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☐ New ☐ Total Rewrite ☐ Revision ☒ Page Change

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
05/12/2006	00	New technical information bulletin to provide information to allow ORAU Team dose reconstructors to assign doses at the Rocky Flats Plant to certain workers who have no or limited monitoring data, based on site coworker data. First approved issue. Initiated by Matthew H. Smith.
01/08/2007	01	Approved Revision 01 due to the release of ORAUT-OTIB-0052 Rev 00 and comments received from NIOSH. Constitutes a total rewrite of the document. Incorporates internal formal review comments. Incorporates NIOSH formal review comments and additional information found regarding neutron to photon ratios for the period 1970-1976. Added Table 6-2. This revision results in an increase in assigned dose and a PER is required. Training required: As determined by the Task Manager. Initiated by Matthew H. Smith. Approval: Signature on File 01/08/2007 John M. Byrne, Document Owner Signature on File 01/08/2007 Edward F. Maher, Task 5 Manager Signature on File 01/08/2007 James P. Griffin, Deputy Project Director Brant A. Ulsh Signature on File for 01/08/2007 James W. Neton, Associate Director for Science
03/29/2007	01 PC-1	Approved page change initiated to correct errors in the steps on pages 9 and 10 of Section 7.0. Step 3 was combined with Step 4 in Rev 01. This resulted in a renumbering of the steps. Step 7 in Rev 01 was redundant and was deleted. Tables 7-3 and 7-6 were removed based on comments from NIOSH. In addition, data for 1969 and 1970 was updated based on an analysis of the HIS-20 dataset with readings of “zero” removed. No further changes occurred as a result of formal internal review. Recalculated coworker dose distributions for 1969-70 in Tables 7.1, 7.2, 7.3. 7.4 on pages 11, 12, 13, and 14. Attributions and Annotations Section was added on page 15. This revision results in no change to the assigned dose and no PER is required. Training required: As determined by the Task Manager. Initiated by Matthew H. Smith.

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ACRONYMS AND ABBREVIATIONS

DOE	U.S. Department of Energy
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
GM	geometric mean
GSD	geometric standard deviation
HIS20	Health Information System
IREP	Interactive RadioEpidemiological Program
keV	kiloelectron-volt, 1,000 electron-volts
LOD	limit of detection
mo	month
NDRP	Neutron Dose Reconstruction Project
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH-OCAS Claims Tracking System
OCAS	Office of Compensation Analysis and Support
ORAU	Oak Ridge Associated Universities
ORNL	Oak Ridge National Laboratory
RFP	Rocky Flats Plant
TIB	technical information bulletin
TLD	thermoluminescent dosimeter
U.S.C.	United States Code
yr	year
§	section or sections

1.0 INTRODUCTION

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

In this document, the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy [DOE] facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [EEOICPA; 42 U.S.C. § 7384l(5) and (12)].

2.0 PURPOSE

The purpose of this TIB is to provide information to allow dose reconstructors to assign doses based on site coworker data to Rocky Flats Plant (RFP) workers who have no or limited monitoring data. In addition, the data in this TIB should be used to assign dose for gaps in the dosimetry record. The data are to be used in conjunction with ORAUT-OTIB-0020, *Use of Coworker Dosimetry Data for External Dose Assignment* (ORAUT 2005a).

3.0 BACKGROUND

The Oak Ridge Associated Universities (ORAU) Team is conducting a series of coworker data studies to permit dose reconstructors to complete certain cases for which external or internal monitoring data are unavailable or incomplete. Cases that do not have complete monitoring data could fall into one of several categories:

- The worker was unmonitored and, even by today's standards, did not need to be monitored (e.g., a nonradiological worker).
- The worker was unmonitored but, by today's standards, would have been monitored.
- The worker might have been monitored, but the data are not available to the dose reconstructor.
- Partial information is available, but it is insufficient to facilitate a dose reconstruction.

As described in ORAUT-OTIB-0020 (ORAUT 2005a), some cases without complete monitoring data can be processed based on assumptions and methodologies that do not involve coworker data. For example, many cases in the first category can be processed by the assignment of ambient external and internal doses based on information in the relevant site technical basis documents.

As described in ORAUT-TKBS-0011-6, *Technical Basis Document for the Rocky Flats Plant – Occupational External Dosimetry* (ORAUT 2004), operations at the site began in 1951. The RFP used a variety of film dosimeters between 1951 and 1969. In 1964, the dosimetry package was incorporated into the security badge, which better ensured that each worker wore a dosimeter (ORAUT 2004). A combination film and thermoluminescent dosimeter (TLD) was used starting in 1970 until a TLD for both gamma and neutrons was implemented in 1971. Use of dosimetry at the RFP expanded as production operations increased. Exchange frequencies varied from quarterly to

weekly depending on job duties. There does not appear to have been any significant administrative practice that would have jeopardized the integrity of the dose of record.

4.0 GENERAL APPROACH

As described in ORAUT-OTIB-0020 (ORAUT 2005a), the general approach to the development of coworker data for cases without external monitoring data is to assign either 50th- or 95th-percentile doses with the intent that the assigned doses represent, but do not underestimate, the doses that would have been assigned had the worker been monitored.

5.0 APPLICATIONS AND LIMITATIONS

Some RFP workers could have worked at one or more other major sites in the DOE complex during their employment histories. Therefore, the data in this TIB must be used with caution to ensure that, for likely noncompensable cases, unmonitored external doses from multiple site employments have been overestimated. This typically requires the availability of the recorded doses or TIBs for external coworker dosimetry data for all relevant sites.

The data in this TIB address penetrating radiation from gamma and neutron radiation and nonpenetrating radiation from electron and/or low-energy photon radiation. Neutron data are not presented separately; methods for determining neutron dose are discussed in Section 7.0. ORAUT-TKBS-0011-6 (ORAUT 2004) and the following two documents should be used as the basis for assigning neutron doses, when relevant:

- ORAUT-OTIB-0050, *Use of Rocky Flats Neutron Dose Reconstruction Project Data in Dose Reconstructions* (ORAUT 2005b).

- ORISE 05-0199, *Technical Basis Document for the Neutron Dose Reconstruction Project* (Falk et al. 2005).

External onsite ambient dose should be applied as specified in the latest revision of ORAUT-PROC-0060*, Occupational On-Site Ambient Dose Reconstruction for DOE Sites* (ORAUT 2006a).

6.0 COWORKER DATA DEVELOPMENT

Dosimetry data for monitored RFP workers in the Health Information System (HIS20) were selected for this evaluation. HIS20 was the last system used at the RFP for the retention of occupational radiation exposure data. The information in this system contains data that have been transferred from previous electronic systems and hard-copy health physics files. In addition, HIS20 contains the results of the Neutron Dose Reconstruction Project (NDRP) (Falk et al. 2005).

The annual data for each worker reported between 1952 and 2005 were prorated to account for partial years of employment based on an analysis of the length of monitored employment associated with the data (see Section 6.2 for further discussion of special considerations). The data were prorated so coworker doses that represent a full year of monitored employment could be derived; this permits the dose reconstructor to assign appropriate doses based on specific employment dates and job descriptions.

The validity of the data that were used for coworker dose development was confirmed by selecting a sampling of beta-gamma film badge worksheets (handwritten records) and comparing them to data for penetrating radiation listed in the HIS20 database.

Each beta-gamma worksheet contains film badge results for numerous workers for a given building and quarter. For each worker-year, four sheets of quarterly data are combined to comprise the annual beta-gamma dose record. Thirty such worker-years were examined and compared to data for the same worker-year.

Of the 30 worker-years compiled (which represent data for 30 individuals), 22 (73%) were complete in that all quarterly data were found and the total annual dose was in agreement. For 5 worker-years (17%), one-quarter of the beta-gamma worksheet data were not found, but the annual total calculated without that missing quarter agreed with the HIS20 database. For 3 worker-years (10%), some quarterly beta-gamma worksheet data were not found or were blank and the annual totals did not agree with the HIS20 database. In all three of those instances, the HIS20 database annual values were higher than the data from the beta-gamma worksheets.

6.1 ADJUSTMENT FOR MISSED DOSE

According to OCAS-IG-001, *External Dose Reconstruction Implementation Guideline* (NIOSH 2006), missed doses are assigned for reported zero readings for each monitoring cycle to account for the possibility that doses were received but either not recorded by the dosimeter or not reported by the site. In addition, reported dose values less than one-half the applicable minimum detection limits are assigned as missed dose. Annual maximum potential missed doses are calculated by multiplying the number of zero or unrecorded badge readings by the reported dosimeter limit of detection (LOD) and summing the results. These values are used as the 95th percentile of a lognormal distribution to calculate the probability of causation, which is determined by the U.S. Department of Labor. Thus, in the Interactive RadioEpidemiological Program (IREP), Parameter 1 input is equal to the calculated maximum annual missed doses multiplied by 0.5, and the Parameter 2 input is equal to 1.52. These values represent the geometric mean (GM) and geometric standard deviation (GSD), respectively, for each year of analysis.

The assignment of maximum potential missed doses for monitored workers is particularly significant for RFP workers from 1954 to 1962, when they could have been monitored weekly. Table 6-1 lists the maximum annual missed dose by monitoring period based on information in ORAUT-TKBS-0011-6 (ORAUT 2004).

Table 6-1. Missed external doses (rem) based on ORAUT-TKBS-0011-6 (ORAUT 2004).

Monitoring period	Penetrating LOD	Nonpenetrating LOD[a]	Exchange frequency	Maximum potential annual missed penetrating dose	Maximum potential annual missed nonpenetrating dose
1952–1953	0.04	0.05	Semimonthly[b]	0.960	1.200
1954–1962	0.04	0.05	Weekly[b]	2.080	2.600
1963–1964	0.04	0.05	Semimonthly[b]	0.960	1.200
1965–1966	0.04	0.05	Monthly[b]	0.480	0.600
1967–1968	0.04	0.05	Semimonthly[b]	0.960	1.200
1969–1976	0.02	0.03	Semimonthly[b]	0.480	0.720
1977–1992	0.02	0.03	Monthly[c]	0.240	0.360
1993–2005	0.01	0.02	Monthly[c]	0.120	0.240

a. Based on analysis of nonpenetrating LODs for other DOE sites in ORAUT-OTIB-0017 (ORAUT 2005c). Specific RFP data for nonpenetrating LOD are not available at this time.
b. Based on maximum potential exchange frequency in ORAUT-TKBS-0011-6 (ORAUT 2004).
c. The exchange frequency was not defined in ORAUT-TKBS-0011-6 (ORAUT 2004). It is based on a review of claim data evaluated under the EEOICPA Subtitle B program.

6.2 SPECIAL CONSIDERATIONS

Certain aspects of the external dosimetry practices at the RFP that are documented in ORAUT-TKBS-0011-6 (ORAUT 2004) were considered in the analysis of the site data. These include:

- Conservatively determined default dosimeter exchange frequencies were used. Not all RFP employees would have had dosimetry exchanged at these upper-bound frequencies.

- During the process of prorating HIS20 dose to account for partial years of employment, it was discovered that artificially short or long wear periods had been entered in the HIS20 database. These artificial periods were entered because only one date (usually the end date) was available in the electronic data from previous database systems. To avoid skewing the overall dataset with artificially high or low prorated dose, data with a wear period less than or equal to 0.1 yr or greater than 1.25 yr were excluded from the analysis described in Section 7.0.

- Inclusion of NDRP data in the HIS20 database led to the development of tables of data for penetrating and nonpenetrating dose that include and exclude the NDRP values. To determine neutron dose for the period from 1952 to 1969, neutron-to-photon ratios defined in the NDRP study (Falk et al. 2005) were used. Neutron-to-photon ratios for the period from 1970 to 1976 are defined in this document (see Table 6-2). For 1977 to 2005, values from ORAUT-OTIB-0050 were used (ORAUT 2005b).

Table 6-2. RFP lognormal neutron-to-photon ratio values, 1970 to 1976.

Year	Neutron-to-photon ratio GM (semimonthly exchange)	GSD	95th percentile	Neutron-to-photon ratio GM (monthly exchange)	GSD	95th percentile
1970	1.61[a]	3.45	12.4	NA	NA	NA
1971	1.61	3.45	12.4	NA	NA	NA
1972	1.32	2.15	4.64	0.8	2.63	3.94
1973	1.32[b]	2.15	4.64	NA	NA	NA
1974	0.68	3.01	4.16	NA	NA	NA
1975	0.67	3.31	4.82	NA	NA	NA
1976	0.95	3.59	7.81	0.78	4.29	8.55

a. Data for 1970 were not available. This value is the greater of the ratios for 1969 and 1971. The high neutron-to-gamma ratio in 1971 for Building 771 is reasonable from a process aspect, and extrapolating that ratio back to 1970 also is reasonable. In the aftermath of the 1969 plutonium fire in Buildings 776 and 777, the salvaged plutonium oxide had to be converted back to plutonium metal, a process done in Building 771. Building 771 had a huge backlog for relatively pure plutonium (little americium, low gamma) to be reprocessed, which was staged in the 776 to 771 tunnel and any other possible staging area in the vicinity. In addition, PuF_4 (a high-neutron source) seemed to be generated faster in Building 771 than it could be reduced to metal, which also caused a staging problem in or near the process areas in Building 771 until the backlog could be reduced.

b. Data for 1973 were not available. This value is the greater of the ratios for 1972 and 1974.

- ORAUT-OTIB-0027 should be used to choose the proper method for processing penetrating and nonpenetrating data to determine low-energy (less-than-30-keV) photon dose or electron (greater-than-15-keV) dose components as needed (ORAUT 2005d).

Neutron-to-photon ratio values for 1970 to 1976 were developed by analyzing records that contain dosimetry reports to supervisors. Data were available for workers on a semimonthly dosimeter exchange cycle for 1971, 1972, 1974, 1975, and 1976. Data for workers on a monthly exchange

cycle were available for 1972 and 1976. Neutron-to-photon ratio values for the semimonthly exchange cycle were used in this document because:

- A semimonthly exchange cycle was assumed for applying missed external dose for this period (see Table 6-1).
- The neutron-to-photon ratio values for semimonthly exchange were equal to or greater than the monthly exchange values.

Table 6-2 lists the neutron-to-photon ratios for this period. The individual ratios for available data were analyzed, and they fit lognormal distributions.

As described in Section 7.0, an approach favorable to the claimant was adopted in the development of coworker dose summaries; this approach was intended to account for any underestimate of doses to radiological workers at the RFP based on these considerations.

7.0 COWORKER ANNUAL DOSE SUMMARIES

Based on the described information and approaches, RFP coworker annual external dosimetry summaries were developed for use in the evaluation of external penetrating and nonpenetrating dose for certain workers who were potentially exposed to workplace radiation, but for whom there is no or limited monitoring data from DOE. These summaries were developed using the following steps:

Step 1. As described in Section 6.0, for data between 1952 and 2005, the reported penetrating dose, which represented annual summary data, was modified for each worker to account for partial years of employment. This adjustment was made by analyzing the dosimetry wear dates in the HIS20 database. For example, if the average employment period for all RFP employees in the NIOSH-Office of Compensation Analysis and Support (OCAS) Claims Tracking System (NOCTS) was 11 mo in a particular calendar year, the reported annual doses were multiplied by 12/11 (1.09). This permits the dose reconstructor to assign an appropriate prorated dose to account for partial years of employment or potential exposure.

Step 2. One-half of the maximum potential annual missed doses listed in Table 6-1 were added to the reported annual doses from Step 1 (with the exception of reported positive doses, in which case the maximum missed dose was reduced by the dose that corresponded to one badge exchange because it is not possible that all individual badge results were zero if a positive annual dose was reported).

Step 3. The 50th- and 95th-percentile annual coworker gamma doses were derived from the doses from Step 2 by ranking the data into cumulative probability curves and extracting the 50th- and 95th-percentile doses for each year.

Step 4. Table 7-1 lists the results of the coworker analysis including NDRP data. These percentile doses should be used for RFP workers with no or limited monitoring data through the use of the methodologies outlined in Section 7.0 of ORAUT-OTIB-0020 (ORAUT 2005a). In general, the 50th-percentile dose can be used as a best estimate of a worker's dose when professional judgment indicates that the worker was probably exposed to intermittent low levels of external radiation. The 50th-percentile dose should generally not be used for workers who were routinely exposed. For routinely exposed workers (i.e., workers who were expected to have been monitored and routinely exposed), the 95th-percentile dose should be applied. However, other options are available through the guidance in ORAUT-OTIB-

0020. For instance, for cases in which routine monitoring data exist and coworker dose is used to supplement missing quarters or years, the percentile dose should be the one that is consistent with the recorded doses unless there is reason to believe that the worker's job or location differs significantly from that held during the years dose was recorded. For workers who are unlikely to have been exposed, external onsite ambient dose should be used rather than coworker doses. Also, for the 1969-1970 time period, the data from the HIS-20 database were analyzed without consideration of the zero readings in the database due to issues regarding the accurate recording of "zero" dose readings during that period.

Step 5. Workers exposed to neutrons from work in plutonium facilities from 1952 to 1969 were, in general, included in the NDRP study. Therefore, the neutron and photon dose components for 1952 to 1969 were calculated by applying the neutron-to-gamma ratios (for "all other" facilities) from Table 11.1 of the NDRP report (Falk et al. 2005) to the penetrating dose values from HIS20. Neutron and gamma dose component values are listed in Table 7-2. Neutron and gamma components of the penetrating dose for 1970 to 1976 were separated using the neutron-to-photon ratio values in Section 6.2 of this document. Neutron and gamma components of the penetrating dose for 1977 to 2005 were separated using the neutron-to-photon ratio values in ORAUT-OTIB-0050 (ORAUT 2005b). The NDRP data include an estimate of missed neutron dose (addressed as notional dose by the NDRP project); therefore, no adjustments are needed for missed neutron dose for 1952 to 1969. Similarly, for 1970 to 2005, missed neutron dose is accounted for when the applicable neutron-to-photon ratio is applied to the data in Table 7-1.

Step 6. In instances where nonpenetrating dose is needed for dose estimation, Table 7-1 values should be used.

Step 7. Tables 7-3 and 7-4 list penetrating dose values (as described in the steps above) that have been adjusted using the guidance in Section 8.0 of ORAUT-OTIB-0052, *Parameters to Consider When Processing Claims for Construction Trade Workers* (ORAUT 2006b). This guidance is applicable for construction trade workers who meet the criteria in Section 3.0 of ORAUT (2006b). Because ORAUT-OTIB-0052 does not provide an adjustment factor for nonpenetrating dose, the guidance in Step 6 should be used to derive the nonpenetrating dose component for construction trade workers.

Table 7-1. Annual RFP external coworker doses (including NDRP data) modified to account for missed dose (rem).

Year	Penetrating 95th percentile	Penetrating 50th percentile	Nonpenetrating 95th percentile	Nonpenetrating 50th percentile	Number of monitored workers
1952	5.018	2.505	5.133	2.620	42
1953	4.190	0.751	4.553	0.892	319
1954	3.233	1.095	3.600	1.361	353
1955	4.411	1.165	5.266	1.431	529
1956	4.461	1.135	5.617	1.415	781
1957	5.136	1.177	6.004	1.454	918
1958	6.015	1.253	7.553	1.584	1,062
1959	7.186	1.581	8.002	1.908	1,063
1960	7.121	1.293	7.728	1.645	1,284
1961	7.850	1.527	8.201	1.923	1,638
1962	6.523	1.542	7.062	1.828	2,003
1963	5.955	0.940	6.232	1.104	2,176
1964	4.875	0.648	5.012	0.799	2,834
1965	3.533	0.511	3.663	0.598	2,826
1966	4.767	0.592	4.976	0.679	2,888
1967	4.379	0.627	4.735	0.761	2,902
1968	3.276	0.578	3.591	0.714	3,101
1969	3.588	0.680	3.788	0.824	3,471
1970	2.894	0.531	3.067	0.651	3,308
1971	1.938	0.384	2.096	0.500	3,398
1972	1.853	0.377	1.995	0.494	3,282
1973	1.697	0.380	1.848	0.497	3,020
1974	1.881	0.497	2.047	0.612	2,687
1975	1.329	0.401	1.525	0.516	2,489
1976	0.826	0.248	1.030	0.364	2,424
1977	0.589	0.122	0.699	0.177	3,740
1978	0.698	0.120	0.830	0.180	4,176
1979	0.906	0.122	1.074	0.180	3,893
1980	0.743	0.120	0.889	0.168	3,752
1981	0.853	0.110	1.008	0.180	4,060
1982	0.990	0.121	1.174	0.166	4,851
1983	1.212	0.134	1.440	0.193	5,360
1984	1.204	0.141	1.551	0.200	5,673
1985	1.302	0.142	1.584	0.203	6,140
1986	1.365	0.183	1.860	0.301	4,942
1987	1.510	0.259	2.265	0.457	2,583
1988	1.236	0.199	1.614	0.373	2,778
1989	0.550	0.115	0.733	0.180	5,296
1990	0.288	0.130	0.435	0.201	3,369
1991	0.337	0.154	0.471	0.228	5,641
1992	0.267	0.150	0.421	0.235	5,831
1993	0.207	0.080	0.296	0.150	5,313
1994	0.179	0.084	0.242	0.142	4,839
1995	0.200	0.080	0.275	0.137	4,130
1996	0.274	0.105	0.357	0.168	3,454
1997	0.352	0.085	0.420	0.145	3,718
1998	0.275	0.073	0.337	0.130	3,470
1999	0.192	0.072	0.256	0.127	3,655
2000	0.164	0.060	0.224	0.120	3,576
2001	0.160	0.060	0.223	0.120	3,443
2002	0.157	0.060	0.215	0.120	3,502
2003	0.127	0.060	0.194	0.120	3,373
2004	0.097	0.060	0.164	0.120	2,758
2005	0.175	0.071	0.234	0.129	955

Table 7-2. Annual RFP external coworker doses (including NDRP data and missed dose) modified to separate penetrating dose components (rem).

Year	Photon 95th percentile	Photon 50th percentile	Neutron 95th percentile	Neutron 50th percentile	Number of monitored workers
1952	2.532	1.390	2.486	1.115	42
1953	2.155	0.592	2.034	0.159	319
1954	2.026	1.054	1.207	0.041	353
1955	2.561	1.086	1.850	0.079	529
1956	2.584	1.072	1.877	0.063	781
1957	2.891	1.091	2.245	0.086	918
1958	3.290	1.126	2.724	0.127	1,062
1959	3.823	1.275	3.363	0.306	1,063
1960	3.199	1.117	3.922	0.175	1,284
1961	3.459	1.201	4.391	0.326	1,638
1962	2.687	1.178	3.835	0.364	2,003
1963	2.125	0.606	3.830	0.335	2,176
1964	1.564	0.507	3.312	0.141	2,834
1965	1.964	0.373	1.569	0.138	2,826
1966	3.251	0.468	1.516	0.124	2,888
1967	2.909	0.565	1.470	0.063	2,902
1968	1.740	0.514	1.536	0.064	3,101
1969	1.573	0.410	2.015	0.270	3,471
1970	1.109	0.204	1.785	0.328	3,308
1971	0.743	0.147	1.196	0.237	3,398
1972	0.799	0.163	1.054	0.215	3,282
1973	0.731	0.164	0.966	0.216	3,020
1974	1.119	0.296	0.761	0.201	2,687
1975	0.796	0.240	0.533	0.161	2,489
1976	0.424	0.127	0.402	0.121	2,424
1977	0.415	0.086	0.174	0.036	3,740
1978	0.492	0.085	0.207	0.035	4,176
1979	0.638	0.086	0.268	0.036	3,893
1980	0.523	0.085	0.220	0.035	3,752
1981	0.600	0.077	0.252	0.033	4,060
1982	0.697	0.085	0.293	0.036	4,851
1983	0.854	0.094	0.359	0.040	5,360
1984	0.848	0.100	0.356	0.042	5,673
1985	0.917	0.100	0.385	0.042	6,140
1986	0.961	0.129	0.404	0.054	4,942
1987	1.063	0.182	0.447	0.077	2,583
1988	0.870	0.140	0.366	0.059	2,778
1989	0.388	0.081	0.163	0.034	5,296
1990	0.203	0.091	0.085	0.038	3,369
1991	0.237	0.108	0.100	0.045	5,641
1992	0.188	0.105	0.079	0.044	5,831
1993	0.146	0.056	0.061	0.024	5,313
1994	0.126	0.059	0.053	0.025	4,839
1995	0.141	0.056	0.059	0.024	4,130
1996	0.193	0.074	0.081	0.031	3,454
1997	0.248	0.060	0.104	0.025	3,718
1998	0.193	0.051	0.081	0.022	3,470
1999	0.136	0.050	0.057	0.021	3,655
2000	0.115	0.042	0.048	0.018	3,576
2001	0.112	0.042	0.047	0.018	3,443
2002	0.110	0.042	0.046	0.018	3,502
2003	0.089	0.042	0.038	0.018	3,373
2004	0.068	0.042	0.029	0.018	2,758
2005	0.123	0.050	0.052	0.021	955

Table 7-3. Annual RFP external coworker doses (including NDRP data and missed dose) modified in accordance with ORAUT-OTIB-0052 (rem) (ORAUT 2006b).

Year	Penetrating 95th percentile	Penetrating 50th percentile	Nonpenetrating 95th percentile	Nonpenetrating 50th percentile	Number of monitored workers
1952	6.842	3.323	5.133	2.620	42
1953	5.681	0.867	4.553	0.892	319
1954	4.118	1.125	3.600	1.361	353
1955	5.768	1.224	5.266	1.431	529
1956	5.838	1.181	5.617	1.415	781
1957	6.782	1.240	6.004	1.454	918
1958	8.012	1.346	7.553	1.584	1,062
1959	9.653	1.805	8.002	1.908	1,063
1960	9.561	1.402	7.728	1.645	1,284
1961	10.583	1.730	8.201	1.923	1,638
1962	8.724	1.751	7.062	1.828	2,003
1963	8.153	1.132	6.232	1.104	2,176
1964	6.641	0.723	5.012	0.799	2,834
1965	4.858	0.627	3.663	0.598	2,826
1966	6.585	0.740	4.976	0.679	2,888
1967	5.947	0.694	4.735	0.761	2,902
1968	4.402	0.625	3.591	0.714	3,101
1969	4.931	0.860	3.788	0.824	3,471
1970	3.959	0.652	3.067	0.651	3,308
1971	2.622	0.446	2.096	0.500	3,398
1972	2.503	0.436	1.995	0.494	3,282
1973	2.284	0.441	1.848	0.497	3,020
1974	2.541	0.603	2.047	0.612	2,687
1975	1.769	0.470	1.525	0.516	2,489
1976	1.064	0.255	1.030	0.364	2,424
1977	0.781	0.127	0.699	0.177	3,740
1978	0.934	0.120	0.830	0.180	4,176
1979	1.224	0.127	1.074	0.180	3,893
1980	0.996	0.120	0.889	0.168	3,752
1981	1.150	0.110	1.008	0.180	4,060
1982	1.343	0.122	1.174	0.166	4,851
1983	1.653	0.143	1.440	0.193	5,360
1984	1.642	0.154	1.551	0.200	5,673
1985	1.779	0.154	1.584	0.203	6,140
1986	1.867	0.212	1.860	0.301	4,942
1987	2.070	0.319	2.265	0.457	2,583
1988	1.686	0.234	1.614	0.373	2,778
1989	0.727	0.117	0.733	0.180	5,296
1990	0.360	0.137	0.435	0.201	3,369
1991	0.427	0.171	0.471	0.228	5,641
1992	0.330	0.165	0.421	0.235	5,831
1993	0.267	0.090	0.296	0.150	5,313
1994	0.229	0.095	0.242	0.142	4,839
1995	0.258	0.090	0.275	0.137	4,130
1996	0.362	0.124	0.357	0.168	3,454
1997	0.471	0.098	0.420	0.145	3,718
1998	0.363	0.080	0.337	0.130	3,470
1999	0.247	0.078	0.256	0.127	3,655
2000	0.207	0.060	0.224	0.120	3,576
2001	0.202	0.060	0.223	0.120	3,443
2002	0.197	0.060	0.215	0.120	3,502
2003	0.156	0.060	0.194	0.120	3,373
2004	0.114	0.060	0.164	0.120	2,758
2005	0.223	0.077	0.234	0.129	955

Table 7-4. Annual RFP external photon and neutron coworker doses (including NDRP data and missed dose) modified in accordance with ORAUT-OTIB-0052 (rem)(ORAUT 2006b).

Year	Photon 95th percentile	Photon 50th percentile	Neutron 95th percentile	Neutron 50th percentile	Number of monitored workers
1952	3.361	1.761	3.481	1.562	42
1953	2.833	0.645	2.848	0.222	319
1954	2.428	1.068	1.690	0.057	353
1955	3.178	1.113	2.590	0.111	529
1956	3.210	1.093	2.628	0.088	781
1957	3.639	1.120	3.143	0.120	918
1958	4.198	1.168	3.814	0.178	1,062
1959	4.944	1.377	4.709	0.428	1,063
1960	4.070	1.156	5.491	0.245	1,284
1961	4.435	1.273	6.147	0.456	1,638
1962	3.354	1.242	5.369	0.510	2,003
1963	2.791	0.664	5.362	0.469	2,176
1964	2.005	0.526	4.636	0.197	2,834
1965	2.661	0.434	2.197	0.193	2,826
1966	4.464	0.567	2.122	0.173	2,888
1967	3.889	0.607	2.058	0.088	2,902
1968	2.252	0.535	2.150	0.090	3,101
1969	2.110	0.482	2.820	0.378	3,471
1970	1.517	0.250	2.442	0.402	3,308
1971	1.004	0.171	1.617	0.275	3,398
1972	1.079	0.188	1.424	0.248	3,282
1973	0.984	0.190	1.299	0.251	3,020
1974	1.512	0.359	1.028	0.244	2,687
1975	1.059	0.281	0.710	0.189	2,489
1976	0.546	0.131	0.519	0.124	2,424
1977	0.550	0.089	0.231	0.037	3,740
1978	0.658	0.085	0.276	0.035	4,176
1979	0.862	0.089	0.362	0.037	3,893
1980	0.702	0.085	0.295	0.035	3,752
1981	0.810	0.077	0.340	0.033	4,060
1982	0.945	0.086	0.397	0.036	4,851
1983	1.164	0.101	0.489	0.042	5,360
1984	1.156	0.108	0.486	0.046	5,673
1985	1.253	0.109	0.526	0.046	6,140
1986	1.315	0.149	0.552	0.063	4,942
1987	1.458	0.225	0.612	0.094	2,583
1988	1.187	0.165	0.499	0.069	2,778
1989	0.512	0.082	0.215	0.035	5,296
1990	0.253	0.097	0.106	0.041	3,369
1991	0.301	0.121	0.126	0.051	5,641
1992	0.232	0.116	0.098	0.049	5,831
1993	0.188	0.063	0.079	0.027	5,313
1994	0.161	0.067	0.068	0.028	4,839
1995	0.182	0.063	0.076	0.027	4,130
1996	0.255	0.088	0.107	0.037	3,454
1997	0.332	0.069	0.139	0.029	3,718
1998	0.255	0.057	0.107	0.024	3,470
1999	0.174	0.055	0.073	0.023	3,655
2000	0.146	0.042	0.061	0.018	3,576
2001	0.142	0.042	0.060	0.018	3,443
2002	0.139	0.042	0.058	0.018	3,502
2003	0.110	0.042	0.046	0.018	3,373
2004	0.080	0.042	0.034	0.018	2,758
2005	0.157	0.054	0.066	0.023	955

8.0 SUPPLEMENTAL INFORMATION ABOUT RFP NEUTRON-TO-PHOTON RATIO ASSUMPTIONS

8.1 JUSTIFICATION FOR EXTRAPOLATION OF NEUTRON-TO-GAMMA RATIOS FROM 1959 TO THE 1952 TO 1958 PERIOD

As stated in the NDRP Protocol, "the values for 1959 were used without modification, since no other information was available to justify modifying the value" (Falk et al. 2005, Section 11.4). Factors that could be expected to modify this ratio include:

1. Changes in source material: The early shipments of plutonium material came from the Hanford Site and Oak Ridge National Laboratory (ORNL) in the form of plutonium nitrate (Putzier 1982; Kazanjian and Navratil 1984). The first shipment from Hanford was received in May 1953 (Putzier 1982). The only changes in the source material (plutonium) known to have occurred at RFP during the involved years were increases in batch size rather than changes in isotopic composition. Therefore, this factor is not expected to have changed the neutron-to-gamma ratio between 1953 and 1959.

2. Changes in shielding configuration: Building 771 was constructed in 1952 and 1953 and received RFP's first shipment of plutonium from Hanford in May 1953 (Putzier 1982). The first significant modification of this building occurred with the work on the americium recovery line from 1957 to 1963 and the commencement of significant americium recovery operations in 1963 and 1964. The expansion in the Plant's plutonium facilities began in the mid-1950s and culminated with Buildings 776 and 777 coming on line in 1957 and 1958. The first significant machining of plutonium began in these buildings in 1958. About 1963, a fast-cycle process was implemented in Room 114 of Building 771, with enhanced neutron shielding around the continuous fluorinator. There were no further significant changes to these buildings until a project in 1967 and 1968 added photon and neutron shielding on gloveboxes in plutonium processing areas. Therefore, this factor is not expected to have changed the neutron-to-gamma ratio between 1953 and 1959.

3. Ingrowth of americium-241: The plutonium processed at RFP throughout the 1950s came from Hanford and ORNL and contained very little ^{241}Am (Putzier 1982). This material was processed as it arrived and shipped off the site. In 1959, researchers at RFP modified a thiocyanate ion exchange process to handle gram quantities of americium; this provided the design basis for an americium recovery system that began significant operations in 1963 (Beach and Navratil 1984). Therefore, this factor is not expected to have changed the neutron-to-gamma ratio between 1953 and 1959.

9.0 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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