for Performing Multiple Dosimetry." HPSN 13.41. Health Physics Society, McLean Virginia.

The equation used to calculate the deep photon external effective dose equivalent is as follows:

$$EDE_d = \Sigma (D_c * CF_c) \quad (6.1)$$

where: EDE_d = external effective dose equivalent from photons (mrem)
D_c = deep photon dose equivalent (mrem) measured for compartment c of the body
CF_c = compartment factor for compartment c from Table 6.3

The same equation is used to calculate the neutron external effective dose equivalent is as follows:

$$EDE_n = \Sigma (D_c * CF_c) \quad (6.2)$$

where: EDE_n = external effective dose equivalent from neutrons (mrem)
D_c = neutron dose equivalent (mrem) measured for compartment c of the body
CF_c = compartment factor for compartment c from Table 6.3

To determine the dose to a given compartment, the highest dosimeter result for that compartment is used. If the compartment was not monitored, the result for the nearest compartment monitored may be assigned. For the abdomen, the highest dosimeter result for an adjacent compartment may be assigned

6.9 Fetal Dose

Hanford contractor dosimetry organizations are responsible for assigning dosimeters to monitor the embryo/fetus dose from external radiation. General guidelines to provide consistency in recorded embryo/fetal dose among Hanford contractor organizations are included the follow:

- The deep + neutron dose as measured with a monthly exchanged personnel dosimeter is to be recorded.

- The deep + neutron dose recorded is that dose which is most representative of the exposure to the embryo/fetus (i.e., in the mother's lower torso region).

- In uniform radiation fields (i.e., no apparent variation within 50% in dose rate over the torso region of the mother's body), the primary dosimeter worn by the mother is representative of the exposure to the embryo/fetus.

- As determined by contractor radiation protection staff, particularly if there is a potential for receiving a 50-mrem or greater dose per month, temporary dosimeters may be assigned in addition to the monthly exchanged compliance dosimeter to monitor accumulated exposure at a frequency more rapid (i.e., weekly or biweekly) than the routine monthly dosimeter

exchange period. The temporary dosimeters should be worn along with the compliance dosimeter.

- In non-uniform radiation fields, including when shielding is used specifically to shield the embryo/fetus from exposure, multiple temporary dosimeters shall be used as described in Section 6.8. Typically, one temporary dosimeter is worn in the lower torso region of the mother (e.g., fetal/embryo exposure) and another temporary dosimeter is worn next to the primary (reference) dosimeter (e.g., mother's exposure). The temporary dosimeters are exchanged at the same time. The dose, obtained from the temporary dosimeter results, that is most representative of the dose to the embryo/fetus is recorded. The primary (reference) dosimeter is exchanged on the routine monthly or quarterly schedule.

6.10 Facility Calibration Codes

A two-digit facility calibration code is used to identify facility-specific correction factors to be used in the dose algorithms. At present, facility calibration codes are used to identify facility-specific ring correction factors and to identify neutron environments where either 1) a ^{252}Cf-based formulation or 2) a $^{239}PuF_4$-based formulation in the HCND algorithm should be used. When a code is not provided by the respective contractor dosimetry organization, the ^{252}Cf-based formulation is used as a default, which is expected to calculate the most conservative personnel dose. When the facility calibration code is not provided for rings, the ring algorithm applies a ring correction factor of 1.5 as a default, which is appropriate for the ^{137}Cs / ^{90}Sr source term typically encountered at Hanford. Ring correction factors are discussed in greater detail in Chapter 5. The general use of facility calibration codes in dose calculation is also discussed in Chapter 5.

6.11 Field Measurements

Field measurements of radiation dose and/or spectra are performed to ensure the credibility of the dosimeter-measured dose. This area is discussed in detail in Section 7.0.

6.12 DOELAP Accreditation Categories

Beginning in 1998, the scope of the DOELAP accreditation process was expanded by DOE to include extremity dosimetry. For 1998 performance testing, HEDP submitted the Hanford ring dosimeter and the HSD as a wrist/ankle dosimeter to be tested for accreditation. The number of categories for the HSD and HCND personnel dosimeters were also expanded. The HSD testing was expanded to neutron categories including both bare and moderated ^{252}Cf and mixtures of ^{137}Cs and x-rays with bare and moderated ^{252}Cf. The HCND application was expanded to include moderated ^{252}Cf and mixtures of ^{137}Cs and x-rays with moderated ^{252}Cf. The DOELAP categories selected for testing are based on radiation fields expected in Hanford work environments. For the testing performed during 1998 and 2000, the categories selected for the

HSD, HCND, Hanford ring, and HSD wrist dosimeter are shown in Tables 6.4 and 6.5.

Hanford Standard Dosimeter (HSD). The DOELAP category IIIB for plutonium work environments was chosen for low-energy photons because of the large inventory of plutonium at Hanford. Category IIIA was chosen because of special radioactive materials and X-ray sources used in PNNL and other labs at Hanford. The general beta radiation category, consisting of ^{90}Sr or ^{204}Tl beta sources, was chosen because of the diversity of potential beta sources at Hanford, including the large quantities of ^{90}Sr material stored at the Hanford Waste Encapsulation Storage Facility and in waste tanks. Waste tank sampling and laboratory analysis activities can involve substantial shallow doses from ^{90}Y beta particles. Category VI (bare and moderated) was chosen for the HSD because it is used on a limited basis as a neutron dosimeter. Workers expected to receive less than 100 mrem/year neutron dose may now be issued an HSD.

Hanford Combination Neutron Dosimeter (HCND). All DOELAP categories requested for accreditation for the HSD were included for the HCND. The moderated ^{252}Cf neutron spectrum was added to the bare ^{252}Cf neutron spectrum in the neutron category because of recent changes in the neutron spectra in Hanford neutron work environments. Specifically, recent changes in the type of work at PFP have resulted in a greater percentage of the neutron exposure occurring in high scatter environments with a softer neutron energy spectrum.

Hanford Ring Dosimeter and HSD Wrist Dosimeter. The performance test categories shown in Table 6.5 are adopted from HPS N 13.32 (HPS 1996a) for use by DOELAP. Because the Hanford beta source term includes ^{90}Sr/^{90}Y, and most extremity exposure at Hanford is from point sources, Category IV-C was selected for performance testing for both the ring and HSD wrist dosimeter. Slab uranium was not chosen for performance testing because uranium handling activities and slab geometries currently do not represent a significant source of extremity exposure at Hanford.

6.13 Operational Quantities and Dose Conversion Factors

Hanford personnel dosimeters are calibrated to measure the operational quantity Personal Dose Equivalent $H_p(d)$ (ICRU 1993; ICRP 1996) at depths d = 0.07 mm, 3 mm and 10 mm in soft tissue. These are generally referred to as shallow dose equivalent, eye dose equivalent and deep dose equivalent, and correspond to density thicknesses of 7 mg/cm^2, 300 mg/cm^2 and 1000 mg/cm^2 in soft tissue (DOE 1999b). For properly used dosimeters, these quantities can be used to demonstrate compliance with applicable protection limits. In particular, deep dose equivalent results from single dosimeters worn on the torso will generally provide a conservative estimate of the protection quantity Effective Dose Equivalent H_E (NCRP 1995). In 10 CFR 835, (DOE 1998c) deep dose equivalent is accepted as a valid estimate for effective dose equivalent for uniform exposures.

Table 6.4. Personnel Dosimeter Test Categories

Test Category	Dosimeter Designations		
	HSD[1]	**HCND(w/o CR-39) [2]**	**HCND (w CR-39)**
I. High-Dose[a] Low-energy photons only (M150)	X	X	X
II. High-Dose[b] High-energy photons only (^{137}Cs)	X	X	X
III. Low-energy photons (NIST-filtered techniques)	X	X	X
A. General (M30, S60, M150, H150)	X	X	X
B. Plutonium Monoenergetic, 15-20 keV Monoenergetic, 55-65 keV ^{241}Am			
IV. High-energy photons (^{137}Cs)	X	X	X
V. Beta particles A. General (Point Geometry) ($^{90}Sr/^{90}Y$, ^{204}Tl)	X	X	X
B. Slab uranium			
C. Special (Point Geometry) [c] ($^{90}Sr/^{90}Y$, ^{204}Tl)			
VI. Neutron[d] ^{252}Cf (bare)	X	X	X
^{252}Cf (moderated)	X	X	X
VII. Mixtures III & IV III & V IV & V III & VI IV & VI	X	X	X

a. Automatically entered into Category IIIA or IIIB
b. Automatically entered if entered into Category IV
c. Specify which beta source is selected for irradiation.
d. Specify which neutron source, or both sources, selected for irradiation.

1. HSD: Hanford standard dosimeter
2. HCND: Hanford combination neutron dosimeter

Table 6.5 Extremity Dosimeter Test Categories

Test Category	Dosimeter Designations		
	HRD[1]	HSD[2]	
I. High-Dose A. Low-energy photons only (M150)			
B. High-energy photons only (^{137}Cs)			
B. General, low and high energy photons[a] (M150, ^{137}Cs)	X	X	
II. Low-energy photons (NIST-filtered techniques) A. General[a] (M30, M60, M100, M150, H150)	X	X	
B. High-energy[a] (M100, M150, H150)			
III. High-energy photons[a] (^{137}Cs, ^{60}Co)	X	X	
IV. Beta particles A. Low-energy only (^{204}Tl)			
B. High-energy only ($^{90}Sr/^{90}Y$)			
C. General[a] ($^{90}Sr/^{90}Y$, ^{204}Tl)	X	X	
D. Slab uranium			
[a] Each dosimeter will be irradiated with only one of the NIST techniques.			

1. HRD: Hanford ring dosimeter, Harshaw XD-740 chipstrate in Siemens ring casing
2. HSD: Hanford standard dosimeter used in wrist configuration.

Dose conversion factors are used in the HPS N13.11 (1993) and DOELAP (DOE 1986a) dosimeter performance standards to relate exposure or air kerma to shallow or deep dose equivalent in phantoms of various compositions and dimensions. Several references provide dose conversion factors often for tissue depths of 7 and 1000 mg/cm^2 and a few references for 300 mg/cm^2. Small differences in the factors are common, based on differences in the radiation beam, exposure geometry, and composition of the phantom. Dose conversion factors presented in HPS N13.11 (1993) for shallow and deep dose, along with factors for 300 mg/cm^2 (Grosswendt 1990), are presented in Table 6.6. These factors can be used to estimate the dose at 7, 300, or 1000 mg/cm^2, based on knowledge of the incident energy and the absorbed dose in air.

Table 6.6. Dose Conversion Factors (Grosswendt 1990)

Photon Energy (keV)	Air Kerma to Dose Equivalent Conversion Factors (Sv/Gy)[a]		
	7 mg/cm^2	300 mg/cm^2	1000 mg/cm^2
15	0.965	0.665	0.274
20	1.034	0.932	0.625
30	1.224	1.204	1.109
40	1.455	1.494	1.471
50	1.629	1.762	1.758
60	1.752	1.848	1.954
70	1.742	1.835	1.931
80	1.767	1.832	1.948
90	1.744	1.858	1.872
100	1.656	1.772	1.800
120	1.609	1.686	1.720
150	1.530	1.548	1.659
662	1.210	1.210	1.210

(a) These factors are for the 30-cm ICRU phantom. All factors, including those in HPS N13.11 (1993), are from Grosswendt (1990).

Similar factors are presented for beta radiation in Figure 6.1. In this figure, obtained from Cross, Wong, and Freedman (1991), variations with electron energy of the dose equivalent divided by electron fluence ϕ, at 0.07, 3, and 10 mm, in water are presented for irradiations by broad, normally incident beams of monoenergetic electrons (Cross, Wong, and Freedman 1991). From this figure, skin dose per unit fluence varies by about a factor of 3 for different beta energies. If the beta ray fluence rate is measured from a distant source at the surface of the body, the skin dose rate can be estimated within a factor of about 2 (Cross, Wong, and Freedman 1991).

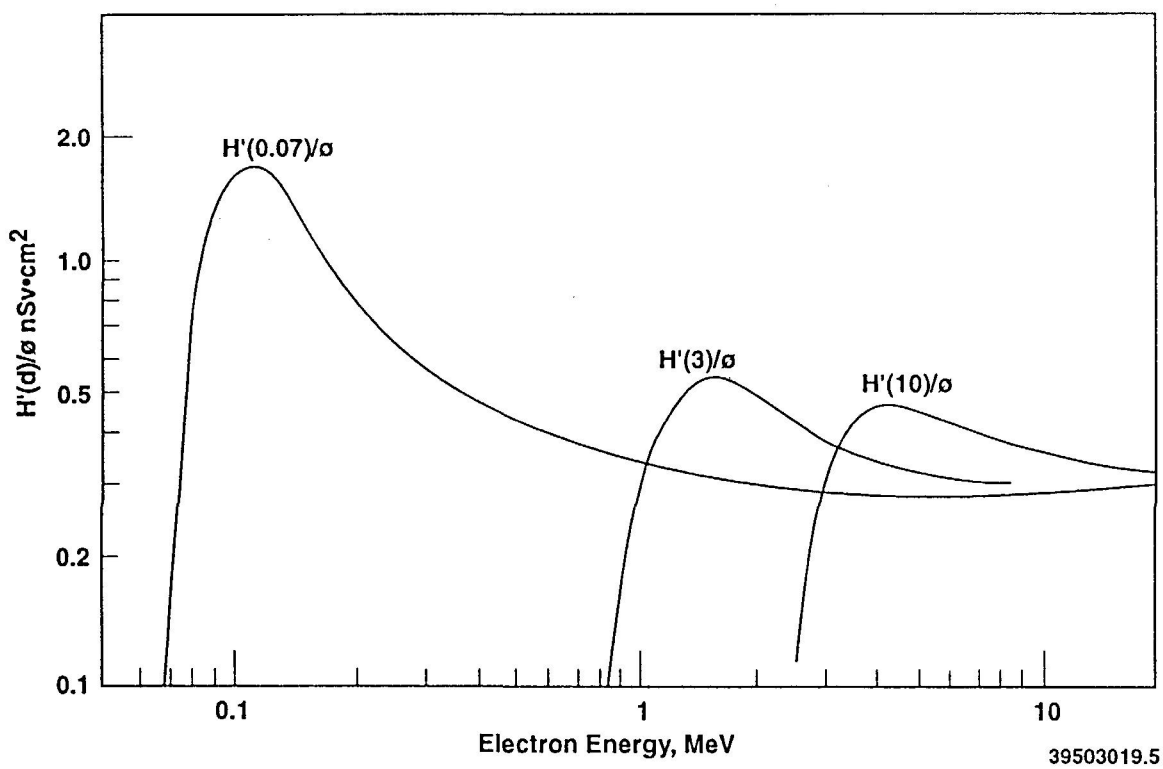

Figure 6.1. Variation in Dose Equivalent for Beta Radiation

6.14 Radiation Types Not Covered by DOELAP Performance Testing

Radiation types and energies not covered in the DOELAP performance testing standard, may require the use of facility specific correction factors and or facility specific algorithms. Examples of this would be neutrons from accelerators or (α,n) sources, and beta particles from soft beta emitters with average beta energies less than approximately 250 keV. For photons, the LiF phosphors in Hanford dosimeters are inherently tissue equivalent. Because of this and the fact that the DOELAP performance test standard is fairly comprehensive in scope for photons, the likelihood of facility specific corrections and or algorithms being needed for photon fields is relatively small. Correction factors for special radiation fields may be based on a knowledge of dosimeter response characteristics and a general knowledge of the radiation types and energies involved. However, if significant uncertainty exists, and significant exposure is expected, instrument measurements will generally be performed to validate the accuracy of the chosen correction factors.

The only work environment at Hanford currently requiring facility specific correction factors and/or algorithms on a routine basis is the plutonium finishing plant where neutron spectra are significantly different from either of the two sources used in the performance test standard. A facility specific neutron dose

algorithm was developed for HCNDs used at PFP and a facility specific ring correction factor has been adopted for rings worn at PFP.