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Extremity Doses for Mound Exposures to Plutonium-238

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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
09/18/2017	00	New document initiated to calculate extremity to whole-body ratios for work performed at Mound for work with Pu-238. 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

AIC	Akaike information criterion
DOE	U.S. Department of Energy
keV	kiloelectron-volt, 1,000 electron-volts
mrem	millirem
NIOSH	National Institute for Occupational Safety and Health
NTA	nuclear track emulsion, type A
ORAU	Oak Ridge Associated Universities
RTG	radioisotope thermoelectric generator
SRDB Ref ID	Site Research Database Reference Identification (number)
TIB	technical information bulletin
TLD	thermoluminescent dosimeter
WB	whole body
U.S.C.	United States Code
§	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 about and comparison of whole-body (WB), wrist, and finger doses. This information may be used to determine ratios to assist in the determination of extremity doses. If worker extremity dosimeter results are available, those results should be used either as the dose to assign or as values from which a ratio can be calculated to better determine the dose to the cancer site, whichever is more appropriate.

1.2 SCOPE

The information in this TIB may be used to determine dose to assign to extremities while working with or around ^{238}Pu at Mound, or other sites where exposure to ^{238}Pu occurred, when WB dose or finger ring dose is available.

2.0 BACKGROUND

Some workers assigned to Mound had only WB dosimetry assigned to them. However, the work they performed might have included working "hands-on" with ^{238}Pu, and it would be expected that the dose to the extremities would be elevated in comparison with the WB dose. For these workers an approach may be needed to assign dose to the extremities. Further, if finger ring dose is available, the wrist-to-finger ratios could be used to determine the dose to other parts of the hand.

3.0 GENERAL APPROACH

Information in Mound reports *Wrist and Fingertip Dose Measurements for Plutonium-238 Processing Operations* (Bigler 1973) and *Extremity Monitoring Study of Personnel in Plutonium Operations* (Bigler and Phillabaum 1973) was reviewed.

Mound initiated a study in September 1972 to determine the need for extremity monitoring for personnel involved in ^{238}Pu operations at the site. Wrist badges suitable for determining both neutron exposure using nuclear track emulsion, type A (NTA) film and gamma exposure using LiF thermoluminescent dosimeters (TLDs) were selected. The workers who performed the operations were monitored for various lengths of time ranging from 2 to 22 weeks with a 2-week dosimeter exchange frequency.

A study was also performed in 1972 and 1973 with wrist and WB gamma and neutron doses during work in gloveboxes where the workers were wearing leaded rubber gloves. The monitoring approach for detecting the gamma and neutron dose used the same monitoring approach (i.e., LiF TLDs and NTA film, respectively) as the other study. This study also involved taping TLDs to the finger tips on

the second or third finger of each hand to be able to determine the gamma dose to the finger tips. The number of days the dosimetry was worn ranged from 3 to 10 days.

The information in these reports can be used to determine the ratios of left wrist to WB and right wrist to WB for gamma and neutron radiation. Ratios for left finger to left wrist and right finger to right wrist gamma ratios for a limited number of applications can also be developed.

3.1 RADIOACTIVE PROFILE

Plutonium-238 is primarily thought of as an alpha emitter, but there are other emitted radiations that can contribute to external dose (Table 3-1). Table 3-1 provides the gamma energies and the percent of time that they are emitted (e.g., 13% of the time a gamma is emitted with 17 keV of energy).

Table 3-1, Gamma components from ^{238}Pu (Foster 1966).

Gamma component (keV)	Absolute intensities (%)[a]
17	1.3×10^{1}
43	3.8×10^{-2}
99	9.0×10^{-3}
150	1.0×10^{-3}
203	4.0×10^{-6}
760	5.0×10^{-5}
875	2.0×10^{-5}

a. Values are absolute intensities because not all disintegrations are accompanied by gamma emission.

When combined into plutonium oxide ($^{238}PuO_2$) for the purpose of a radioisotope thermoelectric generator (RTG), a spectrum of neutron energies as presented in Figure 3-1 are generated.

4.0 APPLICATIONS AND LIMITATIONS

The data from Mound were for workers who were involved in various activities involving ^{238}Pu in 1972 and 1973. This TIB can be used to determine dose to assign to extremities while working with or around ^{238}Pu at Mound, or other sites when exposures to ^{238}Pu (or similar energy spectrum) occurred, when only WB dose is available. In addition, calculated finger-to-wrist ratios can be used to determine finger dose from wrist or WB dosimetry results. In addition, the finger-to-wrist ratios can be used to determine the dose to other parts of the hand if finger ring dose is available.

5.0 EXTREMITY DOSE RATIO DEVELOPMENT

5.1 WRIST-TO-WHOLE BODY DOSE RATIOS

Information from the 1972 and 1973 reports on extremity monitoring of individuals during a number of ^{238}Pu operations is presented in Table 5-1. The calculated value and distribution was determined from the dataset after the data was fitted using the Akaike information criterion (AIC). AIC is used to estimate the quality of a model relative to other models. For a gamma ratio (wrist-to-WB) the values were calculated using a Weibull distribution (see Figure 5-1). The values were determined to be 1.3295 (shape of curve), 1.9271 (scale), and 0.3436 (location). For a neutron ratio (wrist-to-WB) a lognormal distribution with a geometric mean of 1.5796 and geometric standard deviation of 2.5414 was determined to be most appropriate (see Figure 5-2).

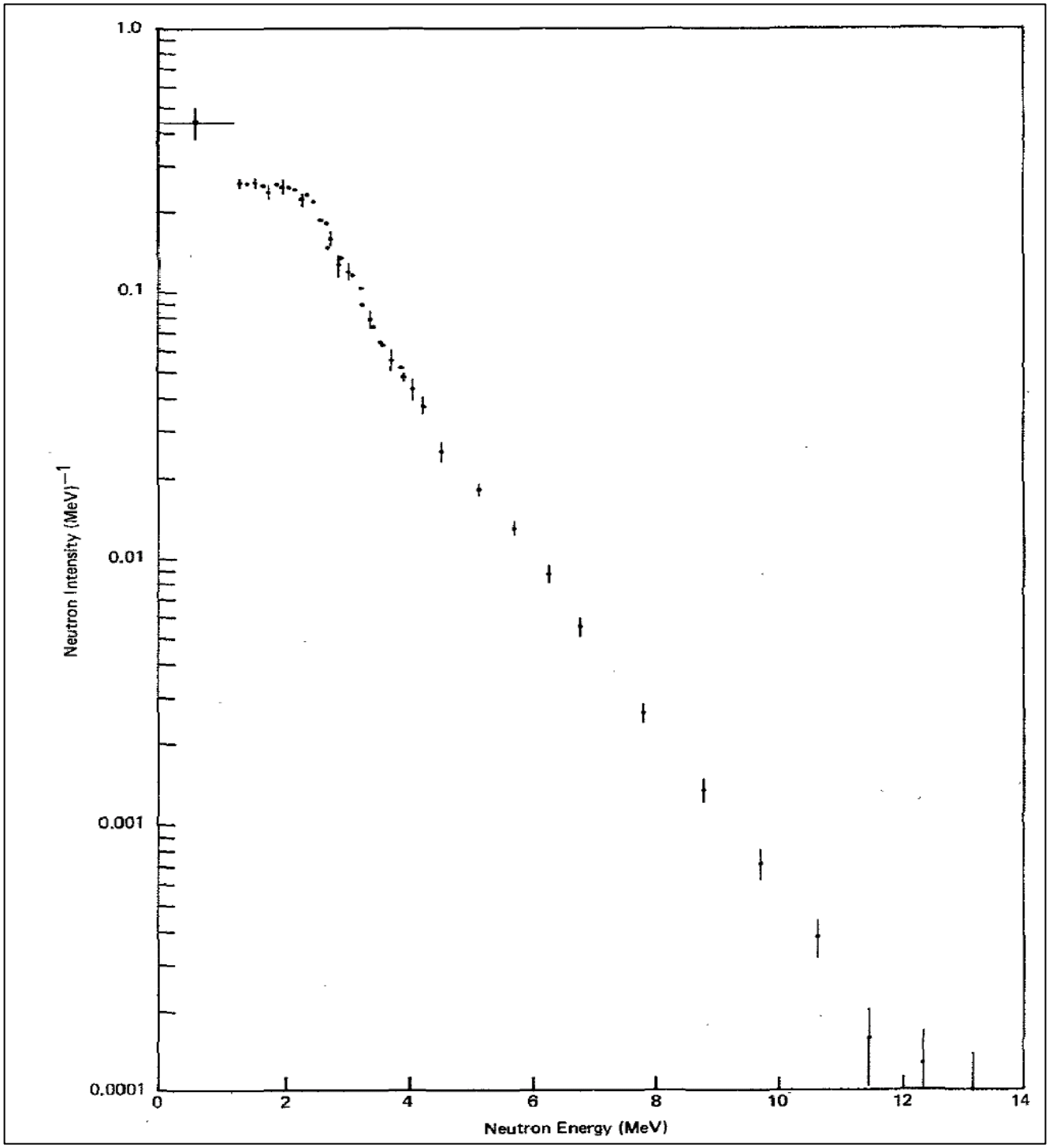

Figure 3-1. Neutron energy spectrum for $^{238}PuO_2$ RTG (Anderson 1985).

Table 5-1. Wrist-to-WB dose ratios.[a,b]

Individual doses - Pu-238 fuel processing

Employee	Left wrist, gamma (mrem)	Right wrist, gamma (mrem)	WB (mrem)	Left wrist-to-WB gamma ratio	Right wrist-to-WB gamma ratio	Left wrist, neutron (mrem)	Right wrist, neutron (mrem)	WB, neutron (mrem)	Left wrist-to-WB neutron ratio	Right wrist-to-WB neutron ratio
1	1,272	1,602	783	1.62	2.05	623	352	650	0.96	0.54
2	2,467	3,344	1,097	2.25	3.05	1,974	1,806	1,360	1.45	1.33
3	2,311	2,380	908	2.55	2.62	1,803	1,761	1,099	1.64	1.60
4	144	184	76	1.89	2.42	92	210	94	0.98	2.23
5	86	189	40	2.15	4.73	80	200	50	1.60	4.00
6	156	199	55	2.84	3.62	120	170	60	2.00	2.83

Individual doses -
Handle encapsulated and project Pu-238 sources outside of glovebox and move sources within plant

Employee	Left wrist, gamma (mrem)	Right wrist, gamma (mrem)	WB (mrem)	Left wrist-to-WB gamma ratio	Right wrist-to-WB gamma ratio	Left wrist, neutron (mrem)	Right wrist, neutron (mrem)	WB, neutron (mrem)	Left wrist-to-WB neutron ratio	Right wrist-to-WB neutron ratio
1	371	344	239	1.55	1.44	634	554	349	1.82	1.59
2	118	N/M	133	0.89	N/A	202	N/M	194	1.04	N/A
3	N/M	175	187	N/A	0.94	N/M	282	273	N/A	1.03

Individual doses - Analytical determination of Pu-238 fuel used in sources

Employee	Left wrist, gamma (mrem)	Right wrist, gamma (mrem)	WB (mrem)	Left wrist-to-WB gamma ratio	Right wrist-to-WB gamma ratio	Left wrist, neutron (mrem)	Right wrist, neutron (mrem)	WB, neutron (mrem)	Left wrist-to-WB neutron ratio	Right wrist-to-WB neutron ratio
1	556	N/M	399	1.39	N/A	3,736	N/M	1,616	2.31	N/A
2	N/M	575	495	N/A	1.16	N/M	2,835	2,030	N/A	1.40
3	660	611	590	1.12	1.04	1,340	1,008	1,033	1.30	0.98

Individual doses - Audit of Pu-238 encapsulation process

Employee	Left wrist, gamma (mrem)	Right wrist, gamma (mrem)	WB (mrem)	Left wrist-to-WB gamma ratio	Right wrist-to-WB gamma ratio	Left wrist, neutron (mrem)	Right wrist, neutron (mrem)	WB, neutron (mrem)	Left wrist-to-WB neutron ratio	Right wrist-to-WB neutron ratio
1	175	225	344	0.51	0.65	327	578	1,214	0.27	0.48
2	28	46	27	1.04	1.70	50	166	54	0.93	3.07

Individual doses - Encapsulation and decontamination of Pu-238 sources

Employee	Left wrist, gamma (mrem)	Right wrist, gamma (mrem)	WB (mrem)	Left wrist-to-WB gamma ratio	Right wrist-to-WB gamma ratio	Left wrist, neutron (mrem)	Right wrist, neutron (mrem)	WB, neutron (mrem)	Left wrist-to-WB neutron ratio	Right wrist-to-WB neutron ratio
1	269	N/M	71	3.79	N/A	237	N/M	169	1.40	N/A
2	N/M	518	397	N/A	1.30	N/M	1,222	4,105	N/A	0.30
3	265	403	282	0.94	1.43	2,001	4,836	2,202	0.91	2.20

Individual doses - Metallurgical evaluations and studies involving encapsulation of Pu-238

Employee	Left wrist, gamma (mrem)	Right wrist, gamma (mrem)	WB (mrem)	Left wrist-to-WB gamma ratio	Right wrist-to-WB gamma ratio	Left wrist, neutron (mrem)	Right wrist, neutron (mrem)	WB, neutron (mrem)	Left wrist-to-WB neutron ratio	Right wrist-to-WB neutron ratio
1	N/M	269	147	N/A	1.83	N/M	1,800	407	N/A	4.42
2	408	350	459	0.89	0.76	779	539	1,079	0.72	0.50
3	851	N/M	171	4.98	N/A	3,821	N/M	178	21.49	N/A
4	N/M	940	310	N/A	3.03	N/M	2,049	527	N/A	3.89

Individual doses - Handling of Pu-238 neutron sources

Employee	Left wrist, gamma (mrem)	Right wrist, gamma (mrem)	WB (mrem)	Left wrist-to-WB gamma ratio	Right wrist-to-WB gamma ratio	Left wrist, neutron (mrem)	Right wrist, neutron (mrem)	WB, neutron (mrem)	Left wrist-to-WB neutron ratio	Right wrist-to-WB neutron ratio
1	176	77	211	0.83	0.36	720	417	1,437	0.50	0.29

Individual doses - Vacuum hot press operation of Pu-238 discs

Employee	Left wrist, gamma (mrem)	Right wrist, gamma (mrem)	WB (mrem)	Left wrist-to-WB gamma ratio	Right wrist-to-WB gamma ratio	Left wrist, neutron (mrem)	Right wrist, neutron (mrem)	WB, neutron (mrem)	Left wrist-to-WB neutron ratio	Right wrist-to-WB neutron ratio
1	115	188	27	4.26	6.96	192	254	N/M	N/A	N/A
2	N/M	339	138	N/A	2.46	N/M	122	52	N/A	2.33
3	764	N/M	296	2.58	N/A	5,065	N/M	287	17.64	N/A
4	63	72	33	1.91	2.18	126	137	40	3.15	3.43
5	31	34	7	4.43	4.86	28	49	28	1.00	1.75

Individual doses - Radiography and leak testing of Pu-238 sources

Employee	Left wrist, gamma (mrem)	Right wrist, gamma (mrem)	WB (mrem)	Left wrist-to-WB gamma ratio	Right wrist-to-WB gamma ratio	Left wrist, neutron (mrem)	Right wrist, neutron (mrem)	WB, neutron (mrem)	Left wrist-to-WB neutron ratio	Right wrist-to-WB neutron ratio
1	145	226	258	0.56	0.88	961	1,598	596	1.61	2.68

a. N/A = not applicable.
b. N/M = not measured.

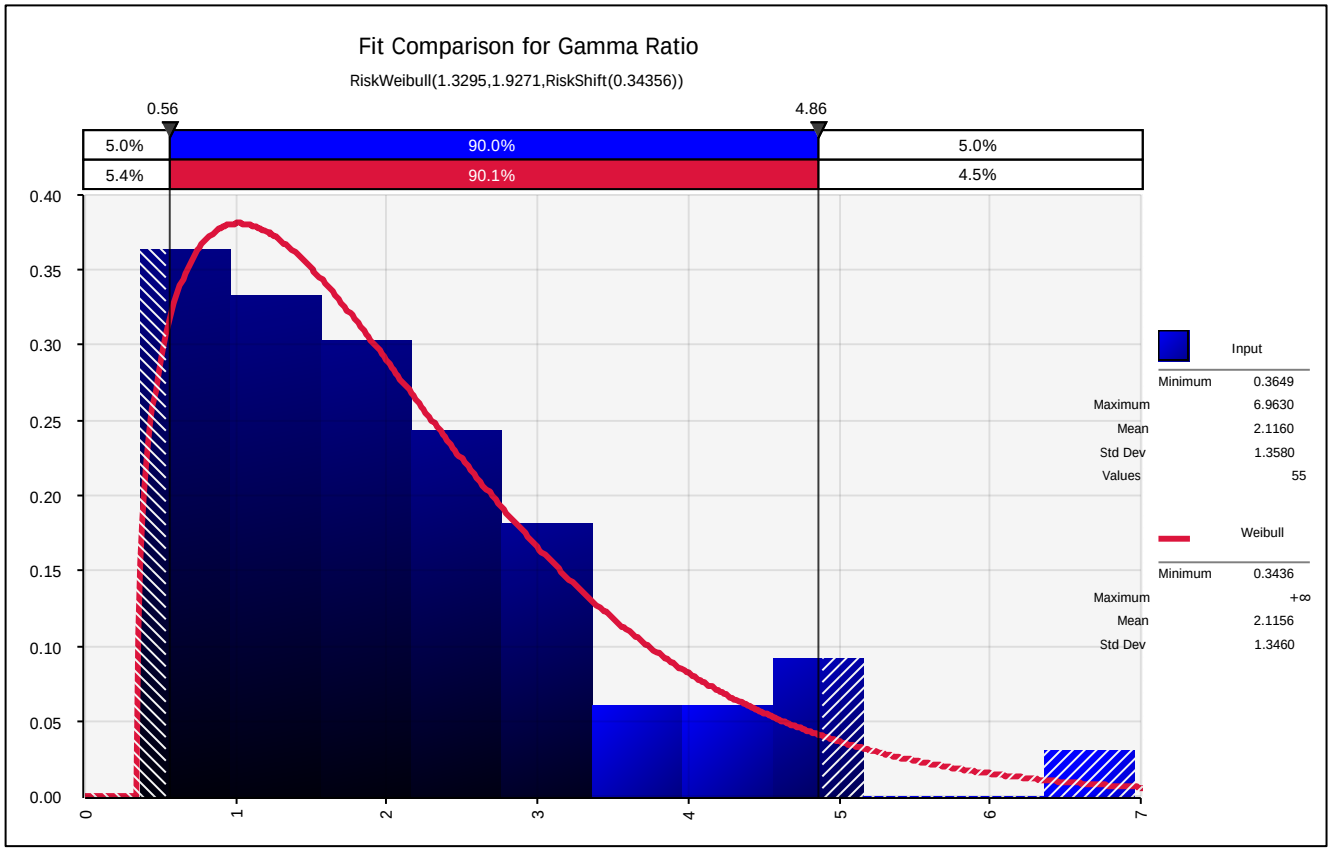

Figure 5-1. Fit comparison for gamma ratio.

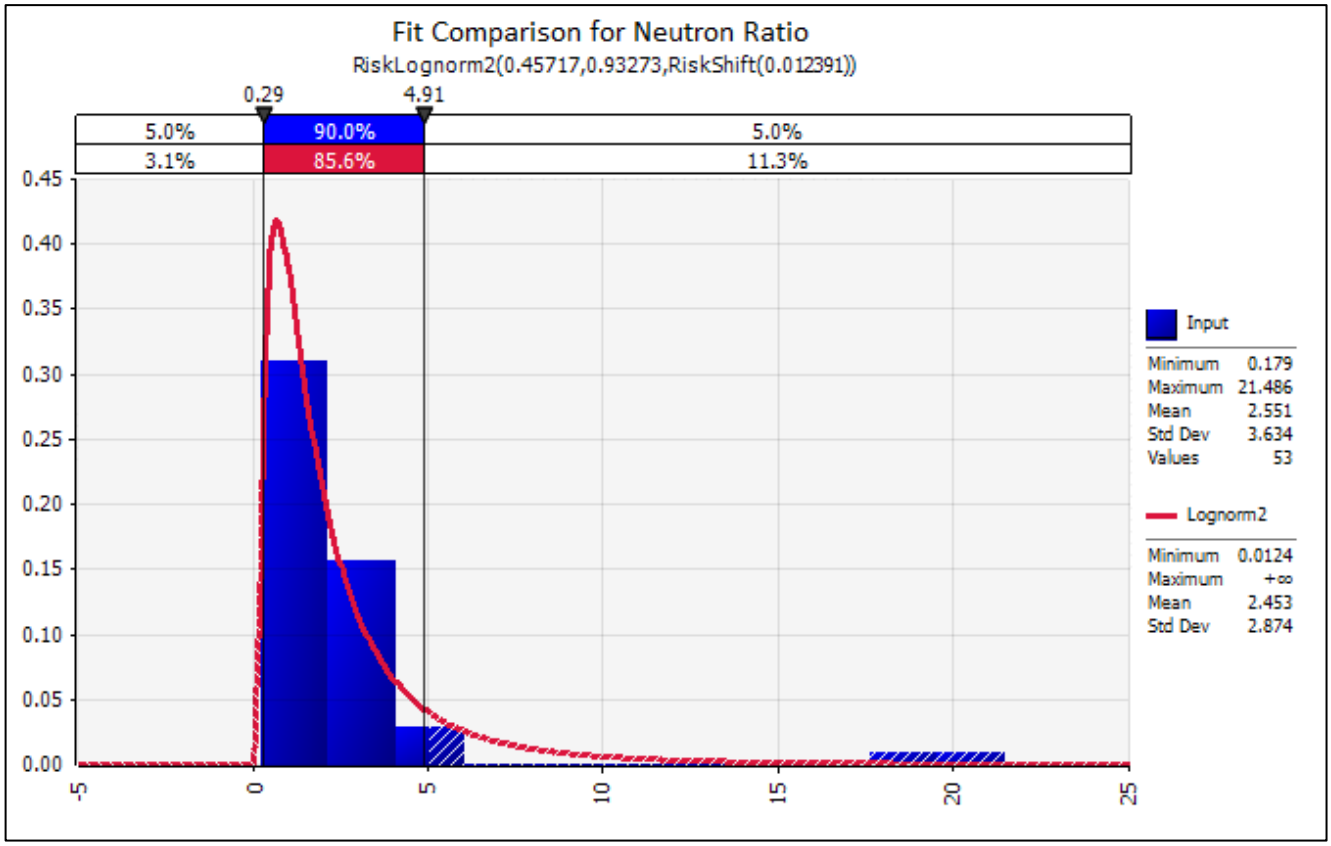

Figure 5-2. Fit comparison for neutron ratio.

5.2 FINGER-TO-WRIST RATIOS

Information from the 1973 report on individuals wearing finger and wrist dosimeters was used to develop finger-to-wrist ratios (Table 5-2). A calculated average and standard deviation was determined from the limited dataset. The average was calculated to be 3.18 and 2.76 (left finger to left wrist and right finger to right wrist, respectively). The associated standard deviations were calculated to be 0.53 and 0.85 (left finger to left wrist and right finger to right wrist, respectively). Since the data is limited, a fit comparison could not be determined and a normal distribution is recommended as a default value.

Unless it is known that an involved worker is right or left-handed, the higher ratio should be used (i.e., 3.18 with a standard deviation of 0.53).

Table 5-2. Finger-to-wrist gamma dose ratios.

Individual Doses - Pu-238 fuel processing

Employee	Left finger (mrem)	Left wrist (mrem)	Right finger (mrem)	Right wrist (mrem)	Left finger-to-wrist ratio	Right finger-to-wrist ratio
1	351	86	641	189	4.08	3.39
2	482	156	369	199	3.09	1.85

Individual Doses - Vacuum hot press of Pu-238 discs

Employee	Left finger (mrem)	Left wrist (mrem)	Right finger (mrem)	Right wrist (mrem)	Left finger-to-wrist ratio	Right finger-to-wrist ratio
1	226	63	241	72	3.59	3.35
2	96	31	70	34	3.10	2.06

Individual Doses - Pu-238 heat source encapsulation

Employee	Left finger (mrem)	Left wrist (mrem)	Right finger (mrem)	Right wrist (mrem)	Left finger-to-wrist ratio	Right finger-to-wrist ratio
1	237	83	200	50	2.86	4.00
2	158	66	76	40	2.39	1.90

6.0 SUMMARY

When it has been determined that a worker was exposed to a ^{238}Pu and an extremity dose is needed use the provided wrist-to-whole body dose ratio and associated distributions to calculate the extremity dose from the whole body dosimeter dose.

As mentioned earlier, the following distributions and parameters best fit the evaluated data:

- Gamma ratio (wrist-to-WB), Figure 5-1. Weibull distribution, shape of the curve being 1.3295, scale being 1.9271, and location being 0.3436. This distribution is multiplied by the whole body dose to determine the wrist dose.

- Neutron ratio (wrist-to-WB), Figure 5-2. Lognormal distribution with a geometric mean of 1.5796 and geometric standard deviation of 2.5414. This distribution is multiplied by the whole body dose to determine the wrist dose.

- There were too few data points when evaluating the finger-to-wrist information to obtain a meaningful fit to a distribution. Since a meaningful fit could not be determined, assign data using a normal distribution. The average was calculated to be 3.18 and 2.76 (left finger to left wrist and right finger to right wrist, respectively). Unless specific information is known about

the workers handedness (i.e., right-handed or left-handed) use the more favorable mean of 3.18 and a standard deviation of 0.53. This value is applied to the appropriate wrist dose to determine the finger dose.

Additionally, finger doses can be determined if needed using the calculated mean finger-to-wrist ratios. If only a whole body dose is available for an Energy Employee, but a finger dose is needed, calculate a wrist dose using the provided wrist-to-WB ratio. Use this calculated dose and the finger-to-wrist ratio to determine the dose to assign to the finger.

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