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DOSE MODELING OF PLUTONIUM-BERYLLIUM SOURCE UNPACKING OPERATIONS

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1. Summary

The effective dose equivalent (EDE, dose) for plutonium-beryllium (PuBe) neutron source unpacking operations has been estimated using the LAMPSHADE tool. Information from four unpacking operations was used as a benchmark and as a data source. Given the nature of the raw data, results are good, and the prospect of using this as a predictive tool is promising.

2. Neutron Source Unpacking Flowsheets

The neutron source unpacking process has been divided into three operations: preparation, unpacking, and source transfer. The flowsheets and step descriptions are provided in the subsections below.

2.1. Neutron Source Unpacking Preparation

Preparatory operations ensure that all equipment and documentation is available and configured for source unpacking operations. A flowsheet describing these steps is shown in Figure 1.

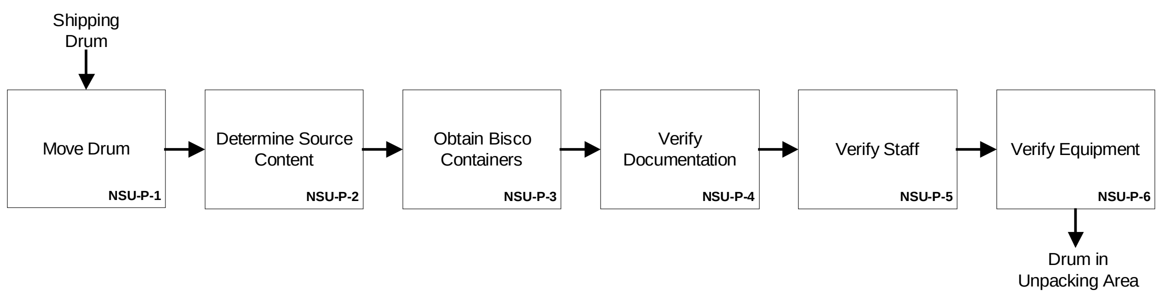

Figure 1. Neutron source unpacking preparation flowsheet.

NSU-P-1 Move Drum

The unpacking personnel arrange for Radiological Control Technician (RCT) support and move the shipping container from the loading dock storage room (B13) to the unpacking area.

NSU-P-2 Determine Source Content

The number of sources in the shipment is determined from associated documentation.

NSU-P-3 Obtain Bisco Containers

Obtain one Bisco container for each neutron source in the drum.

NSU-P-4 Verify Documentation

Before performing work, the unpacking team verifies that all documentation, work permits, and other paperwork are in order.

NSU-P-5 Verify Staff

Before performing work, the unpacking supervisor verifies that all required team members are present and have their respirators.

NSU-P-6 Verify Equipment

Before performing work, the unpacking team verifies that all equipment and unpacking tools are available.

2.2. Neutron Source Unpacking

When the unpacking area is prepared for unpacking operations, operators proceed to remove the neutron sources from a drum and transfer them to individual Bisco containers. The flowsheet for the source unpacking operations is shown in Figure 2.

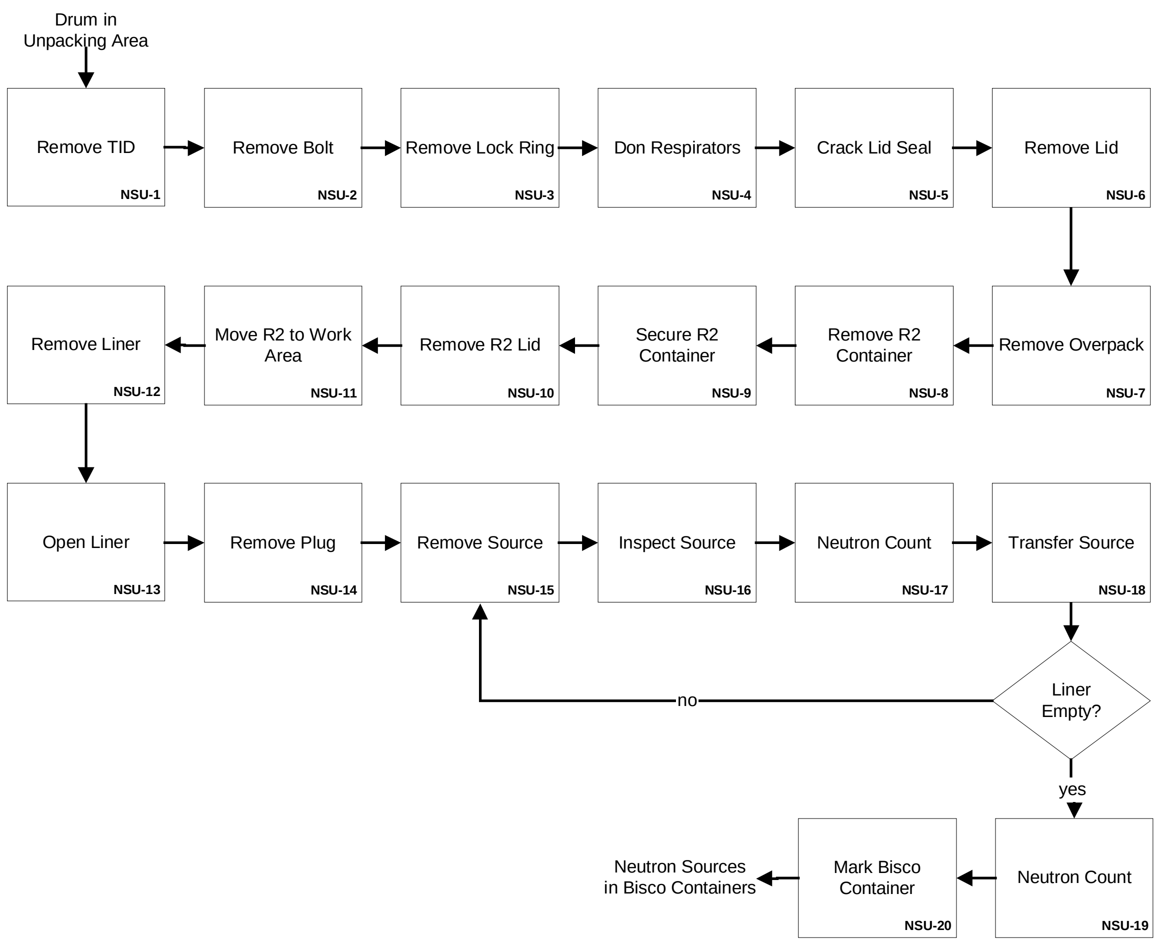

Figure 2. Neutron source unpacking flowsheet.

NSU-1 *Remove TID*
The tamper-indicating device (TID) is removed from the drum. The removal of the TID is recorded on the TID and drum verification form.

NSU-2 *Remove Bolt*
The lock ring bolt is removed from the shipping container using an impact wrench.

NSU-3 *Remove Lock Ring*
The lock ring is removed from the drum. Removing the lock ring does not unseal the drum lid.

NSU-4 *Don Respirators*
Before unsealing the drum, all team members don respirators.

NSU-5 *Crack Lid Seal*
The drum lid seal is cracked and an RCT swipes the area to ensure that no contamination is present.

NSU-6 *Remove Lid*
The drum lid is removed and placed in a designated holding location.

NSU-7 *Remove Overpack*
The Celotex overpack (disk and plug) is removed so that the top edge of the R2 cap lid is exposed.

NSU-8 *Remove R2 Container*
The R2 container is lifted out of the shipping drum.

NSU-9 *Secure R2 Container*
The R2 container is transferred to a chain vise and secured under the chain.

NSU-10 *Remove R2 Lid*
The R2 container cap lid is removed using specialized tools.

NSU-11 *Move R2 to Work Area*
The R2 container is removed from the chain vise and transferred to a work surface.

NSU-12 *Remove Liner*
The polyurethane liner is removed from the R2 vessel and placed on the work surface.

NSU-13 *Open Liner*
The polyurethane liner is opened by releasing the securing bold and opening the lid.

NSU-14 *Remove Plug*
The lid and plug in the polyurethane liner are removed.

NSU-15 Remove Source
The polyurethane liner is tipped to allow a single source to roll out of the container and into the hand of an unpacking team member.

NSU-16 Inspect Source
The neutron source is visually inspected to verify the serial number against accountability records. If the source is old or the surface has been corroded, the surface of the serial number may have to be brushed to obtain an accurate reading.

NSU-17 Neutron Count
The RCT performs contact neutron measurements and records the results on the accountability records.

NSU-18 Transfer Source
The source is transferred to a Bisco-shielded storage container and temporarily sealed. Identification information is placed on the container.

NSU-19 Neutron Count
A second neutron count is taken at the surface of the Bisco container.

NSU-20 Mark Bisco Container
The Bisco container is marked with appropriate source information and unpacking data.

2.3. Neutron Source Transfer

The Bisco containers in which the neutron sources have been placed must be transferred to the vault or to the processing line. The flowsheet for these transfer operations is shown in Figure 3.

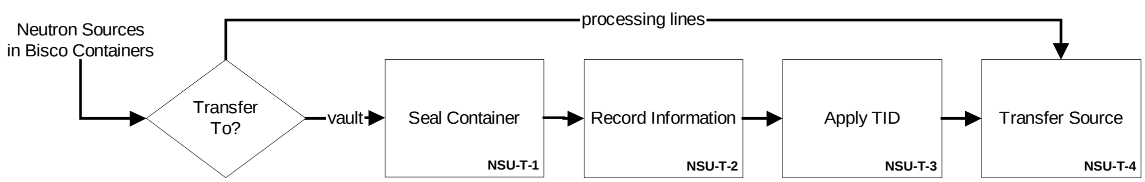

Figure 3. Neutron source transfer flowsheet.

NSU-T-1 Seal Container
If the neutron source is to be transferred to the vault, a yellow tape seal is applied to the Bisco container, and the Bisco container is then weighed.

NSU-T-2 Record Information
The gross weight, container identification number, material type, and lot identification number are recorded on the Bisco container.

NSU-T-3 Apply TID

A paper TID is placed on the marked Bisco container and the TID information is recorded on accountability documentation and on MASS.

NSU-T-4 Transfer Source

The Bisco container is placed in a transfer cart and transferred.

3. Neutron Source Unpacking Dose Calculation Information

Operational data from neutron source unpacking operations is available and can be used as a benchmark to test the results of the dose calculations. This operational information, along with the many assumptions that support the dose calculations, are described in the subsequent sections.

3.1. Operational Data

Special efforts have been made in the past several months to equip neutron source unpacking personnel with special dosimeters to measure the dose received during a particular unpacking operation. In any particular operation, from 2 – 5 persons are present. Table 1 shows the average dose received during the five operations measured in the past six months, along with the process clock time and source information. Only the total source activity and number of sources is available, so the number of 1-, 2-, and 3-Ci sources is estimated from this data. The number and strength of the sources is important for the dose calculations.

Table 1. Neutron Source Unpacking Recent Operations Data.[1]

Date	Avg. EDE (mrem)	Process Time (min)	Tot. Source Activity (Ci)	Total No. of Sources	Estimated No. of 1-Ci Sources	Estimated No. of 2-Ci Sources	Estimated No. of 3-Ci Sources
7/28/98	7.6	65	7	7	7	0	0
9/3/98*	9.8	30	14	12	10	2	0
9/15/98*	30	60	14	12	10	2	0
10/14/98	1.7	30	4	2	0	2	0
12/9/98	8	45	12	4	0	0	4

*These two operations will be combined into one in the subsequent analysis.

[1] Personal communications, J. Johnson, NMT-4, 1998.

3.2. Key Process Information Estimation

To perform any dose calculation, four essential pieces of information must be available or estimated – process time, source-to-detector distance, shielding present, and source strength. The only time information available is the total process time, the individual steps that must occur, and the number of times these steps occur based on the total number of drums and sources that must be processed. Where information is not available, the number of drums is estimated from the number of sources present by assuming that a drum is fully loaded with three sources, and a drum contains at least two sources. The source information from the four unpacking operations shown in Table 1 are used to estimate the number of drums and the number of sources in each drum, as shown in Table 2.

Table 2. Neutron Source Unpacking Drum Count.

Date	Process Time (min)	Total No. of Sources	Estimated No. of Drums	Estimated Sources per Drum
7/28/98	65	7	3	3,2,2
9/3/98	90	12	4	3,3,3,3
10/14/98	30	2	2	1
12/9/98	45	4	4	1,1,1,1
AVG:	**57.5**	**6.25**	**3.25**	

Because there are no clear trends in the process time data (e.g., based on the 9/3/98 and 10/14/98 data, it takes 30 minutes to process 12 and 2 sources, respectively, and both times 3 people were present), averages are used to estimate the total process times. The averages are also shown in Table 2. The total process time is given by

$$T = N_{drum} t_{drum} + N_{source} t_{source} \quad , \tag{1}$$

where

T	=	the total process time [min];
N_{drum}	=	the total number of drums to be processed [drums];
t_{drum}	=	the time required to process a drum [min/drum];
N_{source}	=	the total number of sources of a given source strength to be processed [sources]; and
T_{source}	=	the time required to process a source [min/source].

Inserting the average values of the data, a line for the source processing time as a function of the drum processing time can be obtained, as shown in the equation below.

$$t_{source} = 9.2 - 0.52 t_{drum} \tag{2}$$

From this equation, we estimate that the drum processing time is approximately 9 min. and the source processing time is approximately 4.5 min. With these total processing times, the individual process times can be obtained. Table 3 contains the estimated times of the individual steps from the flowsheets. Neutron Source Unpacking Preparation steps are not shown because they do not contribute to the dose. The estimated source-to-whole body detector distances and shielding present are also shown. The details of the shielding are provided in Table 4.

Table 3. Neutron Source Unpacking Dose Calculation Parameters.

Step	Name	Time (min/ drum)	Time (min/ src)	Dist. (cm)	Shielding
NSU-1	Remove TID	0.5		60	Drum Packing
NSU-2	Remove Bolt	0.5		60	Drum Packing
NSU-3	Remove Lock Ring	0.5		60	Drum Packing
NSU-4	Don Respirators	2		120	Drum Packing
NSU-5	Crack Lid Seal	0.5		60	Drum Packing
NSU-6	Remove Lid	0.25		60	Drum Packing
NSU-7	Remove Overpack	0.25		60	Drum Packing
NSU-8	Remove R2 Container	0.25		40	R2 Container
NSU-9	Secure R2 Container	2		40	R2 Container
NSU-10	Remove R2 Lid	0.5		40	R2 Container
NSU-11	Move R2 to Work Area	0.5		40	R2 Container
NSU-12	Remove Liner	0.5		40	R2 Liner
NSU-13	Open Liner	0.5		40	R2 Liner
NSU-14	Remove Plug	0.5		40	R2 Liner
NSU-15	Remove Source		0.2	40	
NSU-16	Inspect Source		0.25	40	
NSU-17	Neutron Count		1.0	60	
NSU-18	Transfer Source		0.1	40	Bisco Container
NSU-19	Neutron Count		1.0	60	Bisco Container
NSU-20	Mark Bisco Container		0.5	40	Bisco Container
NSU-T-1	Seal Container		0.25	40	Bisco Container
NSU-T-2	Record Information		1.0	60	Bisco Container
NSU-T-3	Apply TID		0.25	40	Bisco Container
	TOTAL TIME	**9.25**	**4.55**		

Table 4. Neutron Source Shielding Information.

Shielding	Water Thickness (in)	Steel Thickness (in)
Drum Packing	12	0.25
R2 Container	4	0.125
R2 Liner	4	0
Bisco Container	2	

3.3. Source Information

A typical PuBe source is assumed to contain plutonium in the chemical form of $PuBe_{13}$.[2] The original isotopic distribution of the plutonium is shown in Table 5; the original amount of Am-241 is assumed to be zero. The source activity is calculated by the following equation:

$$A[\mathrm{Ci}] = \frac{\ln(2)}{T_{1/2}[\mathrm{s}]} \frac{m[\mathrm{g}] N_A[\mathrm{atoms/mol}]}{MW[\mathrm{g/mol}]} \times 3.7\times10^{10}[\mathrm{Ci-s/decays}] \quad .$$

Table 5. Initial Source Parameters for a “1-Ci” Source.

Isotope	Weight Fraction	Mass (g)	α-decay probability	Half-Life (y)	Activity (Ci)
Pu-238	0.0005	3.20E-3	1	87.74	1.37E-1
Pu-239	0.91	1.46E+1	1	24,110	9.03E-1
Pu-240	0.085	1.36E+0	1	6,563	3.09E-1
Pu-241	0.004	6.40E-2	2.45E-5	14.35	1.62E-4
Pu-242	0.0005	1.28E-2	1	373,000	3.17E-5
Total	1	16.0			1.35

The Pu is assumed to be 20 years old. As the plutonium ages, Pu-241 beta-decays into Am-241, which increases the neutron source strength as the source ages. PuBe sources are also assumed to be integer increments of 1-Ci sources, where the activity refers to plutonium content (a 1-Ci source contains 16 g of plutonium). When the other isotopes are included as shown in Table 5, the actual source strength from all plutonium isotopes is 1.35 Ci. 2- and 3-Ci sources are obtained by doubling and tripling the plutonium mass, respectively.

[2] Palmer, M. J., “Recovery of Plutonium from Plutonium-Beryllium Neutron Sources,” Los Alamos National Laboratory, LA-11703-MS (1990).

4. Neutron Source Unpacking Dose Calculation Results

The dose calculations are performed using the spreadsheet-based LAMPSHADE tool. LAMPSHADE (the Los Alamos Model for Process-Specific High-speed Administrative Dose Estimation) is based on an earlier model, the PuDoC[3] (Plutonium Dose Calculator), which was developed at Lawrence Livermore National Laboratory (LLNL). The PuDoC provided relatively fast calculations of process doses by using simple, yet standard, approximations for neutral particle transport. The entire calculation is controlled by Excel™ macros that copy and paste data and calculated information. Originally, PuDoC was written in Excel™ 4.0. LAMPSHADE uses similar spreadsheets but has since been updated to version 5.0, and the macros have been rewritten in Microsoft Visual Basic for Applications. Additional source term data has also been added to LAMPSHADE. Detailed descriptions of the calculation strategies are provided in an associated document.[4]

A set of sample results from the calculation for a 1-Ci neutron source is shown in Table 6. The neutron dose calculation uses ANSI/ANS fluence-to-dose factors[5] to convert neutron fluxes to doses. These factors take into account the thermalization provided by hydrogenous materials by using a 0.15 cm^{-1} macroscopic cross section for fast neutron removal.[6] Neutrons from fission and (α,n) reactions are assumed to be born at 2 and 5 MeV, respectively.

Table 7 provides the results of the dose calculations for all three source types and for three process operations – dealing with a source in a drum, dealing directly with a source, and the background created by sources in the container. The background numbers account for the dose received from other neutron sources in a container while working on a source that has just been removed from a container. The dose numbers in Table 7 include photon doses. In general, photon doses are around 1% of the total dose.

The total dose is obtained from the following equation:

$$D = \sum_{i=1}^{3} \left[N_{source} \left(D_d + D_s \right) \right]_{i-Ci} + D_{bkg-tot}$$

where

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[3] Armantrout, G., L. Collins, T. Edmunds, and I. H. Zimmerman, "Plutonium Dose Calculator (PuDoc)," Lawrence Livermore National Laboratory, U. S. Department of Energy Weapons Complex Reconfiguration Program (UCNI) (1994).

[4] "Analysis of Dose Equivalent Received During PF-4 Recovery Operations for Determination of the New Plutonium Discard Limits," Los Alamos National Laboratory, LA-CP-96-267 (UCNI) (1996).

[5] "American National Standard for Neutron and Gamma-Ray Fluence-to-Dose Factors," ANSI/ANS-6.1.1-1991, American Nuclear Society, 1991.

[6] Kornreich, D. E. and D. E. Dooley, "Pandemonium: Bringing Order to Dose Calculations in Complicated Geometries," Los Alamos National Laboratory (DRAFT), 1999.

D = the total process dose [mrem];
D_d = the EDE from a source in a drum [mrem/source];
D_s = the EDE from an unshielded source [mrem/source]; and
$D_{bkg\text{-}tot}$ = the total EDE from shielded sources while processing an unshielded sources [mrem/source].

Table 6. Sample Results for a 1-Ci Neutron Source.

Process Name	Process Time (min)	Neutron Dose Rate (mrem/hr)	Neutron EDE (mrem)
Remove TID	0.5	0.191	0.0016
Remove Bolt	0.5	0.191	0.0016
Remove Lock Ring	0.5	0.191	0.0016
Don Respirators	2	0.0492	0.0016
Crack Lid Seal	0.5	0.191	0.0016
Remove Lid	0.25	0.191	0.00080
Remove Overpack	0.25	0.191	0.00080
Remove R2 Container	0.25	0.415	0.0017
Secure R2 Container	2	5.58	0.19
Remove R2 Lid	0.5	5.58	0.047
Move R2 to Work Area	0.5	5.58	0.047
Remove Liner	0.5	5.58	0.047
Open Liner	0.5	5.58	0.047
Remove Plug	0.5	5.58	0.047
Total EDE –Drum Ops.			**0.43**
Remove Source	0.2	12.0	0.040
Inspect Source	0.25	12.0	0.050
Neutron Count	1.0	5.52	0.092
Transfer Source	0.1	8.63	0.014
Neutron Count	1.0	3.96	0.066
Mark Bisco Container	0.5	8.63	0.072
Seal Container	0.25	8.63	0.036
Record Information	1.0	3.96	0.066
Apply TID	0.25	8.63	0.036
Total EDE –Source Ops.			**0.47**

Table 7. Neutron Source Unpacking Dose Calculation Results.

Total EDE (mrem/source)	1-Ci Source	2-Ci Source	3-Ci Source
Drum (D_d)	0.434	0.869	1.31
Source (D_s)	0.515	0.994	1.48
Background (D_{bkg})	0.435	0.864	1.30

The background dose is obtained by multiplying the dose from the step "Remove Plug" by the source operations total time (4.55 min). This accounts for the dose received from sources waiting to be processed while another source is processed. The number of times a worker receives this background dose is listed in Table 8. These numbers are estimated by counting the number of times the unpacking process occurs and what sources remain in the container. For example, on 9/3/98, 12 sources were processed. Presumably, three drums contained three 1-Ci sources, and one drum contained two 2-Ci sources and one 1-Ci source. The processing order that produces the number of background sources shown in Table 8 is shown below.

A. Drum 1: 3 1-Ci sources; process first source in presence of 2 background 1-Ci sources, then process second source in presence of 1 background 1-Ci source;

B. Drum 2: 3 1-Ci sources; process first source in presence of 2 background 1-Ci sources, then process second source in presence of 1 background 1-Ci source;

C. Drum 3: 3 1-Ci sources; process first source in presence of 2 background 1-Ci sources, then process second source in presence of 1 background 1-Ci source;

D. Drum 4: 2 2-Ci sources, 1 1-Ci source; process first 2-Ci source in presence of 1 background 2-Ci source and 1 background 1-Ci source, then process second 2-Ci source in presence of 1 background 1-Ci source.

Table 8. Data for Background Calculations.

Date	Total No. of Sources	No. of Bkg. 1-Ci Sources	No. of Bkg. 2-Ci Sources	No. of Bkg. 3-Ci Sources
7/28/98	7	5	0	0
9/3/98	12	11	1	0
10/14/98	2	0	1	0
12/9/98	4	0	0	2

To add formality to the equation for the total dose, the background dose is given by

$$D_{bkg-tot} = \sum_{i=1}^{3} \left[N_{bkg-source} D_{bkg} \right]_{i-Ci}$$

where

$N_{bkg\text{-}source}$	=	the number of background sources of a given source strength [mrem/source]; and
D_{bkg}	=	the EDE from a shielded source while processing an unshielded source [mrem/source].

The results of the calculations and their comparison to the measured doses are provided in Table 9 and graphically in Figure 4. All calculated results are larger than the measured results; however, the results appear to be good given the nature of the raw data.

Table 9. Comparison of Process Readings and Calculations.

Date	Process Avg. Dose (mrem)	Calculated Avg. Dose (mrem)	% Relative Error
7/28/98	7.6	8.8	16
9/3/98	17.9	18.9	6
10/14/98	1.73	4.6	166
12/9/98	8.0	14	75

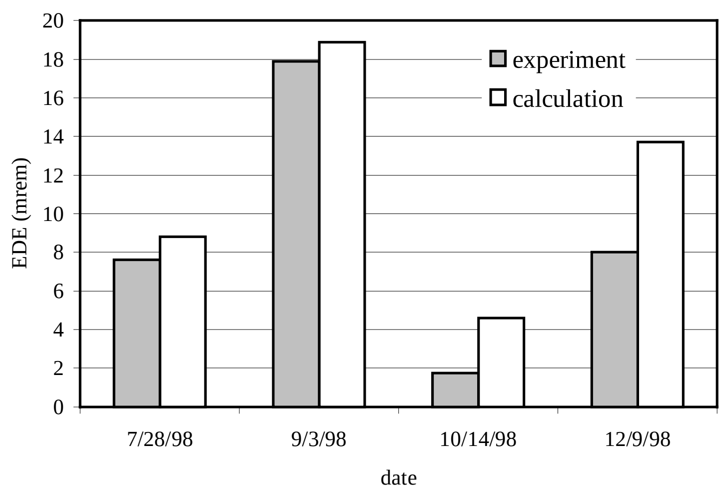

Figure 4. Graphical representation of process readings and calculation results.

5. Summary

Simple yet effective tools were used to estimate the average dose received by workers during the unpacking operations for PuBe neutron sources. The analysis required several assumptions based on the limitations of the source data.

For predictive uses, this work is applicable to 1-, 2-, and 3-Ci neutron sources for which the primary plutonium isotope is Pu-239. To estimate the dose in a given process, the analyst must determine the number and strength of the neutron sources to be processed. From this data, the analyst must determine the number and strength of the background sources as discussed in Section 4. Given this information, the average dose received by a worker during a given unpacking operation is estimated by

$$D = \sum_{i=1}^{3} \left[N_{source} \left(D_d + D_s \right) + N_{bkg-source} D_{bkg} \right]_{i-Ci} \quad .$$

Table 10 is provided below to facilitate this calculation of process dose based on the number and types of sources present by referring to process dose values and the source analyses performed in this document.

Table 10. Data Location Table.

Quantity	Data Found in:
D_d	Table 7
D_s	Table 7
D_{bkg}	Table 7
N_{source}	Table 1
$N_{bkg\text{-}source}$	Table 8