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PUBLICATION RECORD

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05/19/2005	00	First approved issue. No training required. Initiated by Matthew H. Smith.

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ACRONYMS AND ABBREVIATIONS

cSv	centisievert
DCF	dose conversion factor
GM	geometric mean
GSD	geometric standard deviation
Hp(10)	dose equivalent at a depth of 10 millimeters
IREP	Interactive RadioEpidemiological Program
mrem	millirem

1.0 SCOPE

The purpose of this document is to supplement the information given in *Technical Basis Document for Rocky Flats Plant – Occupational External Dosimetry (Rev 00)*,[1] and *Technical Basis Document for Rocky Flats Plant – Occupational External Dosimetry (Rev 01).*[2] Additional information is given for the following topics;

- Calculating dose from low-energy photons and electrons
- Dosimetry uncertainty values

2.0 ESTIMATING RELATIVE CONTRIBUTIONS FROM HIGH, MEDIUM, AND LOW-ENERGY PHOTONS AND ELECTRONS FROM REPORTED DOSES

As discussed in the RFP external TBD (ORAUT-TKBS-0011-6) low energy photons from plutonium are generally stopped by the metal sides of the glove boxes that the majority of the plutonium was handled in. However; low-energy photons that are for the most part shielded do, in fact, escape the glovebox through material release, open glove ports, non-leaded windows, and from oxide coated on the interior surfaces of the gloves, especially when they are pulled outside the glovebox for storage to prevent them from being caught in machinery (DOE 2003). To take credit for this type of exposure, 25% of the photon exposure spectra from freshly separated plutonium is assumed to be from <30 keV photons. The default assumptions are shown in Table 2-1.

Table 2-1. Default photon energy distribution for RFP materials.

Energy	Plutonium	Enriched uranium	Depleted uranium
<30 keV	25%	0%	0%
30-250 keV	75%	100%	50%
>250 keV	0%	0%	50%

To more accurately define the dose at Rocky Flats, various algorithms were applied to measured doses. To accurately define the various spectral components and their contribution to the dose, it is necessary to algebraically manipulate the reported skin and penetrating dose. In the discussion below “Skin” dose and “Pen” dose are the doses as reported for Rocky Flats workers.

Pre - 1960

The two-element film dosimeter used at RFP from prior to 1960 had both Open Window (OW) and cadmium (CD) filter components. Some dosimetry records indicate the dose determined by the film darkening under each dosimeter element, as well as the recorded skin and penetrating dose values. Based on review of some of these data and data after 1960, the skin dose in this era was calculated as a sum of each of the three windows (OW + CD + BR).The dosimeter could not effectively measure the 60 keV photons, thus the reported penetrating (Pen) dose was calculated from the measured OW and CD component doses using the algorithm: Pen = 50% • OW + CD and the reported Skin dose was calculated as Skin= OW + CD. The addition of 50% of the recorded OW dose to the recorded CD dose was determined by Rocky Flats staff to correct the reported Pen dose for this underestimation (i.e. the relative ratio of the 60 keV photon dose to OW dose contribution is was determined to be about 0.5).

Thus the sum of the low-energy (<30 keV photons or >15 keV electron) and the photon doses (30-250 keV and/or >250 keV photons as applicable) exceeds the original reported skin dose. As a result, the following method should be used to estimate the low-energy photon dose for plutonium workers,

intermediate/high-energy photons for plutonium and uranium workers, as well as the >15 keV electrons for uranium workers:

$$\text{electrons}_{>15\ keV} \text{ or } \text{photon}_{<30\ keV} = [\text{skin-pen}]/0.50 = OW$$

$$\text{photon}_{(30\ keV\text{-}250\ keV)} + \text{photon}_{(>250\ keV)} = \text{pen} = CD + 50\%*OW$$

Using these equations and available knowledge of source material (e.g. plutonium, enriched or depleted uranium) spectra, an estimate of >15 keV electrons, <30 keV photons, 30-250 keV photons and >250 keV photon dose for use in dose reconstruction can be calculated from the reported Pen and Skin doses. Alternatively, if original component data is available in the dosimetry record, Pen and Skin doses can be calculated using the CD and OW results and the equations above.

1960 - 1970

The three-element film dosimeter used at RFP from 1960 to 1969 also had an Open Window (OW), a cadmium (CD) filter, and an additional brass (BR) filter providing half the filtration of the CD. The brass filter was added to more accurately measure the 60 keV photons. This dosimeter was phased out during the year 1970.

Some dosimetry records (illustrated in Attachment A-7 of the External Dose TBD) indicate the dose determined by the film darkening under each dosimeter element, as well as the recorded skin and penetrating dose values. Based on review of some of these data, the skin dose in this era was calculated as a sum of each of the three windows (OW + CD + BR). The penetrating dose was calculated by adding the CD + BR + 35% • OW. The 35% OW addition to the deep dose was a DOE weapons complex standard practice during this time period (including Hanford and Savannah River) to account for some low-energy photon (<30 keV) contribution to deep dose.

To properly reconstruct the low-energy and intermediate-energy photon dose between 1960 and 1970, the following reverse algorithm should be applied:

$$\text{electrons}_{>15\ keV} \text{ or } \text{photon}_{<30\ keV} = [\text{Skin-Pen}]/0.65 = OW$$

$$\text{photon}_{(30\ keV\text{-}250\ keV)} + \text{photon}_{(>250\ keV)} = \text{Skin} - (\text{electrons}_{>15\ keV} \text{ or } \text{photon}_{<30\ keV}) = BR + CD$$

Using these equations and available knowledge of source material (e.g. plutonium, enriched or depleted uranium) spectra, an estimate of >15 keV electrons, <30 keV photons, 30-250 keV photons and >250 keV photon dose for use in dose reconstruction can be calculated from the reported Pen and Skin doses. Alternatively, if original component data is available in the dosimetry record, Pen and Skin doses can be calculated using the CD, BR and OW results and the equations above.

1970 - Present

Starting in 1970, RFP used TLDs to measure photon dose. The TLD materials used were much more tissue-equivalent and the response much less energy-dependent. Dosimeters were calibrated to more appropriate photon energies and filter design had advanced. It is believed that these dosimeters performed substantially better than film. Although various chip and filter combinations were used, data provided in DOE dosimetry files does not generally include dose from individual components similar to the CD, BR and OW categories from the film era. However, in order to avoid omission or over application of dose due to filter design, the following relationships should be used for this time period:

$$\text{electrons}_{>15\ keV} \text{ or } \text{photon}_{<30\ keV} = \textit{Skin - Pen}$$

$$photon_{(30\ keV\text{-}250\ keV)} + photon_{(>250\ keV)} = Pen$$

Using these equations and available knowledge of source material (plutonium, enriched or depleted uranium) spectra, an estimate of >15 keV electrons, <30 keV photons, 30-250 keV photons and >250 keV photon dose for use in dose reconstruction can be calculated from the reported Pen and Skin doses.

3.0 UNCERTAINTY

The Technical Basis Document for Rocky Flats Plant Occupational External Dosimetry, (ORAUT-TKBS-0011-6) provides estimates of the 95% upper confidence dose at various reported doses. Table 4-1 provides factors for dosimetry uncertainty for the variety of systems in use during operations at RFP. The factors are taken directly from tables provided in the TBD when available or calculated from upper 95% confidence dose provided. The estimated error factors are proportional to the individual dosimeter reading. Choice of a specifically applicable uncertainty will depend on the dosimeter result. Also provided in Table 4-1 are correction multipliers that apply to neutron dosimetry. These correction multipliers are provided for completeness but are not related directly to statistical uncertainty. Table 4-2 provides a claimant favorable interpretation of the more detailed information in Table 4-1 that is only related to Uncertainty Factors on the dosimeter response.

Table 4-1. RFP external dosimetry uncertainty values and correction multipliers.

		(Correction multipliers)			Uncertainty factors		
Dosimeter type	**Period**	**Unmonitored energies**	**Building**	**Film reading bias**	**LOD**	**Dosimeter result range (mrem)**	**Upper 95% confidence dose multiplier**
Photon							
Film	1951 - 1969	1	All	1	40	>LOD	1.2* reported dose
Loose-Chip TLD	1970 - 1982	1	All	1	20	>LOD to 100	2.0* reported dose
						>100	1.26* reported dose
Panasonic TLD	1983 - 1998	1	All	1	20	<2	1.00* reported dose
						>2	1.23* reported dose
	1999 - 2003	1	All	1	10	<2	1.00* reported dose
						>2	1.18* reported dose
Neutron							
Film	1951 - 1963	2.5	B-771	1.99	120-400	All until NDRP data	1.93* reported dose
			Other neutron buildings	1.13			2.45* reported dose
	1964 - 1970	1	B-771	1.99	120-320	All until NDRP data	1.93* reported dose
			Other neutron buildings	1.13			2.45* reported dose
Loose-Chip TLD	1971 - 1982	1	All	1	20	>5	1.20* reported dose
Panasonic TLD (initial algorithm)	1983 - 1990	1	All	1	32	>5	1.21* reported dose
Panasonic TLD (Sanford algorithm)	1991 - 1992	1	All	1	32	>5	1.14* reported dose
Panasonic TLD (1993 updated algorithm)	1993 - 2003	1	All	1	15	>5	1.18* reported dose
Electron							
Film	1951 – 1968	1	All	1	40	>LOD to 100	1.5* reported dose
						>100	1.2* reported dose
Loose-Chip TLD	1969 - 1982	1	All	1	20	>LOD to 100	1.5* reported dose
						>100	1.26* reported dose
Panasonic TLD	All years (1983-2003)	1	All	1		≤2	1.19 (2 rem), 1.14 (1rem)
	1983-1989				18	>2	1.12* reported dose
	1990-1992				80	>2	1.12* reported dose
	1993 – 2003				15	>2	1.12* reported dose

Table 4-2. RFP external dosimetry claimant favorable uncertainty factors.

Dosimeter type	Period	Building	Uncertainty factor to estimate claimant favorable upper 95% confidence dose
Photon			
Film	1951 - 1969	All	1.20
Loose-Chip TLD	1970 - 1982	All	2.0 (1.26)a
Panasonic TLD	1983 - 1998	All	1.23
Neutron			
Film	1951 - 1970	B-771	1.93
		Other neutron buildings	2.45
Loose-Chip TLD	1971 - 1982	All	1.21
Panasonic TLD (initial algorithm)	1983 - 1990	All	1.21
Panasonic TLD (Sanford algorithm)	1991 - 1992	All	1.21
Panasonic TLD (1993 updated algorithm)	1993 - 2003	All	1.21
Electron			
Film	1951 – 1968	All	1.5
Loose-Chip TLD	1969 - 1982	All	1.5
Panasonic TLD	All years (1983-2003)	All	1.19

a. If all individual dosimeter readings are over 100 mrem, then the lower factor of 1.26 can be used.

REFERENCES

1. ORAUT-TKBS-0011-6, Technical Basis Document for Rocky Flats Plant Occupational External Dosimetry, Rev 00, January, 2004.

2. ORAUT-TKBS-0011-4, Technical Basis Document for Rocky Flats Plant-Occupational Environmental Dose, Rev 01, June 29, 2004.

3. DOE (U.S. Department of Energy), 2003, Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities, DOE-STD-1128-98, Reaffirmation with Errata.