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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
08/07/2015	00	Converted white paper to technical information bulletin. Incorporates formal internal and NIOSH review comments. Training required: As determined by the Objective Manager. Initiated by Matthew H. Smith.
11/04/2016	01	Revision initiated to update document and instructions (Section 5.1, Table 7-2, and Attachment A) to reflect that the use of nuclear track emulsion, Type A film for personnel neutron dosimetry ceased at the end of 1973. Incorporates formal internal review comments and updated coworker data in Tables 7-1, 7-2, and 7-3 based on updated instructions in Attachment A. Incorporates formal NIOSH review comments regarding data in Tables 7-1, 7-2, and 7-3 for the era 1960-1962. Tables 7-1 through 7-3 have been updated and footnoted. In addition, explanatory language was added to Section 5.0. Constitutes a total rewrite of the document. Training required: As determined by the Objective Manager. Initiated by Matthew H. Smith.

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ACRONYMS AND ABBREVIATIONS

AEC	U.S. Atomic Energy Commission
AP	anterior-posterior
cm	centimeter
DOE	U.S. Department of Energy
DOELAP	DOE Laboratory Accreditation Program
GM	geometric mean
GSD	geometric standard deviation
ICRP	International Commission on Radiation Protection
in.	inches
LOD	limit of detection
keV	kiloelectron-volt, 1,000 electron-volts
MCNP	Monte Carlo *n*-particle
MDL	minimum detectable level
MeV	megaelectron-volt, 1 million electron-volts
MRD	minimum recordable dose
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
NTA	nuclear track emulsion, Type A
ORAU	Oak Ridge Associated Universities
RDX	Research Department Formula X
SC&A	S. Cohen & Associates
SRDB Ref ID	Site Research Database Reference Identification (number)
SSN	Social Security Number
TBD	technical basis document
TIB	technical information bulletin
TLD	thermoluminescent dosimeter
U.S.C.	United States Code
WB	whole body
β	beta particle
λ	gamma ray
§	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 historical 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 [42 U.S.C. § 7384l(5) and (12)].

1.1 PURPOSE

This TIB provides information that allows dose reconstructors to base external doses on known site coworker data for Pantex Plant 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. Please note that if the unmonitored period is short and the EE was monitored before and after the gap with no apparent change in work assignments, the gap may be filled with the average of the surrounding measurements (see OCAS-IG-001).

In cases where the monitoring records list a recorded “0,” that entry is assumed to mean that the dosimeter was issued and processed, and that no exposure or dose was detected in excess of the dosimeter limit of detection (LOD). In cases in which the records show that the worker was monitored for occupational external exposures and one or more dosimeter exchange cycles are blank (or listed as a dash, slash, or hash mark), then the absence of an entry is assumed to indicate that the worker:

1. Was not issued a dosimeter in that exchange cycle, or
2. That a dosimeter might have been issued but was not processed due to loss or damage, or
3. That the results of processing were incomplete or suspect and no dose was assigned because of the absence of processing or an errant result.

In such cases for years before 1988, NIOSH intends to apply (after consideration of the worker’s job title and the totality of the monitoring record), either (1) unmonitored dose based on external coworker data, (2) missed dose, or (3) ambient dose. In 1988 and later years, all personnel who entered the operational areas of the plant were required to wear a dosimeter as a condition for entry. The absence of a listed result, or the presence of a dash, slash, or hash mark for a given dosimeter exchange cycle in 1988 and later years, should be interpreted to mean that the worker was not monitored because he or she was not present in the operational areas. Therefore, ambient dose should be assigned for those exchange cycles.

1.2 SCOPE

Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 8.0.

2.0 BACKGROUND

The Oak Ridge Associated Universities (ORAU) Team has prepared 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, *Use of Coworker Dosimetry Data for External Dose Assignment*, some cases without complete monitoring data can be processed based on assumptions and methodologies that do not involve coworker data (ORAUT 2011). 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 (TBDs).

Pantex used a variety of film and thermoluminescent dosimeter (TLD) dosimetry systems, as described in the latest revision of ORAUT-TKBS-0013-6, *Pantex Plant – Occupational External Dose* (ORAUT 2015a). In this TIB, see Attachment A, External Dose Coworker Study Instructions (1960 to 2010), for a description of these systems.

3.0 GENERAL APPROACH

External dose is measured with a dosimeter that indicates the dose that is received by an individual over a given length of time (e.g., a month or quarter). Multiple measurements over a year are summed to give the annual dose for the individual. Dosimeter readings below a given censoring level are reported as less than that level (usually referred to as the LOD). For example, the dose for a given month might be reported as <0.050 rem. These censored data are problematic for the development of coworker models. The previous approach to handling censored dosimeter readings (ORAUT 2011) was to substitute one-half of the censoring level for the censored results and then calculate the empirical 50th and 95th percentiles of the dataset. In statistics, this substitution is referred to as an imputation. In general, the imputation of a constant value like LOD/2 is not recommended (Helsel 2012) because it biases parameter estimates high. ORAUT-RPRT-0071, *External Dose Coworker Methodology* (ORAUT 2015b), outlines an alternative approach to analyzing the censored data that:

- Uses a lognormal probability model to generate a distribution of values to use for imputation rather than a constant one-half of the censoring level,
- Uses survival analysis techniques like those currently used for internal dose coworker modeling to estimate the parameters of a lognormal fit [i.e., the geometric mean (GM) and geometric standard deviation (GSD)] to the data rather than using the empirical 50th and 95th percentile, and
- Uses multiple imputation to account for the uncertainty introduced into the parameter estimates by the imputation process.

4.0 APPLICATIONS AND LIMITATIONS

Some Pantex 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 TBDs or TIBs that cover external coworker dosimetry data for all relevant sites. In situations where a best estimate of dose is needed, the appropriate distributions for factors such as dose conversion factors, geometric correction factors, and other applicable factors as defined by TBDs or TIBs should be applied.

The data in this document address penetrating gamma radiation, nonpenetrating dose, and neutron dose.

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

5.0 COWORKER DATA DEVELOPMENT

Information for coworker analysis was found in two data sources provided by Pantex Plant staff (BWXT Pantex 2011, 2013). The former contains unadjusted Pantex dosimetry data for the period 1960 to 2010, and the latter contains Pantex dosimetry data that were adjusted using an improved algorithm for the Panasonic 802 dosimetry system that was first introduced in 1980.

Only a small portion of the worker population (approximately 60 out of 220) were monitored each year during the era 1960-1962. It is likely that this small population represented workers who had the highest potential for exposure. Due to the statistically small number of data points, and the likelihood of a biased population, the data for 1963 were used as a surrogate for the era 1960-1962. The monitored population in 1963 is larger and numerically similar to the data in subsequent years. Therefore, the 1963 data are a better representation of the entire exposed worker population for the years in the earlier era - which is more appropriate to meet the coworker modeling needs outlined in Section 2.0.

In relation to neutron dosimetry data, the following sections outline four general eras that were considered during the analysis.

5.1 NTA ERA, 1960 TO 1973

During most of this period (1960 to 1973), nuclear track emulsion, type A (NTA) film was used for neutron dosimetry. To address NTA film energy threshold under-response, angular dependence, and fading, a correction factor of 2.9 was applied to neutron data from BWXT Pantex (2011) (see Attachment B, NTA Film Issues and Dose Assignments for Monitored and Unmonitored Workers). No adjustments to photon or skin dose were needed.

5.2 PRE-STANFORD ERA 1974 TO 1979

Information from Landauer indicated that the use of NTA film for personnel neutron dosimetry ceased at the end of 1973 (NIOSH 2016). Therefore, for the period 1974 - 1979, dosimetry data for neutrons, photons, and skin from BWXT Pantex (2011) were used with no corrections or adjustments.

5.3 STANFORD ERA 1980 TO 1993

Starting in 1980, Pantex monitored personnel for external photon and neutron doses with the four-element Panasonic 802 TLD dosimeter. In late 1992, the algorithm Pantex used to calculate doses was changed to resolve performance issues encountered during the 1989 Department of Energy Laboratory Accreditation Program (DOELAP) performance testing. This algorithm, called the "Stanford Algorithm," was used to successfully pass DOELAP performance testing during 1993. The data that were recalculated using the Stanford Algorithm are contained in BWXT Pantex (2013). They are used in conjunction with the data in BWXT Pantex (2011) for the analyses during this period in this document. Specifically, due to data deficiencies noted by Pantex personnel (TLD data could only be recalculated for persons for whom the actual TLD element readings were available), the following data were discarded from each workbook (Prather 2015):

- Data that were present in BWXT Pantex (2011), but not present in BWXT Pantex (2013), and likewise,
- Data that were present in BWXT Pantex (2013), but not present in BWXT Pantex (2011).

In addition, for a given year and month for an individual, the highest whole-body (WB) skin dose, WB gamma dose, and WB neutron dose values were used, respectively, when comparing data (filtered as described above) in BWXT Pantex (2011, 2013). Finally, it should be noted that the neutron results using this improved algorithm are likely biased high because an unmoderated ^{252}Cf source was used for calibration rather than a moderated ^{252}Cf source that would have been more similar to Pantex workplace neutron spectra (Prather 2004).

5.4 RECENT ERA, 1994 TO 2010

In 1993, Pantex switched to the Panasonic 809/812 dosimetry system. This system passed DOELAP accreditation tests at that time, and no adjustments to dose are needed for the data in BWXT Pantex (2011) for this period.

See Attachment A for additional information and assumptions about the development of these coworker datasets.

6.0 STATISTICAL ANALYSIS

The data from BWXT Pantex (2011, 2013) were analyzed in accordance with the instructions in Attachment A and ORAUT-RPRT-0071 (ORAUT 2015b). The imputation model plots, fit with lognormal regression on order statistics, are included in ORAUT (2015c). Censored monthly badge readings were imputed from these lognormal imputation distributions, monthly doses were summed to compute annual doses, and yearly lognormal fits were made. After multiple imputations (K = 30), the parameters were averaged, resulting in the plots in ORAUT (2015d).

7.0 COWORKER ANNUAL DOSE SUMMARIES

The results of the analysis method described above are shown in Tables 7-1 to 7-3 for photon, neutron, and skin (nonpenetrating) dose, respectively. The tables also include the 95th percentile of the specified lognormal distribution and the number of workers in each year (N). These data should be used in the same manner as described in ORAUT-OTIB-0020 in relation to using either the GM (50th percentile) or the 95th-percentile value as a constant depending on the energy employee's work history (ORAUT 2011). These doses should be assigned with energy ranges – and any applicable correction factors – as described in ORAUT-TKBS-0013-6, *Pantex Plant – Occupational External Dose* (ORAUT 2015b). Note that there were an insufficient number of monitored workers for neutron and skin dose in the early years, so doses from 1960 to 1963 were combined to form multiyear coworker models.

8.0 ATTRIBUTIONS AND ANNOTATIONS

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

Table 7-1. Annual external photon doses (rem).

Year	GM	GSD	95th percentile	N
1960[a]	0.010	7.95	0.302	217
1961[a]	0.010	7.95	0.302	217
1962[a]	0.010	7.95	0.302	217
1963	0.010	7.95	0.302	217
1964	0.101	4.05	1.007	253
1965	0.029	5.27	0.440	416
1966	0.042	4.21	0.442	581
1967	0.045	4.33	0.505	562
1968	0.035	3.41	0.264	423
1969	0.032	3.82	0.293	432
1970	0.065	4.20	0.688	467
1971	0.057	4.92	0.778	495
1972	0.055	4.09	0.557	467
1973	0.124	2.44	0.539	441
1974	0.067	3.48	0.519	500
1975	0.037	3.24	0.255	493
1976	0.044	2.79	0.241	463
1977	0.080	2.15	0.281	465
1978	0.032	3.99	0.316	518
1979	0.086	2.85	0.481	714
1980	0.012	5.71	0.204	772
1981	0.066	4.86	0.889	908
1982	0.039	4.09	0.397	1,002
1983[b]	0.042	4.03	0.419	Not applicable
1984	0.046	3.97	0.441	1,093
1985	0.039	4.10	0.395	1,172
1986	0.036	3.13	0.235	1,128
1987	0.023	2.80	0.123	1,160
1988	0.028	2.57	0.130	1,121
1989	0.020	3.10	0.127	1,437
1990	0.021	2.56	0.100	2,090
1991	0.023	2.35	0.095	2,126
1992	0.028	2.56	0.130	2,316
1993	0.009	3.36	0.064	2,633
1994	0.008	3.16	0.050	2,978
1995	0.008	3.08	0.048	3,107
1996	0.007	3.14	0.048	3,162
1997	0.006	2.91	0.037	3,000
1998	0.007	2.95	0.040	2,786
1999	0.007	2.90	0.041	2,686
2000	0.007	2.90	0.038	2,642
2001	0.007	2.85	0.037	2,770
2002	0.007	2.95	0.039	2,947
2003	0.007	2.75	0.035	2,996
2004	0.006	2.72	0.033	3,168
2005	0.003	2.94	0.018	3,210
2006	0.003	3.02	0.018	3,237
2007	0.003	3.35	0.019	3,183
2008	0.003	3.94	0.027	2,159
2009	0.003	3.84	0.029	2,110
2010	0.002	3.98	0.024	2,067

a. Values from 1963 are used as surrogate data for 1960 to 1962 based on the discussion in Section 5.0 Coworker Data Development.

b. Per the instructions in Attachment A, the data for 1983 have been interpolated between the 1982 and 1984 values.

Table 7-2. Annual external neutron doses (rem).

Year	GM	GSD	95th percentile	N
1960[a]	0.007	12.30	0.482	209
1961[a]	0.007	12.30	0.482	209
1962[a]	0.007	12.30	0.482	209
1963	0.007	12.30	0.482	209
1964	0.043	5.21	0.645	249
1965	0.015	4.27	0.168	415
1966	0.022	3.13	0.147	581
1967	0.020	2.55	0.094	563
1968	0.021	2.27	0.080	423
1969	0.003	7.06	0.084	66
1970	0.017	2.49	0.075	465
1971	0.019	2.23	0.071	494
1972	0.021	2.13	0.072	464
1973	0.022	2.51	0.101	59
1974	0.019	3.71	0.164	29
1975	0.213	2.60	1.028	54
1976	0.001	12.88	0.042	463
1977	0.001	14.04	0.052	465
1978	0.001	14.27	0.052	518
1979	0.005	7.68	0.146	714
1980	0.003	5.71	0.058	772
1981	0.023	3.46	0.180	908
1982	0.024	3.39	0.180	1,002
1983[b]	0.022	3.39	0.165	Not applicable
1984	0.020	3.39	0.150	1,093
1985	0.025	4.00	0.240	1,172
1986	0.027	3.47	0.213	1,128
1987	0.019	2.81	0.103	1,160
1988	0.019	2.72	0.101	1,121
1989	0.016	3.11	0.102	1,437
1990	0.017	2.71	0.089	2,090
1991	0.019	2.49	0.084	2,126
1992	0.007	5.08	0.100	2,316
1993	0.004	2.98	0.024	2,633
1994	0.004	2.99	0.026	2,978
1995	0.004	2.98	0.027	3,107
1996	0.004	2.99	0.026	3,162
1997	0.004	2.85	0.021	3,000
1998	0.004	2.73	0.020	2,786
1999	0.004	2.65	0.020	2,686
2000	0.004	2.74	0.020	2,642
2001	0.004	2.73	0.020	2,770
2002	0.004	2.77	0.020	2,947
2003	0.004	2.62	0.019	2,996
2004	0.004	2.65	0.018	3,168
2005	0.004	2.59	0.018	3,210
2006	0.004	2.63	0.018	3,237
2007	0.003	2.85	0.018	3,183
2008	0.004	2.96	0.021	2,159
2009	0.004	2.76	0.019	2,110
2010	0.003	3.06	0.018	2,067

a. Values from 1963 are used as surrogate data for 1960 to 1962 based on the discussion in Section 5.0 Coworker Data Development

b. Per the instructions in Attachment A, the data for 1983 have been interpolated between the 1982 and 1984 values.

Table 7-3. Annual external skin doses (rem).

Year	GM	GSD	95th percentile	N
1960[a]	0.012	3.86	0.112	215
1961[a]	0.012	3.86	0.112	215
1962[a]	0.012	3.86	0.112	215
1963	0.012	3.86	0.112	215
1964	0.056	1.82	0.148	249
1965	0.036	2.67	0.180	414
1966	0.051	2.01	0.160	579
1967	0.053	1.99	0.165	559
1968	0.060	1.96	0.182	421
1969	0.057	1.82	0.154	393
1970	0.116	2.66	0.582	119
1971	0.139	3.20	0.944	97
1972	0.198	2.96	1.183	83
1973	0.021	4.81	0.284	409
1974	0.015	8.90	0.543	423
1975	0.008	4.46	0.093	483
1976	0.003	11.97	0.189	463
1977	0.006	9.28	0.217	466
1978	0.004	11.22	0.235	519
1979	0.015	5.65	0.254	714
1980	0.018	8.35	0.583	772
1981	0.097	6.34	2.017	908
1982	0.055	6.16	1.099	1,002
1983[b]	0.068	5.60	1.124	Not applicable
1984	0.080	5.04	1.150	1,093
1985	0.061	6.80	1.429	1,172
1986	0.068	5.65	1.165	1,128
1987	0.035	5.08	0.502	1,160
1988	0.037	4.43	0.428	1,121
1989	0.022	4.45	0.258	1,437
1990	0.021	3.10	0.134	2,090
1991	0.020	2.47	0.088	2,126
1992	0.018	4.03	0.178	2,316
1993	0.008	4.32	0.086	2,633
1994	0.007	3.74	0.061	2,978
1995	0.007	3.63	0.058	3,107
1996	0.007	3.76	0.060	3,162
1997	0.006	3.59	0.048	3,000
1998	0.006	3.61	0.053	2,786
1999	0.007	3.52	0.053	2,686
2000	0.006	3.54	0.051	2,642
2001	0.006	3.47	0.049	2,770
2002	0.006	3.52	0.048	2,947
2003	0.006	3.27	0.044	2,996
2004	0.006	3.25	0.041	3,168
2005	0.006	3.12	0.038	3,210
2006	0.012	2.36	0.051	3,237
2007	0.011	2.57	0.052	3,183
2008	0.012	2.92	0.071	2,159
2009	0.013	2.69	0.065	2,110
2010	0.010	2.89	0.059	2,067

a. Values from 1963 are used as surrogate data for 1960 to 1962 based on the discussion in Section 5.0 Coworker Data Development.

b. Per the instructions in Attachment A, the data for 1983 have been interpolated between the 1982 and 1984 values.

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ATTACHMENT A
EXTERNAL DOSE COWORKER STUDY INSTRUCTIONS (1960 TO 2010)

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ATTACHMENT A
EXTERNAL DOSE COWORKER STUDY INSTRUCTIONS (1960 TO 2010) (continued)

A.1 DATA SOURCES

BWXT Pantex 2011 (Unadjusted Pantex Data)

Doses worksheet: Columns to be used:
SSN (Column B),
Year (Column G),
Month (Column H),
WB Skin (Column K),
WB Gamma (Column L), and
WB Neutron (Column M).

BWXT Pantex 2013

Sheet1 worksheet: Columns to be used:
Badge number (Column C),
Year (Column A),
Month (Column B),
WB Skin (Column E),
WB Gamma (Column F), and
WB Neutron (Column G).

A.2 GENERAL COMMENTS

- A blank cell means an individual was not monitored.
- A missing month means an individual was not monitored that month.
- A cell containing zero means the individual was monitored, but the result was below the censoring level. In this case, use the censoring level values discussed below.
- There are four eras at Pantex: the NTA era from 1960 to 1973, the pre-Stanford era from 1974 to 1979, the Stanford era from 1980 to mid-1993, and the more recent era from mid-1993 to 2010:
  - During the NTA era (1960 – 1973), the adjustment factor for neutron dose is 2.9.
  - For the period from 1974 to 1979, use the dosimetry data as they are recorded with no corrections or adjustments.
  - For 1980 to 1983, use the Stanford algorithm data (BWXT Pantex 2013) and the unadjusted Pantex data (BWXT Pantex 2011) (see below).
  - For 1994 to 2010, use BWXT Pantex (2011).
  - For 1983, which has no available Stanford algorithm data, omit this year from the analysis. Dose reconstructors should interpolate between the 1982 and 1984 values. (Note: The data for 1983 in Tables 7-1, 7-2, and 7-3 have been interpolated per these instructions).

ATTACHMENT A
EXTERNAL DOSE COWORKER STUDY INSTRUCTIONS (1960 TO 2010) (continued)

A.3 INSTRUCTIONS

The following four data fields are required:

- The year in which the dosimeter was worn.
- The month in which the dosimeter was worn.
- The identification (ID) number of the individual who wore the dosimeter. Social Security Number (SSN) is preferred over badge number.
- The dose indicated by the dosimeter. NTA correction factor is 2.9 for 1960 to 1973.

Table A-1 provides the sources of these data fields by period.

Due to data deficiencies noted by Pantex personnel (TLD data could only be recalculated for persons for whom the actual TLD element readings were available), the following data rows should be discarded from each workbook (Prather 2015):

- Data that is present in BWXT Pantex (2011), but not present in BWXT Pantex (2013), and
- Data that is present in BWXT Pantex (2013), but not present in BWXT Pantex (2011).

For a given year and month for an individual, use the highest WB skin dose, WB gamma dose, and WB neutron dose values when comparing data (filtered as described above) in BWXT Pantex (2011, 2013).

Imputation models should be calculated using the following CL values:

- Gamma: CL = 10 mrem (1960-2004), CL = 5 mrem (2005-2010)
- Neutron: CL = 10 mrem (1960 – 1979), CL = 50 mrem (1980 – 1992), CL = 10 mrem (1993 – 2010)
- Skin: CL = 40 mrem (1960-1972), CL = 10 mrem (1973-2005), CL = 15 mrem (2006-2010)

Due to insufficient data for neutron and skin badge readings, use 1963 annual doses as a surrogate for 1960 to 1962 neutron, skin, and gamma badge readings.

ATTACHMENT A
EXTERNAL DOSE COWORKER STUDY INSTRUCTIONS (1960 TO 2010) (continued)

Table A-1. Sources of dose information.

Period	Year	Month	Individual ID[a]	Dosimeter Dose
1960–1979 and 1994–2010	BWXT Pantex 2011, Column G	BWXT Pantex 2011, Column H	BWXT Pantex 2011, Column B	BWXT Pantex 2011, Column K, WB skin dose; Column L, WB gamma dose; and Column M, WB neutron dose[b]
1980–1993	BWXT Pantex 2013, Column A; and BWXT Pantex 2011, Column G	BWXT Pantex 2013, Column B; and BWXT Pantex 2011, Column H	BWXT Pantex 2013, Column C; and BWXT Pantex 2011, Column A	BWXT Pantex 2013, Column E, WB skin dose; Column F, WB gamma dose; and Column G, WB neutron dose as well as BWXT Pantex 2011, Column K, WB skin dose; Column L, WB gamma dose; and Column M, WB neutron dose

a. SSN is preferred over badge number.
b. NTA correction factor is 2.9 for 1960 to 1973.

ATTACHMENT B
NTA FILM ISSUES AND DOSE ASSIGNMENTS FOR MONITORED WORKERS

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ATTACHMENT B
NTA FILM ISSUES AND DOSE ASSIGNMENTS FOR MONITORED WORKERS (continued)

B.1 INTRODUCTION

This attachment summarizes the issues concerning NTA film in relation to the NIOSH proposal for evaluating neutron doses at Pantex. The effect of these issues on the proposed approach is discussed in detail sufficient to establish the appropriate method for interpreting neutron exposures for monitored personnel. The following issues are common to all sites that used NTA film:

- Dosimeter threshold response to thermal neutrons,
- Methods used to correct for fading,
- Energy dependence of fading characteristics,
- Calibration sources and protocol, and
- Exchange or wear periods and wear conditions (temperature and humidity conditions).

In addition, there are other uncertainty corrections.

B.2 MONITORED WORKERS

NIOSH recommends that measured doses for monitored workers be adjusted using a correction factor that includes corrections for the threshold energy of NTA film, the angular dependence of film, and for fading that occurs during the use of NTA film.

B.3 RESPONSE TO THERMAL NEUTRONS

NTA film has an effective threshold energy of about 500 keV. It is not sensitive to thermal neutrons and monitors only fast neutrons. The NIOSH recommendation recognizes this deficiency in NTA film and recommends a correction factor to adjust monitored doses. A Monte Carlo *n*-particle (MCNP) model was developed to determine the amount of dose that was missed due to a sensitivity threshold of 500 keV for the conditions likely to have been encountered by workers who received neutron doses at Pantex (LANL 2003). The model used Research Department Formula X (RDX) thicknesses of 0 to 4 in., which is an appropriate approximation of the possible exposure scenarios. The results indicated that NTA film would miss 16% of the dose equivalent at the operator position (distance of 60 cm), which is the position likely to receive the highest dose. The MCNP evaluation also indicated that the NTA film would miss 29% of the dose equivalent at the observer position (distance of 240 cm), which would experience much lower doses by a factor of 16. Greater distances could result in larger fractions of low-energy neutrons, but the corresponding dose rates would be much smaller due to the distance factor as well as the fact that low-energy neutrons are much less effective at delivering dose. The NIOSH recommendation selects the more conservative value from the observer position to be applied to all doses. The resulting correction factor is 1.4 versus a corresponding correction factor of 1.2 for the operator position. This recommendation is favorable to claimants.

B.4 ANGULAR RESPONSE OF NTA FILM

NIOSH recommends a factor of 1.33 to account for the angular response of NTA film. This factor is based on a study conducted by Kathren, Prevo, and Block (1965). Calibrations are typically done by irradiating the dosimeter to be calibrated in an anterior-posterior (AP) configuration. The AP configuration is used because that is the anticipated exposure configuration when a worker is wearing the badge on the front portion of the body. The study was performed to determine the effect of irradiation at other angles by rotating the NTA film in front of a neutron source. This rotational movement resulted in AP, posterior-anterior, and lateral exposure; the results were the composite of exposure from all directions.

ATTACHMENT B
NTA FILM ISSUES AND DOSE ASSIGNMENTS FOR MONITORED WORKERS (continued)

DOELAP requires the angular response of a dosimeter to be evaluated but does not require that an angular dependence correction be made to measured exposures. A study of angular dependence problems pointed out that exposures at some non-AP angles are less effective in delivering an effective dose equivalent because most of the important organs are in the anterior portion of the body (Xu, Reece, and Poston 1995). An AP exposure position delivers the highest effective dose equivalent. As a result, it is possible for exposures from isotropic dosimeters to overestimate the actual effective dose equivalent.

The correction factor recommended by NIOSH (1.33) is soundly based and favorable to claimants in that the dosimeter can in fact provide a reasonably accurate effective dose equivalent from an angular perspective because the exposure to neutrons normally occurs while working with the source of neutrons in front of the body. NIOSH is recommending an additional one-third be added to the monitored exposure.

B.5 NTA TRACK FADING

The NTA film issues at Pantex are essentially identical to the issues that have been raised and addressed at the Mound site. The fading issue was a major area of discussion in documented Mound calibration and fading experimentation on NTA film. The fading information from Mound is similar to that observed at other U.S. Atomic Energy Commission (AEC) sites that used NTA film.

In the July 27, 2010, transcript of the Mound Work Group meeting, S. Cohen and Associates (SC&A) summarized the issues in relation to neutron fading. SC&A made the point that, in general, workers were exposed to moderated (shielded) neutron sources that lowered the average energy of the neutron spectrum in comparison with unshielded neutron sources. Lower-energy neutron tracks in NTA film fade faster than tracks from higher-energy neutrons, and even when the calibration source and exchange frequency were matched with the work conditions, the moderation might not have been well matched. As a result, SC&A suggested that the fading values used by NIOSH in the site profile (33% in the first week after exposure and 56% in the 2-week period) might not be favorable to the claimant. From the transcript it appears that all agreed that no worker at Mound would be exposed to a source that was exclusively composed of low-energy neutrons (below the NTA energy threshold), so there would always be some signal that could be registered by the NTA film (NIOSH 2010).

On July 23, 2010, SC&A and Salient published a white paper, *Sensitivity of NTA Film to Neutron Sources at Mound Laboratory* (SC&A and Salient 2010), which noted that NTA track fading was studied by the Mound staff in 1967 and 1968 and a formal Mound report was issued July 1, 1968, reporting that 33% of the tracks faded after 1 week and 56% after 2 weeks. However, the purpose of that study was to establish the calibration and processing protocols that would appropriately compensate for the fading phenomena that was known to exist.

After the Work Group meeting, NIOSH found that the Mound experiments had also been published in the *Health Physics* journal (Kahle, Arnett, and Meyer 1969). The experimental description in this published peer-reviewed report provides detail that might not have been clear in the initial reports. Twenty NTA film badges were exposed to a PuF_4 source with an average energy of 1.3 MeV, and 20 badges were exposed to a moderated $^{238}PuO_2$ source with an average energy of 0.9 MeV. Based on the unpublished Mound reports, NIOSH believes each badge contained four NTA films, which would be consistent with uncertainty data in the unpublished Mound reports. Each group of 20 badges was subdivided into two groups of 10. One group of 10 badges was exposed to the source each day for 2 weeks, and one group was exposed on the day of development. The film badges were stored away from radiation before exposure, and during the interval from exposure to film development, at a

ATTACHMENT B
NTA FILM ISSUES AND DOSE ASSIGNMENTS FOR MONITORED WORKERS (continued)

constant temperature and constant relative humidity. Ordinary development and readout procedures were followed. Only those tracks that could be positively identified were counted. Kahle, Arnett, and Meyer (1969) reported:

> *Contrary to what was expected, the results indicated less fading of neutron tracks in films exposed to the lower average energy moderated* $^{238}PuO_2$ *source. There was 33% fading of neutron tracks for film exposed to the PuF source for a seven day interval from exposure to film development and 56% fading for a fourteen day interval. There was 17% fading of neutron tracks for film exposed to the moderated* $^{238}Pu0_2$ *source for a seven day interval from exposure to film development and 30% fading for a fourteen day interval. These results are shown in* [Figure B-1].
>
> *Since more fading is expected for lower energy neutrons, the combined results of the two experiments indicate that latent image fading cannot be accurately predicted on the basis of average energy alone. The entire neutron spectrum must be considered to predict latent image fading of tracks in neutron monitoring film.*

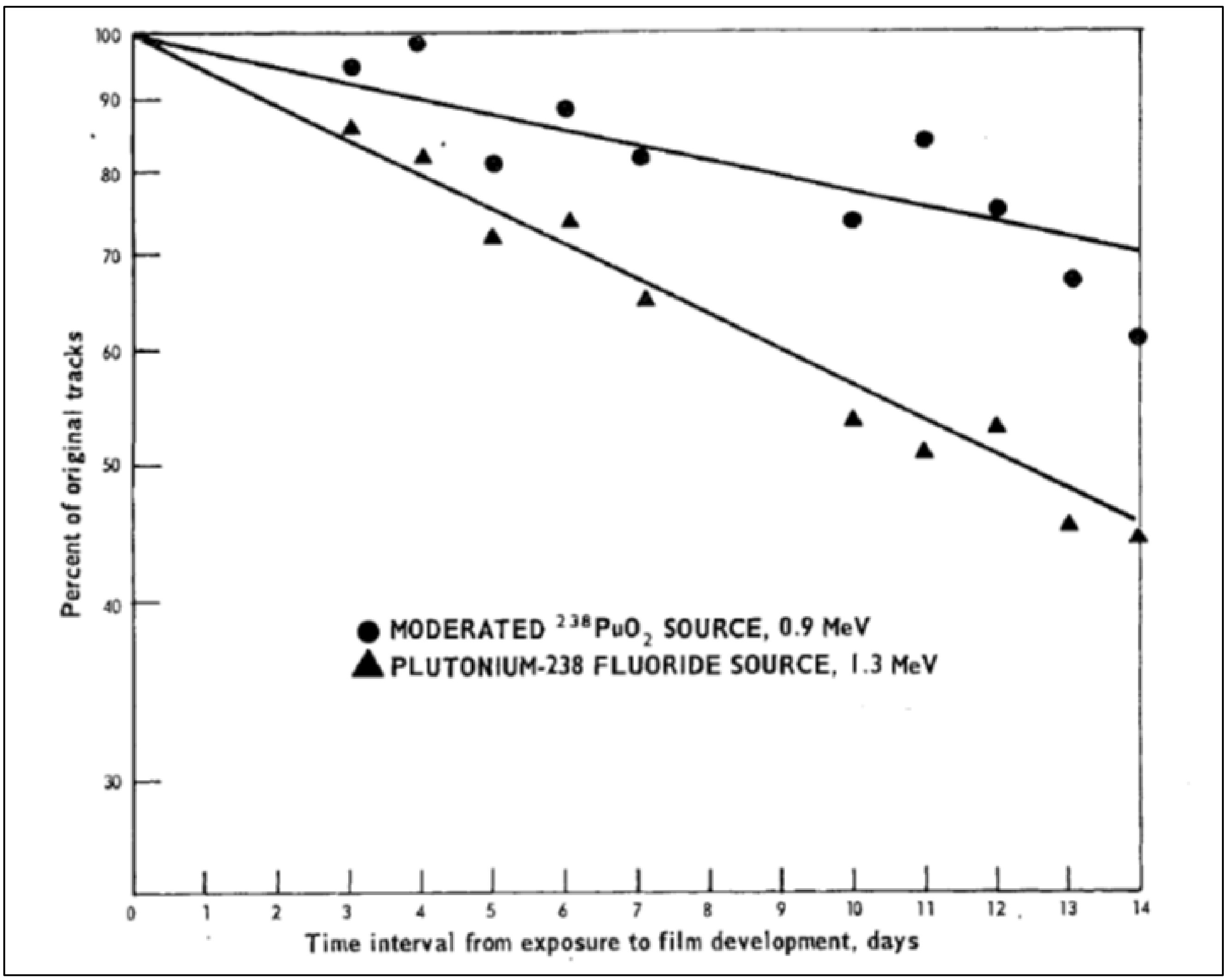

Figure B-1. Latent image fading of neutron film plotted as a function of time (Kahle, Arnett, and Meyer 1969).

ATTACHMENT B
NTA FILM ISSUES AND DOSE ASSIGNMENTS FOR MONITORED WORKERS (continued)

NIOSH has recommended that a correction factor be applied to the neutron monitoring results to accommodate any fading that could have occurred during the wear period of the NTA film dosimeter. The correction factor is based on a value determined at Mound Laboratory of 9% per week for a 4-week (1-month) period. Because fading corrections were incorporated into the processing protocol, the NIOSH recommendation to apply a fading correction of 1.56 is favorable to claimants.

B.6 CONCLUSIONS

For monitored workers, the NIOSH recommendation is to apply a correction factor of 1.4 to correct for the threshold energy response of NTA film, a correction factor of 1.33 for angular dependence, and a correction factor of 1.56 to account for uncorrected fading of the NTA film. These correction factors produce the overall NIOSH correction factor of 2.9. Further, the final dose is modified by the International Commission on Radiation Protection (ICRP) Publication 60 correction factor of 1.91 (ICRP 1991) (before January 1, 2010, when Publication 60 quality factors were implemented by Pantex dosimetry staff). In a paper by Vallario, Hankins, and Unruh (1969), the results of an intercomparison of AEC contractors and vendors were reported, with the observation that NTA film generally under-responded by 25% to 50%. This study was based on laboratory irradiations to known doses; no corrections were made for angular dependence. If the 50% under-response is corrected for angular response using the value above, the correction factor becomes 2.7, which is in reasonable agreement with the NIOSH recommendation. The NIOSH recommendation has a sound technical basis and should be implemented for monitored workers.