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## PUBLICATION RECORD

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| 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. |

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## ACRONYMS AND ABBREVIATIONS

| | |
| --- | --- |
| AP | anterior-posterior |
| cm | centimeters |
| 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 |
| 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) |
| 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 doses to Pantex Plant workers who have no or limited monitoring data on known site coworker data. In addition, the data in this TIB should be used to assign dose for gaps in the dosimetry record.

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 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. After 1988, 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, 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,* (currently in the NIOSH comment resolution phase). In this TIB, see Attachment A, Pantex 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.

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 On-Site Ambient Dose Reconstruction for DOE Sites*.

## 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.

With respect to neutron dosimetry data, there are three general eras that were considered during the analysis:

### 5.1 1960 TO 1977

During this period, 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 (see Attachment B, Pantex NTA Film Issues and Dose Assignments for Monitored and Unmonitored Workers) was applied to neutron data from BWXT Pantex (2011). No adjustments to photon or skin dose were needed. For 1978 and 1979, dosimetry data for neutrons, photons, and skin from BWXT Pantex (2011) were used with no corrections or adjustments.

### 5.2 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 Cf-252 source was used for calibration rather than a moderated Cf-252 source that would have been more similar to Pantex workplace neutron spectra (Prather 2004).

### 5.3 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.

Additional information and assumptions about the development of these coworker datasets can be found in Attachment A, Pantex External Dose Coworker Study Instructions (1960 to 2010) of this TIB.

## 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 (2015c).

## 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 2007). 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 Pantex external photon doses (rem).

| Year | GM | GSD | 95th percentile | *N* |
|---|---|---|---|---|
| 1960 | 0.030 | 2.38 | 0.127 | 59 |
| 1961 | 0.040 | 2.77 | 0.211 | 61 |
| 1962 | 0.056 | 3.10 | 0.362 | 57 |
| 1963 | 0.018 | 4.79 | 0.240 | 217 |
| 1964 | 0.112 | 3.70 | 0.968 | 253 |
| 1965 | 0.037 | 4.31 | 0.406 | 416 |
| 1966 | 0.052 | 3.54 | 0.416 | 581 |
| 1967 | 0.057 | 3.62 | 0.471 | 562 |
| 1968 | 0.046 | 2.90 | 0.264 | 423 |
| 1969 | 0.042 | 3.22 | 0.289 | 432 |
| 1970 | 0.076 | 3.64 | 0.635 | 467 |
| 1971 | 0.070 | 4.05 | 0.700 | 495 |
| 1972 | 0.068 | 3.44 | 0.515 | 467 |
| 1973 | 0.125 | 2.43 | 0.537 | 441 |
| 1974 | 0.068 | 3.40 | 0.509 | 500 |
| 1975 | 0.039 | 2.99 | 0.237 | 493 |
| 1976 | 0.045 | 2.79 | 0.241 | 463 |
| 1977 | 0.080 | 2.15 | 0.281 | 465 |
| 1978 | 0.032 | 4.03 | 0.318 | 518 |
| 1979 | 0.087 | 2.81 | 0.478 | 714 |
| 1980 | 0.012 | 6.28 | 0.247 | 772 |
| 1981 | 0.072 | 4.63 | 0.900 | 908 |
| 1982 | 0.044 | 4.00 | 0.429 | 1,002 |
| 1983 [a] | 0.048 | 3.82 | 0.430 | NA |
| 1984 | 0.051 | 3.68 | 0.431 | 1,093 |
| 1985 | 0.043 | 3.95 | 0.415 | 1,172 |
| 1986 | 0.040 | 3.05 | 0.253 | 1,128 |
| 1987 | 0.027 | 2.83 | 0.147 | 1,160 |
| 1988 | 0.032 | 2.56 | 0.148 | 1,121 |
| 1989 | 0.023 | 3.13 | 0.151 | 1,437 |
| 1990 | 0.025 | 2.58 | 0.119 | 2,090 |
| 1991 | 0.027 | 2.40 | 0.115 | 2,126 |
| 1992 | 0.039 | 2.11 | 0.134 | 2,316 |
| 1993 | 0.020 | 2.27 | 0.077 | 2,633 |
| 1994 | 0.010 | 2.85 | 0.057 | 2,978 |
| 1995 | 0.010 | 2.78 | 0.056 | 3,107 |
| 1996 | 0.010 | 2.82 | 0.055 | 3,162 |
| 1997 | 0.009 | 2.65 | 0.043 | 3,000 |
| 1998 | 0.009 | 2.66 | 0.046 | 2,786 |
| 1999 | 0.010 | 2.57 | 0.045 | 2,686 |
| 2000 | 0.009 | 2.60 | 0.044 | 2,642 |
| 2001 | 0.009 | 2.53 | 0.042 | 2,770 |
| 2002 | 0.009 | 2.62 | 0.043 | 2,947 |
| 2003 | 0.009 | 2.46 | 0.040 | 2,996 |
| 2004 | 0.009 | 2.45 | 0.038 | 3,168 |
| 2005 | 0.009 | 2.44 | 0.039 | 3,210 |
| 2006 | 0.009 | 2.50 | 0.039 | 3,237 |
| 2007 | 0.008 | 2.73 | 0.040 | 3,183 |
| 2008 | 0.008 | 3.03 | 0.052 | 2,159 |
| 2009 | 0.009 | 2.95 | 0.054 | 2,110 |
| 2010 | 0.007 | 3.12 | 0.047 | 2,067 |

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

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

| Year | GM | GSD | 95th percentile | *N* |
|---|---|---|---|---|
| 1960–1963 | 0.063 | 5.66 | 1.099 | 284 |
| 1964 | 0.049 | 4.33 | 0.542 | 249 |
| 1965 | 0.020 | 3.38 | 0.146 | 415 |
| 1966 | 0.027 | 2.63 | 0.133 | 581 |
| 1967 | 0.025 | 2.12 | 0.085 | 563 |
| 1968 | 0.026 | 1.81 | 0.069 | 423 |
| 1969 | 0.005 | 4.83 | 0.066 | 66 |
| 1970 | 0.022 | 1.96 | 0.066 | 465 |
| 1971 | 0.024 | 1.78 | 0.062 | 494 |
| 1972 | 0.026 | 1.67 | 0.060 | 464 |
| 1973 | 0.040 | 1.63 | 0.090 | 59 |
| 1974 | 0.052 | 3.99 | 0.508 | 29 |
| 1975 | 0.618 | 2.61 | 2.986 | 54 |
| 1976 | 0.004 | 4.62 | 0.044 | 463 |
| 1977 | 0.003 | 13.54 | 0.230 | 465 |
| 1978 | 0.003 | 11.51 | 0.155 | 518 |
| 1979 | 0.020 | 5.77 | 0.364 | 714 |
| 1980 | 0.003 | 5.71 | 0.058 | 772 |
| 1981 | 0.023 | 3.44 | 0.178 | 908 |
| 1982 | 0.024 | 3.41 | 0.182 | 1,002 |
| 1983 [a] | 0.022 | 3.42 | 0.166 | NA |
| 1984 | 0.020 | 3.36 | 0.150 | 1,093 |
| 1985 | 0.025 | 4.01 | 0.241 | 1,172 |
| 1986 | 0.027 | 3.50 | 0.216 | 1,128 |
| 1987 | 0.019 | 2.84 | 0.105 | 1,160 |
| 1988 | 0.020 | 2.71 | 0.100 | 1,121 |
| 1989 | 0.016 | 3.10 | 0.101 | 1,437 |
| 1990 | 0.017 | 2.72 | 0.090 | 2,090 |
| 1991 | 0.019 | 2.49 | 0.084 | 2,126 |
| 1992 | 0.038 | 2.68 | 0.192 | 2,316 |
| 1993 | 0.033 | 2.51 | 0.151 | 2,633 |
| 1994 | 0.006 | 2.56 | 0.030 | 2,978 |
| 1995 | 0.006 | 2.56 | 0.030 | 3,107 |
| 1996 | 0.006 | 2.56 | 0.029 | 3,162 |
| 1997 | 0.006 | 2.45 | 0.024 | 3,000 |
| 1998 | 0.006 | 2.35 | 0.023 | 2,786 |
| 1999 | 0.006 | 2.28 | 0.022 | 2,686 |
| 2000 | 0.006 | 2.35 | 0.023 | 2,642 |
| 2001 | 0.006 | 2.35 | 0.023 | 2,770 |
| 2002 | 0.006 | 2.37 | 0.023 | 2,947 |
| 2003 | 0.006 | 2.25 | 0.021 | 2,996 |
| 2004 | 0.005 | 2.27 | 0.021 | 3,168 |
| 2005 | 0.006 | 2.22 | 0.021 | 3,210 |
| 2006 | 0.005 | 2.26 | 0.021 | 3,237 |
| 2007 | 0.005 | 2.45 | 0.021 | 3,183 |
| 2008 | 0.005 | 2.52 | 0.025 | 2,159 |
| 2009 | 0.005 | 2.36 | 0.022 | 2,110 |
| 2010 | 0.004 | 2.60 | 0.021 | 2,067 |

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

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

| Year | GM | GSD | 95th percentile | *N* |
|---|---|---|---|---|
| 1960–1963 | 0.011 | 3.72 | 0.100 | 230 |
| 1964 | 0.057 | 1.82 | 0.152 | 249 |
| 1965 | 0.037 | 2.67 | 0.186 | 414 |
| 1966 | 0.053 | 2.00 | 0.164 | 579 |
| 1967 | 0.055 | 1.97 | 0.168 | 559 |
| 1968 | 0.061 | 1.97 | 0.187 | 421 |
| 1969 | 0.059 | 1.79 | 0.155 | 393 |
| 1970 | 0.116 | 2.66 | 0.582 | 119 |
| 1971 | 0.139 | 3.20 | 0.942 | 97 |
| 1972 | 0.199 | 2.95 | 1.176 | 83 |
| 1973 | 0.028 | 3.58 | 0.231 | 409 |
| 1974 | 0.022 | 5.29 | 0.345 | 423 |
| 1975 | 0.016 | 2.78 | 0.084 | 483 |
| 1976 | 0.007 | 5.13 | 0.097 | 463 |
| 1977 | 0.008 | 5.44 | 0.134 | 466 |
| 1978 | 0.007 | 6.27 | 0.143 | 519 |
| 1979 | 0.021 | 4.01 | 0.207 | 714 |
| 1980 | 0.027 | 5.75 | 0.473 | 772 |
| 1981 | 0.131 | 4.71 | 1.675 | 908 |
| 1982 | 0.088 | 4.55 | 1.057 | 1,002 |
| 1983 [a] | 0.097 | 4.16 | 1.013 | NA |
| 1984 | 0.106 | 3.83 | 0.968 | 1,093 |
| 1985 | 0.093 | 4.97 | 1.296 | 1,172 |
| 1986 | 0.100 | 4.22 | 1.072 | 1,128 |
| 1987 | 0.059 | 3.72 | 0.508 | 1,160 |
| 1988 | 0.061 | 3.32 | 0.435 | 1,121 |
| 1989 | 0.041 | 3.34 | 0.298 | 1,437 |
| 1990 | 0.040 | 2.39 | 0.169 | 2,090 |
| 1991 | 0.040 | 2.04 | 0.130 | 2,126 |
| 1992 | 0.023 | 3.46 | 0.179 | 2,316 |
| 1993 | 0.012 | 3.83 | 0.109 | 2,633 |
| 1994 | 0.012 | 2.98 | 0.072 | 2,978 |
| 1995 | 0.012 | 2.92 | 0.070 | 3,107 |
| 1996 | 0.012 | 3.00 | 0.072 | 3,162 |
| 1997 | 0.010 | 2.86 | 0.058 | 3,000 |
| 1998 | 0.011 | 2.84 | 0.061 | 2,786 |
| 1999 | 0.011 | 2.72 | 0.059 | 2,686 |
| 2000 | 0.011 | 2.77 | 0.058 | 2,642 |
| 2001 | 0.011 | 2.68 | 0.055 | 2,770 |
| 2002 | 0.011 | 2.75 | 0.056 | 2,947 |
| 2003 | 0.011 | 2.57 | 0.051 | 2,996 |
| 2004 | 0.010 | 2.57 | 0.049 | 3,168 |
| 2005 | 0.010 | 2.46 | 0.045 | 3,210 |
| 2006 | 0.010 | 2.56 | 0.048 | 3,237 |
| 2007 | 0.009 | 2.80 | 0.049 | 3,183 |
| 2008 | 0.010 | 3.20 | 0.069 | 2,159 |
| 2009 | 0.011 | 2.95 | 0.063 | 2,110 |
| 2010 | 0.008 | 3.21 | 0.058 | 2,067 |

a. 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
## PANTEX EXTERNAL DOSE COWORKER STUDY INSTRUCTIONS (1960 to 2010)

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**ATTACHMENT A**
**PANTEX 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 recording limit. In this case, use the minimum recordable dose (MRD) values from Table A-1 [from Table 6-2 of ORAUT-TKBS-0013-6 (ORAUT 2006)]. Proceed as follows:

  - For 1963, use a neutron MRD of 15 mrem and MRD of 30 mrem for skin.
  - For October 1964 to December 1972, use a neutron MRD of 20 mrem.
  - For 1980, use a photon MRD of 20 mrem and MRD of 20 for skin.
  - For time periods during which there were monthly and quarterly exchange periods, use the MRDs associated with the quarterly exchange period.
  - For 1992 to 1993, use the Panasonic 802 MRDs.
  - For 1994 to 2010, use the Panasonic 809/812 MRDs.
  - For 1994 to 2010, use the quarterly neutron MRDs associated with moderated $^{252}$Cf neutrons.

- There are three eras at Pantex: the NTA era from 1960 to 1977, the Stanford era from 1980 to mid-1993, and the more recent era from mid-1993 to 2010.

- For 1978 and 1979, use the dosimetry data as they are recorded with no corrections or adjustments.

- During the NTA era, the adjustment factor for neutron dose is 2.9.

- For 1980 to 1983, use the Stanford algorithm data (BWXT Pantex 2013) and the unadjusted Pantex data (BWXT Pantex 2011) (see below).

## ATTACHMENT A
## PANTEX EXTERNAL DOSE COWORKER STUDY INSTRUCTIONS (1960 to 2010) (continued)

- 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).

Table A-1. Dosimeter types, periods of use, exchange frequencies, MRDs, and MDLs (mrem) (derived from Table 6-2 of ORAUT 2007).

| Dosimeter type/ provider | Period | Exchange frequency[a] | Skin MRD | β/γ deep MRD | Neutron MRD | Skin MDL | Deep MDL | Neutron MDL |
|---|---|---|---|---|---|---|---|---|
| βλ film/Tracerlab | 01/1952–12/1959 | Weekly | 30[b] | 10[b] | None | 40[c] | 40[c] | None |
| βγ film and NTA film/ Tracerlab | 01/1960–03/1961 | Weekly | 30[b] | 10[b] | 15[b] | 40[c] | 40[c] | None |
| | 04/1961–05/1963 | Monthly | 30[b] | 10[b] | 15[b] | 40[c] | 40[c] | None |
| βγ film and NTA film/ Eberline | 06/1963–09/1964 | Monthly | 10[b] | 10[b] | 10[b] | 40[c] | 40[c] | None |
| βγ film and NTA film/ Landauer | 10/1964–12/1968 | 2/month | 40[b] | 10[b] | 10[b,d] | 40[c] | 40[c] | None |
| βγ film and NTA film/ Landauer | 01/1969–12/1972 | Monthly | 40[b] | 10[b] | 20[b,e] | 40[c] | 40[c] | None |
| TLD 2-element/in-house and NTA film/Landauer[f] | 01/1973–12/1975 | Monthly | 10 | 4 | 10[b,d] | 30 | 30 | None |
| TLD 6-element/in-house | 01/1977–13/1979 | Monthly | 10 | 4 | 50 | 30 | 30 | 50 |
| Panasonic 802/in-house[g] | 01/1980–12/1990 | Monthly | 20 | 20 | 50 | 30 | 30 | 50 |
| Panasonic 802/in-house[g] | 01/1992–12/1999 | Monthly | 15 | 10 | 70 | 30 | 30 | 50 |
| Panasonic 802/in-house[g] | 01/1992–12/1999 | Quarterly | 20 | 15 | 85 | 30 | 30 | 50 |
| Panasonic 809/812/in-house[h] | 01/1994–present | Monthly | 10 | 10 | 5[i], 25[j] | 30 | 30 | 50 |
| Panasonic 809/812/in-house[h] | 01/1994–present | Quarterly | 15 | 15 | 10[i], 65[j] | 30 | 30 | 50 |

a. Exchange frequencies were established from dosimetry reports. The initial weekly exchange frequency was changed to monthly in March 1961 (Tracerlab 1962–1963). A monthly exchange frequency continued with Eberline (Ashton 2003). An exchange frequency of twice per month for both beta/gamma and neutron films was established with Landauer in October 1964; this frequency changed, for both beta/gamma and neutron films, to monthly in January 1969 (Adams 2003). NTA film provided by Landauer was used with the two-element TLD and exchanged monthly (Adams 2003).
b. Based on minimum doses recorded on dosimetry reports (Adams 2003; Ashton 2003; Tracerlab 1962–1963).
c. Estimated MDL typical of film dosimeter capabilities (Lalos 1989; NIOSH 1993; Wilson 1960, 1987; Wilson et al. 1990).
d. MRD for thermal neutrons (Adams 2003).
e. MRD for fast neutrons (greater than 1 MeV) (Adams 2003).
f. The Pantex in-house two-element TLD was implemented in 1973 for monitoring only beta/gamma radiation exposures. Use of NTA film continued for monitoring neutron exposures until the implementation of the six-element TLD system in 1977.
g. In 1992, the algorithms were changed for the Panasonic 802 to the Stanford algorithms (BWXT Pantex 2001). The dosimeter exchange frequency for nonradiation workers was changed from monthly to quarterly in 1992.
h. Beginning in January 1994, the Panasonic 809/812 dosimeter was provided to radiation workers and exchanged monthly. The Panasonic 802 dosimeter was provided to all other Pantex workers and exchanged quarterly. Between 1994 and 2000, Panasonic 802 dosimeters were gradually phased out and replaced by Panasonic 809/812 dosimeters for all workers.
i. DOELAP performance testing with moderated Cf-252 neutrons.
j. DOELAP performance testing with unmoderated Cf-252 neutrons.

### 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.

## ATTACHMENT A
## PANTEX EXTERNAL DOSE COWORKER STUDY INSTRUCTIONS (1960 to 2010) (continued)

- 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 1977.

Table A-2 provides the sources of these data fields by period.

Table A-2. 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 1977.

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 periods in Table A-3, with MRDs (in mrem) derived using Section A.2 and Table A-1.

Table A-3. Periods and MRDs (mrem) for imputation models.

| Years | Neutron | Gamma | Skin |
|---|---|---|---|
| 1960–1963 | 15 | 10 | 30 |
| 1964–1972 | 20 | 10 | 40 |
| 1973–1976 | 10 | 4 | 10 |
| 1977–1979 | 50 | 4 | 10 |
| 1980–1991 | 50 | 20 | 20 |
| 1992–1993 | 85 | 15 | 20 |
| 1994–2010 | 10 | 15 | 15 |

Due to insufficient data for neutron and skin badge readings, combine 1960 to 1963 annual doses for coworker models (meaning there should be a coworker model for neutrons for 1960 to 1963 and a

**ATTACHMENT A**
**PANTEX EXTERNAL DOSE COWORKER STUDY INSTRUCTIONS (1960 to 2010) (continued)**

coworker model for skin for 1960 to 1963). If a worker has more than one annual dose in the 1960 to 1963 period, each of the annual doses should be included in the coworker model.

# ATTACHMENT B
# PANTEX NTA FILM ISSUES AND DOSE ASSIGNMENTS FOR MONITORED WORKERS

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# ATTACHMENT B
# PANTEX 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. Further 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 et al. (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,

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

posterior-anterior, and lateral exposure; the results were the composite of exposure from all directions.

DOELAP requires the angular response of a dosimeter to be evaluated, but does not require that any angular dependence correction be made to measured exposures. A study of angular dependence problems (Xu et al. 1995), 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. 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 AEC sites that used NTA film.

In the July 28, 2010, transcript of the Mound Work Group meeting, the SC&A staff summarized the issues in relation to neutron fading. SC&A made the points 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.

On July 23, 2010, SC&A published a white paper, *Sensitivity of NTA Film to Neutron Sources at Mound Laboratory*, DRAFT Rev. 1 (SC&A 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 et al. 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

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

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 constant temperature and constant relative humidity. Ordinary development and readout procedures were followed. Only those tracks that could be positively identified were counted. Mound 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 $^{238}PuO_2$ source for a seven day interval from exposure to film development and 30% fading for a fourteen day interval. These results are shown in Fig. 1.* [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.*

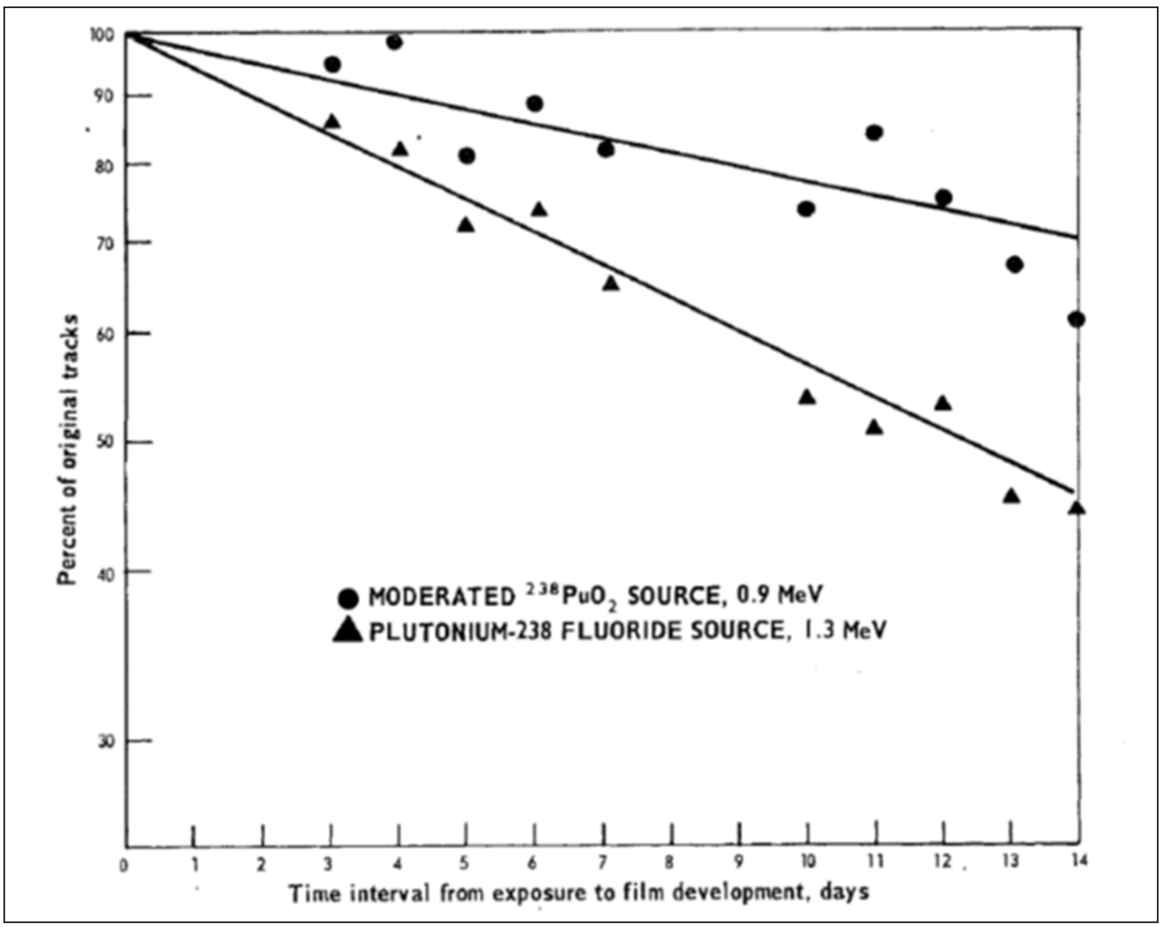


Figure B-1. Latent image fading of neutron film plotted as a function of time.

**ATTACHMENT B**
**PANTEX 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 (CF) 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 et al. (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.