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1972 INTERCOMPARISON OF NUCLEAR ACCIDENT DOSIMETRY SYSTEMS AT THE OAK RIDGE NATIONAL LABORATORY

J. W. Poston
F. F. Haywood

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HEALTH PHYSICS DIVISION

1972 INTERCOMPARISON OF NUCLEAR ACCIDENT DOSIMETRY SYSTEMS AT THE OAK RIDGE NATIONAL LABORATORY

J. W. Poston and F. F. Haywood

JULY 1972

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
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1972 INTERCOMPARISON OF NUCLEAR ACCIDENT DOSIMETRY SYSTEMS AT THE OAK RIDGE NATIONAL LABORATORY*

J. W. Poston and F. F. Haywood

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Abstract

The ninth in the continuing series of intercomparison studies of accident monitoring systems was held from July 17-28, 1972. The ORNL Health Physics Research Reactor, operated in the pulse mode, served as the fission source. Three different spectra were used to simulate nuclear accidents. Detectors used as area monitors as well as personnel monitoring badges were intercompared under a set of standard conditions. Results of the experiment indicated that reported values of fast neutron dose were within ±30 percent for all pulses, while gamma-ray measurements were within ±26 percent at one standard deviation.

The ninth in the series of intercomparisons of nuclear accident dosimetry systems was conducted at the Oak Ridge National Laboratory's DOSAR Facility during the period July 17-28, 1972. Studies of this

*Research sponsored by the U. S. Atomic Energy Commission, under contract with Union Carbide Corporation.

type are conducted annually, and are generally comprised of participants from laboratories in the United States as well as several foreign countries. This series of experiments, which began in 1964, was established for the following reasons: (1) wide interest at ORNL in the field of dosimetry for human exposures (2) a lack of adequate dose determinations for persons exposed during criticality accidents, (3) the necessity for developing guidelines in instrumentation and procedures, and (4) the need for standardized radiation fields whose characteristics, such as energy spectrum, intensity, and uniformity, had been determined using widely accepted instruments and techniques (such radiation fields to be used to simulate nuclear accidents).

Laboratories represented at this study were: (1) Pacific Northwest Laboratories, (2) Goodyear Atomic, (3) Los Alamos Scientific Laboratory, (4) U. S. Naval Ordnance Laboratory, (5) Oak Ridge Gaseous Diffusion Plant, (6) Savannah River Laboratory, (7) Union Carbide Corporation (Y-12 Plant), and (8) Oak Ridge National Laboratory. In addition, R. S. Landauer, Jr. and Company and Radiation Detection Company participated by mail. The Babcock and Wilcox Company and the Institute of Atomic Energy in Sao Paulo, Brazil sent observers. A complete list of the participants is given in Appendix A.

The ORNL Health Physics Research Reactor (HPRR), operated in the pulse mode, was used to provide the radiation fields for these experiments. In this intercomparison there were four pulses planned, three of which provided radiation fields of differing neutron spectrum and neutron-to-gamma ratio. In addition, two phantoms were provided for each exposure. One phantom was oriented "facing" the reactor,

while the other had a "sideways" orientation. Table 1 summarizes the experimental conditions for the four pulses. In addition, the schedule for the entire study is given in Appendix B. A view of the experimental setup for pulses 1-3 are given in Figures 1, 2, and 3, respectively. Pulse 4 was essentially identical to pulse 1 and therefore is not included.

Final results for the intercomparison are presented in tabular form. Tables 2-5 present the results of measurements in air at three meters from the HPRR. Personnel monitoring data for the phantom studies are given in Tables 6-8. These data are summarized in Tables 9 and 10. A brief description of the nomenclature employed in the last two columns of Tables 2-8 will be given below. In addition, more detailed information on the individual systems as well as additional results are given in the appendices.

Neutron Dose

(1) TDU - Neutron Energy Threshold Detector Unit - Contains foils of fissionable material (0.4-5 grams) generally Pu, Np, and U, and activation foils consisting of Au and S. Frequently used in this system are two ^{235}U foils of differing enrichment. These foils, which are enclosed in a boron (enriched in ^{10}B) shield, have cross sections with thresholds at different energy levels. Fission product gamma rays are analyzed using gamma scintillation detectors, thus allowing one to compute the incident neutron fluence between these energy levels.

(2) ACT - Activation of Foils - Various foils, such as copper, indium, nickel, gold, sulfur, zirconium, etc., are exposed in the

neutron field. Threshold and resonance reactions yield data which are related to dose through assumptions about the incident spectrum and weighted dose per neutron ($\frac{rad}{n/cm^2}$) factors. Included in this category are special techniques developed by the different laboratories and badge systems.

(3) TSEE + ACT - Thermally Stimulated Exo-electron Emission and Activation of Foils - use of proton radiators and BeO ceramic disks to give fast neutron dose. The activation of a sulfur pellet is included to provide fast neutron dose information above 2.5 MeV.

Gamma Exposure

(1) RPL - Radiophotoluminescent Glass Dosimeter - This includes all types and sizes of glasses.

(2) Film - Standard gamma-ray film dosimetry techniques.

(3) TLD - Thermoluminescent Dosimeter - All TLD materials are included in this category.

(4) TSEE - Thermally Stimulated Exo-electron Emission

The results of this intercomparison are not grouped as closely as in previous intercomparisons (for example see reference 1). An analysis of the results for the measurement of fast neutron dose at the three meter station for pulses 1 through 3 shows that the results of Landauer are significantly different than those reported by other participants. The counting system used to evaluate the foils was not calibrated adequately (see Appendix H). If one excludes these results plus the results of the Naval Ordnancee Laboratory and the DOSAR experimental dosimeter from pulse number three there is a significant change in the average fast neutron dose and the standard deviation.

For example, the fast neutron dose for pulses 1 through 3 becomes 248±22, 42.9±8.2, and 108±9.7 rad, respectively.

During this experiment, as in others in the past, a large amount of data was accumulated which did not fit logically into the standard tabular format. Therefore, in addition to a description of their dosimetry systems, the data reported by each laboratory is quoted in the appendices essentially as reported to the authors.

ACKNOWLEDGMENTS

The success of each Intercomparison is the result of the cooperative attitude of the participants and the staff of the DOSAR Facility. The authors express their sincere appreciation to both these groups. Special acknowledgment is made of the contributions of L. J. Brown, W. F. Fox, J. E. Jackson, E. M. Robinson, W. H. Shinpaugh, and D. R. Ward.

TABLE 1. SUMMARY OF INTERCOMPARISON EXPOSURE CONDITIONS

Date	Time (E.D.T.)	Neutron Yield (Fissions)	Primary Shield	Dosimetry Station (meters)	Phantom Shield	Phantom Distance (meters)
7-19-72	0647	6.3×10^{16}	None	3.0	None	3.0
7-20-72	1014	4.8×10^{16}	Lucite	3.0	Lucite	3.0
7-25-72	1029	6.8×10^{16}	Steel	3.0	Steel	3.0
7-26-72	1034	6.2×10^{16}	None	3.0	None	3.0

Table 2. ORNL Ninth Intercomparison of Nuclear Accident Dosimetry Systems

July 17–28, 1972
Pulse No. 1: reactor unshielded
Yield: 6.3×10^{16} fissions

Study group	Neutron dose (rad)	Gamma dose (rad)	D_n/D_γ	Neutron fluence $\times 10^{-10}$ (n/cm^2)							n detector system	γ detector system
				Thermal	Pu, >1 keV	Np, >0.75 MeV	U, >1.5 MeV	S, >2.5 MeV	Cu	In		
BNWL	222	32/32	6.9	0.42/0.27				1.6	5.0	5.9	Act.	TLD
Goodyear Atomic	272/253	–	–	–	10.9	8.4	3.5/3.6	2.0			TDU/U-foil	–
LASL				See phantom results							–	–
NOL	213	39.2	5.4								Act.	TLD
ORGDP	253	–	–	0.55	10.7	7.96	3.4	1.4		0.06	TDU	–
SRL	248	45	5.5	1.25	12			1.55	5.2	3.7	Act.	TLD ribbon
UCND	216	44	4.9	0.87	8.9	5.8	2.8	2.0			TDU	Film – RPL
ORNL – AHPS	257	43	6.0	0.47	10.7	7.4	3.45	1.86			TDU	Film
ORNL – DOSAR I	256	35	7.3	0.46	10.4	7.5	3.5	1.9			TDU	RPL
ORNL – DOSAR II	250	36.3	6.9								TSEE + Act.	TSEE
R. S. Landauer	65.8	15.6	4.2								Act.	RPL
Radiation Detection	283	39/38	7.3	1.3				1.8			Act.	Film – TLD

Table 3. ORNL Ninth Intercomparison of Nuclear Accident Dosimetry Systems

July 17–28, 1972
Pulse No. 2: reactor shielded by 12-cm hydrogenous shield
Yield: 4.8×10^{16} fissions

Study group	Neutron dose (rad)	Gamma dose (rad)	D_n/D_γ	Neutron fluence $\times 10^{-10}$ (n/cm^2)							n detector system	γ detector system
				Thermal	Pu, >1 keV	Np, >0.75 MeV	U, >1.5 MeV	S, >2.5 MeV	Cu	In		
BNWL		32/27		0.82/1.3				0.28	2.7	0.67	Act.	TLD
Goodyear Atomic	40/48	–	–	0.83	1.37	0.78	0.55/0.70	0.37/0.40			TDU/U-foil	–
LASL				See phantom results							–	–
NOL	38	25.3	1.5								Act.	TLD
ORGDP	40	–	–	1.39	1.25	0.83	0.52	0.2		0.6	TDU	–
SRL	52	46	–		4.9			0.31	2.1	2.1	Act.	TLD ribbon
UCND	34	34	1.0	1.2	1.3	0.73	0.42	0.28			TDU	Film – RPL
ORNL – AHPS	–	30		1.8				0.4			Personnel badge	Personnel badge
ORNL – DOSAR I	34	34	1.0	1.3	1.3	0.9	0.56	0.3			TDU	RPL
ORNL – DOSAR II	42.4	31.8	1.3								TSEE + Act.	TSEE
R. S. Landauer	19.3	–	–								Act.	RPL
Radiation Detection	58	34/36	1.7	1.6				0.37			Act.	Film – TLD

Table 4. ORNL Ninth Intercomparison of Nuclear Accident Dosimetry Systems

July 17–28, 1972
Pulse No. 3: reactor shielded by 13-cm steel shield
Yield: 6.8×10^{16} fissions

Study group	Neutron dose (rad)	Gamma dose (rad)	D_n/D_γ	Neutron fluence $\times 10^{-10}$ (n/cm^2)							n detector system	γ detector system
				Thermal	Pu, >1 keV	Np, >0.75 MeV	U, >1.5 MeV	S, >2.5 MeV	Cu	In		
BNWL	102	11/10		0.29/0.47				0.32	3.8	1.8	Act.	TLD
Goodyear Atomic	112/112			0.17			0.83/1.4	0.33/0.33			TDU/U-foil	–
LASL		15.5/13.8				See phantom results					–	TLD
NOL	33.6	21	1.6								Act.	TLD
ORGDP	120			0.41	5.3	2.8	0.82	0.3		1.0	TDU	–
SRL	91	13	7.0	0.57	5.6			0.28	3.5	1.2	Act.	TLD ribbon
UCND	103	14	7.4	0.48	5.12	2.45	0.8	0.33			TDU	Film – RPL
ORNL – AHPS	–	16		0.49				0.38			Badge	Badge
ORNL – DOSAR I	114	11	10.4	0.26	5.6	2.9	0.8	0.3			TDU	RPL
ORNL – DOSAR II	74.2	13	5.7								TSEE + Act.	TSEE
R. S. Landauer	63.4	8.0	7.9								Act.	RPL
Radiation Detection	–	–									Act.	Film – TLD

Table 5. ORNL Ninth Intercomparison of Nuclear Accident Dosimetry Systems

July 17–28, 1972
Pulse No. 4: reactor unshielded
Yield: 6.2×10^{16} fissions

Study group	Neutron dose (rad)	Gamma dose (rad)	D_n/D_γ	Neutron fluence $\times 10^{-10}$ (n/cm^2)							n detector system	γ detector system
				Thermal	Pu, >1 keV	Np, >0.75 MeV	U, >1.5 MeV	S, >2.5 MeV	Cu	In		
BNWL	210	35	6.0	0.36/0.58				1.9	4.1	6.0	Act.	TLD
Goodyear Atomic	–	–									–	–
LASL				See phantom results							–	–
NOL	215.5	37.3	5.8								Act.	TLD
ORGDP	–	–									–	–
SRL	–	–									–	–
UCND	–	–									–	–
ORNL – APHS	–	–									–	–
ORNL – DOSAR I	254	–		0.5	10.4	7.4	3.5	2.0			TDU	–
ORNL – DOSAR II	263	40.2	6.5								TSEE + Act.	TSEE
R. S. Landauer											–	–
Radiation Detection	325	35/43	9.3/7.6	0.56				2.1			Act.	Film – TLD

Table 6. ORNL Ninth Intercomparison of Nuclear Accident Dosimetry Systems: phantom studies

July 17–28, 1972
Pulse No. 1: reactor unshielded
Phantom facing reactor

Study group	Neutron dose (rad)	Gamma dose (rad)	^{24}Na		Basis for estimating neutron dose	Basis for estimating gamma dose
			μCi/ml	μCi/mg		
BNWL	252	87/58	–	–	Activation	Multipurpose/Basic dosimeter
Goodyear Atomic		Did not participate in this phase				
LASL	258	83	–	–	Albedo TLD	TLD
NOL	232	89	–	–	Activation	TLD
ORGDP	232	–	1×10^{-3}	–	^{24}Na activity	–
SRL	211	68	0.904×10^{-3}	–	Activation (CND)	TLD Personnel Badge
UCND	277	56	1.01×10^{-3}	0.63×10^{-3}	TDU + ^{24}Na activity	Film
ORNL – AHPS	239	65	0.96×10^{-3}	0.6×10^{-3}	^{24}Na activity	Film
ORNL – DOSAR I	245	73	0.6×10^{-3}	0.4×10^{-3}	^{24}Na activity	RPL
ORNL – DOSAR II		Did not participate in this phase				
R. S. Landauer		Did not participate in this phase				
Radiation Detection		Did not participate in this phase				

Table 7. ORNL Ninth Intercomparison of Nuclear Accident Dosimetry Systems: phantom studies

July 17–28, 1972
Pulse No. 2: reactor shielded by 12-cm hydrogenous shield
Phantom facing reactor

Study group	Neutron dose (rad)	Gamma dose (rad)	^{24}Na		Basis for estimating neutron dose	Basis for estimating gamma dose
			μCi/ml	μCi/mg		
BNWL	35	54/45			Activation	Multipurpose/Basic dosimeter
Goodyear Atomic		Did not participate in this phase				
LASL	40	56	–	–	Albedo TLD	TLD
NOL	38	60	–	–	Activation	TLD
ORGDP	44	–	1.98×10^{-4}	–	^{24}Na activity	–
SRL	45	46	1.82×10^{-4}	–	Activation (CND)	TLD personnel badge
UCND	35	36	1.32×10^{-4}	0.83×10^{-4}	TDU + ^{24}Na activity	Film
ORNL – AHPS	44	44	1.76×10^{-4}	1.10×10^{-4}	^{24}Na activity	Film
ORNL – DOSAR I	46	52	1.15×10^{-4}	0.7×10^{-4}	^{24}Na activity	RPL
ORNL – DOSAR II		Did not participate in this phase				
R. S. Landauer		Did not participate in this phase				
Radiation Detection		Did not participate in this phase				

Table 8. ORNL Ninth Intercomparison of Nuclear Accident Dosimetry Systems: phantom studies

July 17–28, 1972
Pulse No. 3: reactor shielded by a 13-cm steel shield
Phantom facing reactor

Study group	Neutron dose (rad)	Gamma dose (rad)	^{24}Na		Basis for estimating neutron dose	Basis for estimating gamma dose
			μCi/ml	μCi/mg		
BNWL	131	33/23			Activation	Multipurpose/Basic dosimeter
Goodyear Atomic		Did not participate in this phase				
LASL	130	41			Albedo TLD	TLD
NOL	38.5	39.6			Activation	TLD
ORGDP	135	–	6.14×10^{-4}	–	^{24}Na activity	–
SRL	90	34	6.26×10^{-4}	–	Activation (CND)	TLD personnel badge
UCND	145	30	6.08×10^{-4}	3.8×10^{-4}	TDU + ^{24}Na activity	Film
ORNL – AHPS	129	35	5.0×10^{-4}	3.2×10^{-4}	^{24}Na activity	Film
ORNL – DOSAR I	139	25	3.5×10^{-4}	2.2×10^{-4}	^{24}Na activity	RPL
ORNL – DOSAR II		Did not participate in this phase				
R. S. Landauer		Did not participate in this phase				
Radiation Detection		Did not participate in this phase				

TABLE 9. SUMMARY OF RESULTS STATIONS IN AIR AT 3 METERS

Pulse Number	Neutron Dose (rad)	Gamma Dose (rad)	n/γ
1	232 ± 56.6*	36.3 ± 8.2	6.0 ± 1.1
2	40.6 ± 10.7	33.0 ± 5.7	1.3 ± 0.3
3	92.5 ± 27.6	13.3 ± 3.5	6.7 ± 2.9
4	253 ± 45.8	36.1 ± 6.9	7.0 ± 1.4

*one standard deviation

TABLE 10. SUMMARY OF RESULTS

PHANTOM STUDIES
PHANTOM FACING HPRR ONLY

Pulse Number	Neutron Dose (rad)	Gamma Dose (rad)	^{24}Na Activity ($\mu Ci/ml$)
1	243 ± 19.8*	64.3 ± 19.3	$0.89 \pm 0.17 \times 10^{-3}$
2	39.6 ± 7.0	49.1 ± 7.8	$1.61 \pm 0.35 \times 10^{-4}$
3	117 ± 35.8	32.6 ± 6.4	$5.4 \pm 1.2 \times 10^{-4}$

*one standard deviation

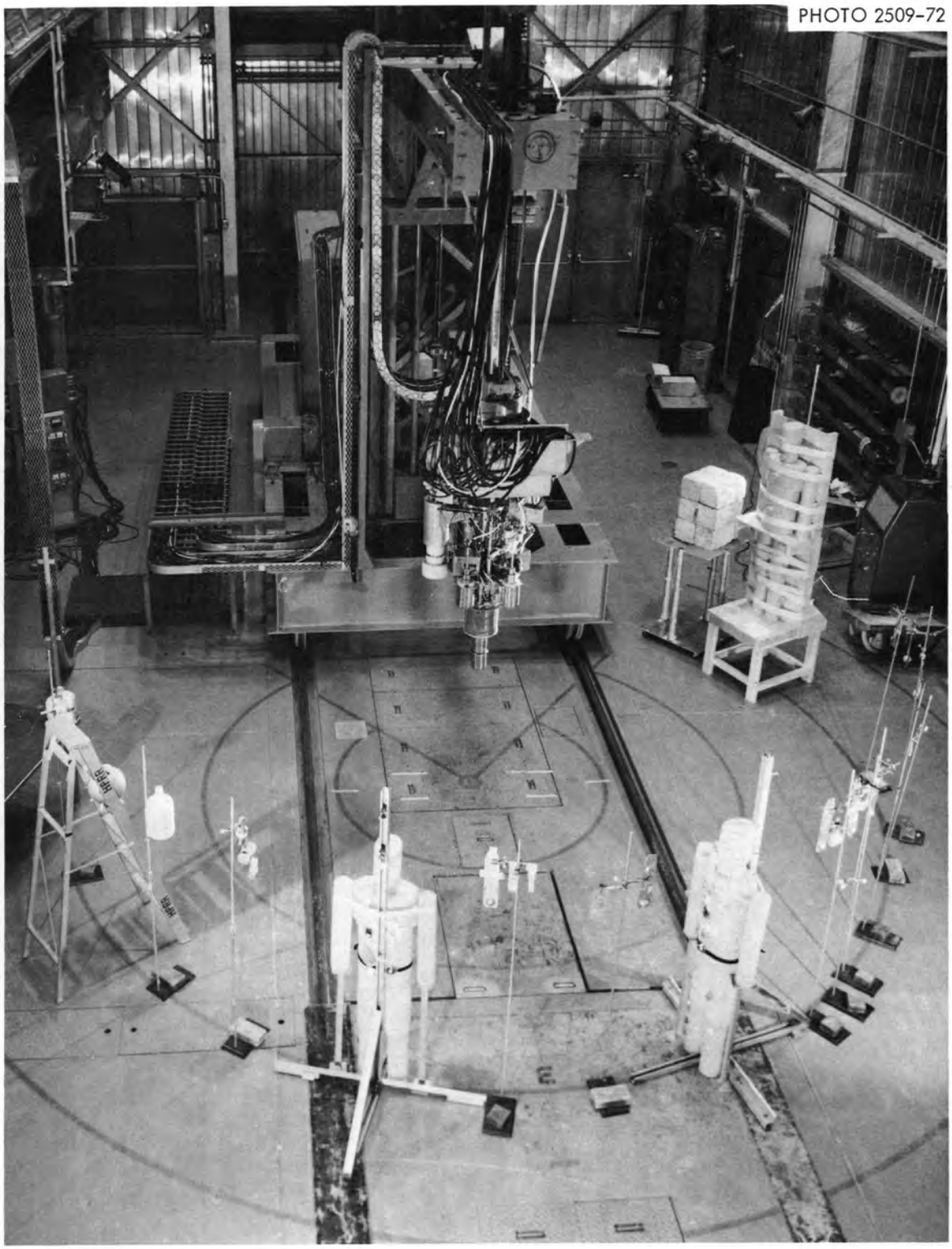

Figure 1. Experimental Arrangement for Pulse No. 1

Figure 2. Experimental Arrangement for Pulse No. 2

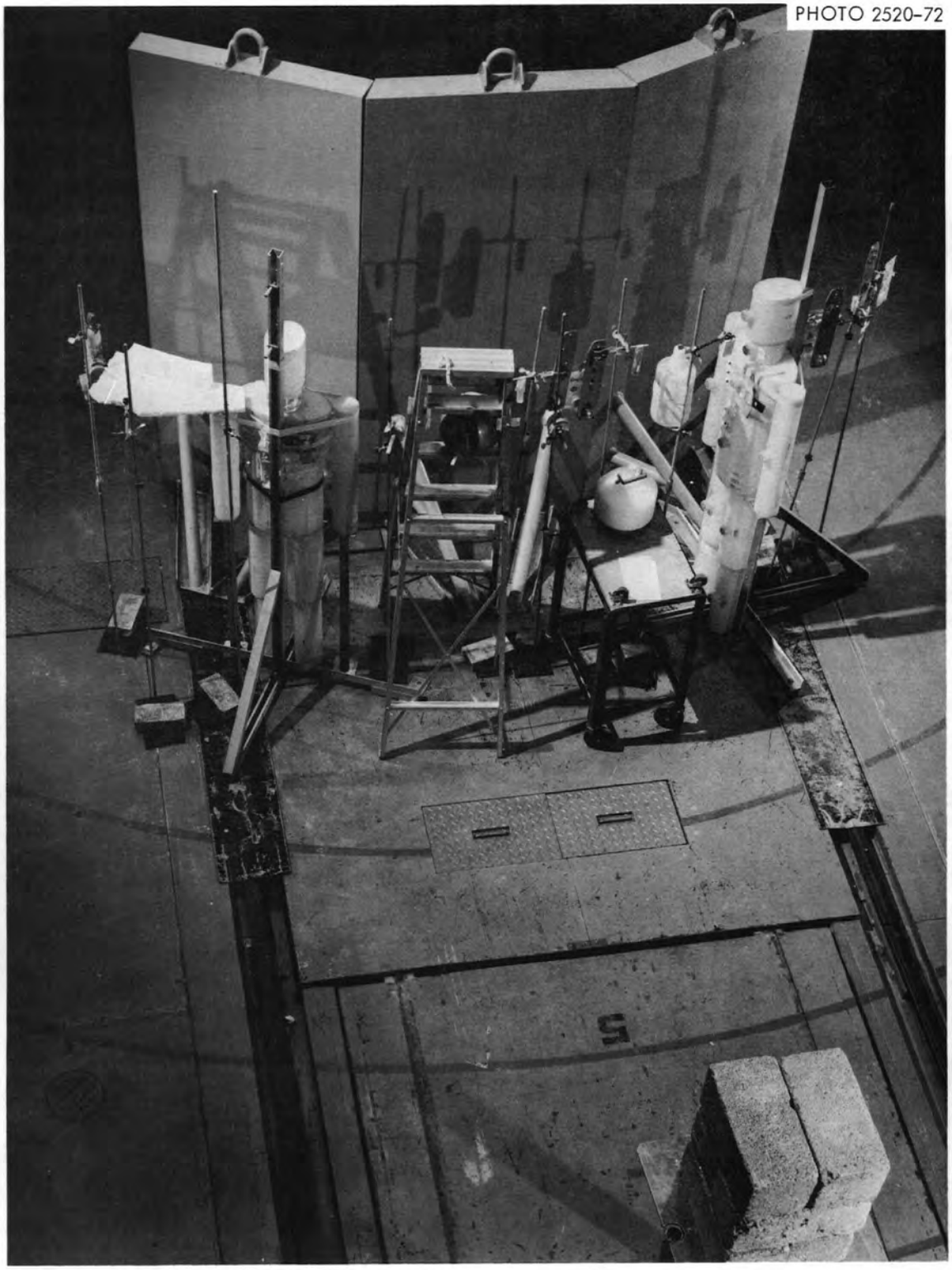

Figure 3. Experimental Arrangement for Pulse No. 3

APPENDIX A

LIST OF PARTICIPANTS

NINTH ORNL NUCLEAR ACCIDENT DOSIMETRY INTERCOMPARISON

July 17-28, 1972

Name	Affiliation
W. E. Thomas (observer)	BABCOCK & WILCOX COMPANY Naval Nuclear Fuel Division P. O. Box 785 Lynchburg, Virginia 24505
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APPENDIX B

NINTH ORNL NUCLEAR ACCIDENT DOSIMETRY INTERCOMPARISON

July 17-28, 1972

Date	Activity
July 17	Arrival, Orientation, Assignment of Work Space.
	Unpacking and checkout of instrumentation and equipment.
July 18	Initial Setup for Pulse No. 1
	Informal lectures and discussions by participants about their types of dosimetry systems and the extent of their use. Review of previous intercomparisons.
	Final Setup of Dosimetry Systems (Afternoon).
July 19	Pulse No. 1* - Unmoderated, about 7:00 AM.
	Collect samples, analyze and reduce data (arrangements will be made for use of facilities after normal hours where needed).
	Initial Setup for Pulse No. 2.
July 20	Final Setup of Dosimetry Systems for Pulse No. 2.
	Pulse No. 2 - Neutrons Moderated by 12 cm Thick Hydrogeneous Shield Between HPRR and Detectors, about 10:00 AM.
	Collect samples, analyze and reduce data.
July 21	Data reduction, counting of long-lived radioactive samples, and summarization.
	Packing of equipment to be returned to participants.
	Preliminary Critique of First Week's Results, about 11:00 AM.
	DOSAR BARBECUE - 7:00 PM - Clark Center Park.
July 24	Lectures and Laboratory Demonstrations by Members of the DOSAR Staff. Topics to be announced.

	Informal Discussions with Staff.
	Initial Setup for Pulse No. 3.
July 25	Final Setup of Dosimetry Systems for Pulse No. 3.
	Pulse No. 3 - Neutrons Moderated by 13 cm Thick Steel Shield Between HPRR and Detectors, about 10:00 AM.
	Collect samples, analyze and reduce data.
	Initial Setup for Pulse No. 4, if required.
July 26	Data Reduction, Follow Up Counting of Long-Lived Radioactive Samples, and Summarization.
	Final Setup for Pulse No. 4.
	Pulse No. 4 - Unmoderated, about 10:00 AM.
	Collect samples, analyze and reduce data.
July 27	Data Analysis, Counting of Long-Lived Activities, Informal Discussions.
	Data Analysis.
	Packing of Equipment to be Returned to Participating Organizations.
July 28	Final Critique for Intercomparison Study.
	Packing of Equipment to be Returned to Participating Organizations.

APPENDIX C

BATTELLE NORTHWEST LABORATORIES

REPRESENTATIVE: W. P. WALSH

TLD PERSONNEL DOSIMETERS

The "multipurpose" thermoluminescent, (TLD), is designed to measure the radiation dose resulting from non-penetrating radiation, penetrating radiation, neutrons of energies below cadmium cut off, and neutrons of energies above cadmium cut off. An exploded view of the dosimeter is illustrated in Figure C-1 and the physical characteristics of the filter system is presented in Table C-1.

The "basic" TLD has only one chip of ^{7}LiF in a plastic card. The location of this chip in the card is the same as location #1 in the "multipurpose" TLD, (Figure C-1). The card is placed behind a security credential and both are placed in a thin plastic holder that is normally worn clipped to the shirt pocket.

The doses as measured with these dosimeters are listed in Tables C-2 and C-3.

ACTIVANT MATERIAL CRITICALITY DOSIMETER

These dosimeters are marketed by Reactor Experiments Inc. A simplified diagram of the dosimeter is attached as Figure C-2. The doses and other pertinent information are listed in Tables C-4 through C-7.

The foils, except for the sulfur, were counted with a GeLi detector with an energy response described by:

$$\frac{\text{Counts}}{\text{Gamma}} = 32.2\ E_{\gamma}^{-1.073}$$

where E_γ is the energy of the gamma ray of interest in units of keV. This relationship is valid for gamma rays from approximately 60 keV to about 2.7 MeV but only for the particular foil to detector geometry used.

The fluence, neutrons/cm , was calculated by:

$$\phi = \frac{\frac{1}{\text{counts}/\gamma} \times \frac{1}{\gamma/\text{dis.}} \times \frac{1}{\lambda} \quad \frac{\text{counts}}{\text{unit time-unit mass}} \quad e^{\lambda t}}{(6.023 \times 10^{23}) \times 1/A \times 1/f_D \times 1/f_{sa} \times C}$$

Where:

$\frac{\text{count}}{\gamma}$ = detector efficiency

$\frac{\gamma}{\text{dis}}$ = gamma rays per radioisotope disintegration

$1/\lambda$ = $\frac{T_{1/2}}{.693}$ inverse radioactive decay constant

counts = events in the photopeak of interest

t = time between neutron exposure and gamma counting

σ = microscopic cross section in cm^2.

A = atomic number of the parent isotope.

f_D = neutron flux depression due to cadmium cover if applicable.

f_{sa} = neutron flux depression and the self absorption of the gamma rays of interest by the foil itself.

C = backscatter coefficient for neutrons scattered by material adjacent to the activant material.

The numerical values used for these parameters are listed in Table C-8. The radiation dose measured with these activants is calculated by:

$$\text{Dose} = \left[0.22\phi_{th} + .004\phi_{epi} + 1.39\ \phi'_{Cu} - 2.2\phi_{epi} + 2.87\ \phi'_{In} - 1.7\phi_s + 3.84\phi_s\right] \times 10^{-9}$$

Where:

ϕ_{th} is measured using the difference in activation of bare and cadmium covered indium or gold. If indium is used the radiation from the 54 minute half-life of ^{116}In is utilized.

ϕ_{epi} is measured using the activation of cadmium covered indium or gold. Again the ^{116}In nuclide is utilized.

ϕ'_{Cu} is measured using the activation of cadmium covered ^{63}Cu nuclide.

ϕ'_{In} is measured using the radiation from the 4.5 hour half-life ^{115m}In nuclide.

ϕ_s is measured using the radiation from the ^{32}P nuclide. The calibration of the scintillation detector is based on DOSAR's value for the fluence above 2.9 MeV.

QUICK SORT DEVICES

Items exposed for quick sort purposes were quarters, dimes, nickles, pennies, personnel dosimeter holders, and personnel dosimeter pocket clips. Some of the data from these are presented in Tables C-6 through C-12.

The data in Tables C-9, C-10, and C-11 were obtained by F. M. Tomnovec of the U. S. Naval Ordnance Laboratory at Silver Springs, MD. An explanation of the symbols and abbreviations used in Tables C-12 through C-15 are listed here for the reader's convenience.

JN = Dosimeter supplied to a private corporation by the U. S. Testing Company.

PCD = Pocket Criticality Dosimeter manufactured by Reactor Experiments Inc. and illustrated in Figure C-2.

Location A = Front of Phantom A in the region of the chest.

Location B = Front of Phantom B in the region of the chest. This location oriented the dosimeters and other items sideways to the reactor.

Location C = Rear of Phantom A in the region of the chest.

Location G = Dosimeters and other items hung in air at a distance of 3 meters and oriented facing the reactor.

Location F = Dosimeters and other items were attached to the front of a polyethylene sphere that represented an infinite reflector.

Location H = Dosimeters and other items were attached to the front of high density concrete blocks that represented an infinite reflector.

REFERENCES

(1) Hanford Criticality Dosimeter; P. E. Bramson, HW71710, January 1962.

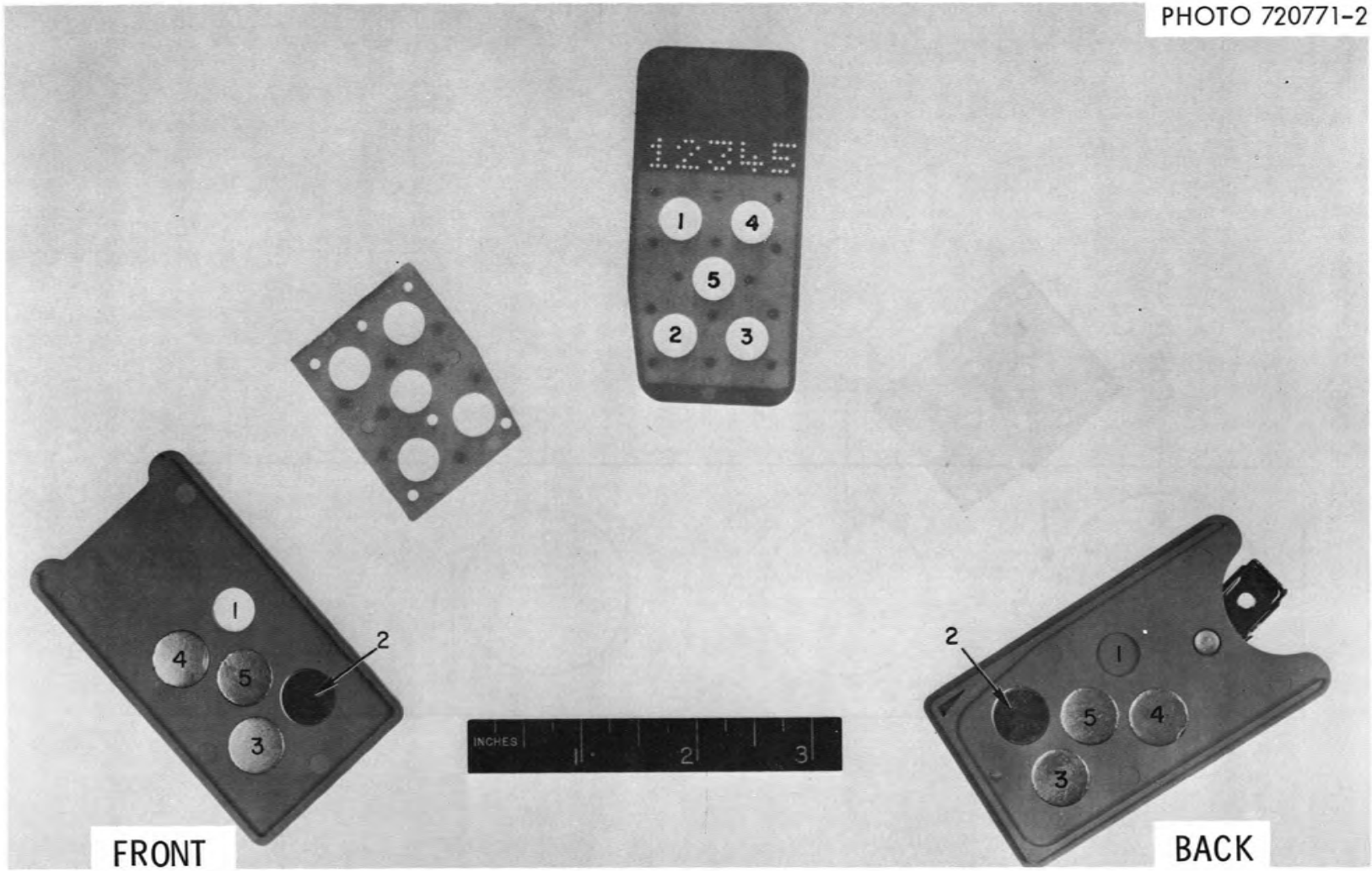


Figure C-1. An Exploded View of the Hanford Multipurpose Dosimeter Card

ORNL DWG. 73-10869

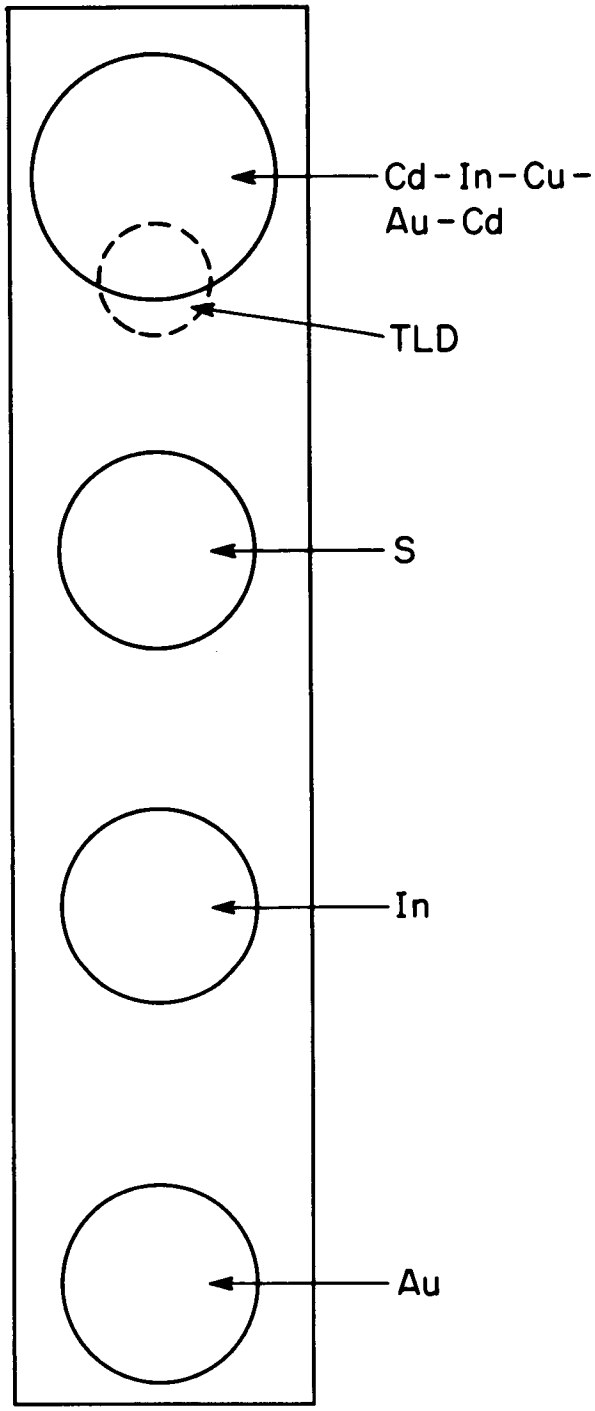


Figure C-2. PCD Foil Arrangement

TABLE C-1

FILTER SYSTEM - PHYSICAL CHARACTERISTICS

Filter #	Shield	Diameter in cm.	Thickness in cm.	Total mg/cm^2
1	Open Window	0.95	0.0	0
	Teflon TFE Tape		0.005	12
2	Cycolac	1.27	0.089	93
	Aluminum		0.064	173
	Mylar		0.007	7
	Teflon TFE Tape		0.005	12
3	Cycolac	1.27	0.051	53
	Tin		0.102	750
	Mylar		0.007	7
	Teflon TFE Tape		0.005	12
4	Cycolac	1.27	0.051	53
	Tin		0.051	375
	Cadmium		0.051	440
	Mylar		0.007	7
	Teflon TFE Tape		0.005	12
5	Cycolac	1.27	0.051	53
	Tin		0.102	750
	Mylar		0.007	7
	Teflon TFE Tape		0.005	12

TABLE C-2

TLD NEUTRON DOSE (RAD.)

BURST	PHANTOM A-3 METERS Front** FAST	PHANTOM A-3 METERS Front** SLOW	PHANTOM A-3 METERS Rear FAST	PHANTOM A-3 METERS Rear SLOW	PHANTOM B 3-meters Sideways FAST	PHANTOM B 3-meters Sideways SLOW	PHANTOM B 6-meters Front FAST	PHANTOM B 6-meters Front SLOW	POLYETHYLENE SPHERE @ 3 meters FAST	POLYETHYLENE SPHERE @ 3 meters SLOW	AIR* @ 3 meters FAST	AIR* @ 3 meters SLOW
Bare	244	1.8	83	.6	162	.7	---	---	315	1.8	23	.7
12 cm. Hyd.	61	2.6	14	.3	53	.5	---	---	52	2.7	0	2.1
3.13 cm Iron	193	1.0	34	.4	58	.6	---	---	227	.8	14	.5
Bare	210***	1.8	153	.3	---	---	66	.6	266	2.1	15	.7

* Results of exposure in air are expected to be in gross error since the albedo condition is not satisfied.

** If the energy response characteristic of the multipurpose dosimeter and the differences between the calibration spectrum and the exposure spectra are taken into consideration, the TLD dose data on the front of Phantom A for fast neutrons is comparable to the "all time" average dose data in air at 3 meters. Refer to "The Hanford Thermoluminescent Multipurpose Dosimeter; L. F. Kocher, G. W. R. Endres, L. L. Nichols, D. B. Shipler, and A. J. Haverfield, BNWL-SA-3955, May 1971.

***This dosimeter was placed on the outside of a package of cigarettes that were taped to the Phantom.

TABLE C-3

*TLD GAMMA DOSE (Rem)

BURST	PHANTOM A @ 3 METERS				PHANTOM B			
	FRONT		REAR		SIDEWAYS @3 METERS		FRONT @6 METERS	
	MULTIPURPOSE DOSIMETER	BASIC DOSIMETER	MULTIPURPOSE DOSIMETER	BASIC DOSIMETER	MULTIPURPOSE DOSIMETER	BASIC DOSIMETER	MULTIPURPOSE DOSIMETER	BASIC DOSIMETER
Bare	87	58	40	30	61	38	---	---
12 cm. Hyd.	54	45	19	14	29	22	---	---
13 cm. Iron	33	23	16	12	17	13	---	---
Bare	69	58	21	17	---	---	32	27

POLYETHYLENE CALIBRATION

BURST	AIR @ 3 METERS		SPHERE @3 METERS		FRONT OF CONCRETE BLOCKS BASIC DOSIMETER		
	MULTIPURPOSE DOSIMETER	BASIC DOSIMETER	MULTIPURPOSE DOSIMETER	BASIC DOSIMETER	@ 3 meters	@ 5 meters	@ 6 meters
Bare	32	32	70	51	45	---	---
12 cm. Hyd.	32	27	37	32	---	10	---
13 cm. Iron	11	10	31	20	---	---	4
Bare	35	---	73	50	---	---	---

*These dosimeters are calibrated with the use of a radium source while hanging in air.

TABLE C-4

BURST # 1 BARE REACTOR

LOCATION PHANTOM A FRONT-3 METER DISTANCE

DETECTOR	Disintegrations / Min-gm of isotope		Neutrons/cm^2					Rad Neutrons
	Bare Foil	Cd. Cov. Foil	.025 to .3 eV	.3 to 10 eV	.3 eV to 1 MeV	>.5 keV	>2.9 MeV	
^{116m}In	3.9×10^{8}	$.92\times10^{8}$	1.3×10^{10}	$.038\times10^{10}$				
^{198}Au	3.5×10^{6}	2.2×10^{5}	2.1×10^{10}	$.045\times10^{10}$				
^{64}Cu		2.3×10^{5}			7.0×10^{10}			
^{115m}In		1.7×10^{5}				5.9×10^{10}		252
^{32}S							1.7×10^{10}	
LOCATION AIR-3 METER DISTANCE								
^{116m}In	$.77\times10^{8}$	$.28\times10^{8}$	$.42\times10^{10}$	$.019\times10^{10}$				
^{198}Au	$.71\times10^{6}$	$.42\times10^{6}$	$.27\times10^{10}$	$.03\times10^{10}$				
^{64}Cu		$.86\times10^{5}$			5.0×10^{10}			
^{115m}In	1.6×10^{5}	1.9×10^{5}				5.9×10^{10}		222
^{32}S							1.6×10^{10}	

TABLE C-4 (CONT'D)

LOCATION CONCRETE BLOCK-3 METER DISTANCE

DETECTOR	Disintegrations / Min-gm of isotope		Neutrons/cm^2					Rad Neutrons
	Bare Foil	Cd. Cov. Foil	.025 to .3 eV	.3 to 10 eV	.3 eV to 1 MeV	> .5 keV	> 2.9 MeV	
^{116m}In	1.6×10^{8}	$.67\times10^{8}$	$.47\times10^{10}$	$.028\times10^{10}$				
^{198}Au	1.6×10^{6}	$.84\times10^{6}$	$.87\times10^{10}$	$.036\times10^{10}$				
^{64}Cu		1.8×10^{5}			6.9×10^{10}			
^{115m}In	1.5×10^{5}	2.2×10^{5}				6.3×10^{10}		259
^{32}S							1.8×10^{10}	

TABLE C-5

BURST # 2 - 12 cm HYDROGENEOUS SHIELD

LOCATION PHANTOM A FRONT - 3 METER DISTANCE

DETECTOR	Disintegrations / Min-gm of isotope		Neutrons/cm^2					Rad Neutrons
	Bare Foil	Cd. Cov. Foil	.025 to .3 eV	.3 to 10 eV	.3 eV to 1 MeV	> .5 keV	> 2.9 MeV	
^{116m}In	2.8×10^{8}	$.31\times10^{8}$	1.2×10^{10}	$.01\times10^{10}$				
^{198}Au	2.2×10^{6}	$.37\times10^{6}$	1.7×10^{10}	$.013\times10^{10}$				
^{64}Cu		$.41\times10^{5}$			1.2×10^{10}			
^{115m}In	$.15\times10^{5}$	$.21\times10^{5}$				$.61\times10^{10}$		35
^{32}S							$.39\times10^{10}$	
LOCATION AIR-3 METER DISTANCE								
^{116m}In	1.1×10^{8}	$.20\times10^{8}$	$.82\times10^{10}$	$.013\times10^{10}$				
^{198}Au	$.89\times10^{6}$	$.22\times10^{6}$	1.3×10^{10}	$.016\times10^{10}$				
^{64}Cu		$.39\times10^{5}$			2.7×10^{10}			
^{115m}In	$.17\times10^{5}$	$.23\times10^{5}$				$.67\times10^{10}$		56
^{32}S							$.28\times10^{10}$	

TABLE C-5 (CONT'D)

LOCATION CONCRETE BLOCK- 5 METER DISTANCE

DETECTOR	Disintegrations / Min-gm of isotope		Neutrons/cm^2					Rad Neutrons
	Bare Foil	Cd. Cov. Foil	.025 to .3 eV	.3 to 10 eV	.3 eV to 1 MeV	.5 keV	2.9 MeV	
^{116m}In	$.72 \times 10^8$	$.17 \times 10^8$	$.30 \times 10^{10}$	$.007 \times 10^{10}$				
^{198}Au	$.62 \times 10^6$	$.14 \times 10^6$	$.55 \times 10^{10}$	$.0061 \times 10^{10}$				
^{64}Cu		$.25 \times 10^5$			1.2×10^{10}			
^{115m}In	$.18 \times 10^5$	$.097 \times 10^5$				$.47 \times 10^{10}$		31
^{32}S								

TABLE C-6

BURST #3-13 cm IRON SHIELD

LOCATION PHANTOM A FRONT-3 METER DISTANCE

DETECTOR	Disintegrations / Min-gm of isotope		Neutrons/cm^2					Rad Neutrons
	Bare Foil	Cd. Cov. Foil	.025 to .3 eV	.3 to 10 eV	.3 eV to 1 MeV	> .5 keV	> 2.9 MeV	
^{116m}In	1.9×10^{8}	$.58\times10^{8}$	$.58\times10^{10}$	$.019\times10^{10}$				
^{198}Au	1.3×10^{6}	$.71\times10^{6}$	$.55\times10^{10}$	$.025\times10^{10}$				
^{64}Cu		1.2×10^{5}			4.1×10^{10}			
^{115m}In	$.73\times10^{5}$	$.85\times10^{5}$				2.7×10^{10}		131
^{32}S							$.34\times10^{10}$	
LOCATION AIR-3 METER DISTANCE								
^{116m}In	$.52\times10^{8}$	$.18\times10^{8}$	$.29\times10^{10}$	$.012\times10^{10}$				
^{198}Au	$.49\times10^{6}$	$.24\times10^{6}$	$.47\times10^{10}$	$.017\times10^{10}$				
^{64}Cu		$.53\times10^{5}$			3.8×10^{10}			
^{115m}In	$.53\times10^{5}$	$.51\times10^{5}$				1.8×10^{10}		102
^{32}S							$.32\times10^{10}$	

TABLE C-6 (CONT'D)

LOCATION CONCRETE BLOCK-6 METER DISTANCE

DETECTOR	Disintegrations / Min-gm of isotope		Neutrons/cm^2					Rad Neutrons
	Bare Foil	Cd. Cov. Foil	.025 to .3 eV	.3 to 10 eV	.3 eV to 1 MeV	> .5 keV	> 2.9 MeV	
^{116m}In	$.5x10^8$	$.19x10^8$	$.16x10^{10}$	$.008x10^{10}$				
^{198}Au	$.34x10^6$	$.2x10^6$	$.16x10^{10}$	$.009x10^{10}$				
^{64}Cu		$.38x10^5$			$1.7x10^{10}$			
^{115m}In	$.16x10^5$	$.17x10^5$				$5.8x10^{10}$		40
^{32}S							$.078x10^{10}$	

TABLE C-7

BURST #4 BARE REACTOR

LOCATION PHANTOM A FRONT -3 METER DISTANCE

DETECTOR	Disintegrations / Min-gm of isotope		Neutrons/cm^2					Rad Neutrons
	Bare Foil	Cd. Cov. Foil	.025 to .3 eV	.3 to 10 eV	.3 eV to 1 MeV	> .5 keV	> 2.9 MeV	
^{116m}In	3.8×10^{8}	$.82\times10^{8}$	1.3×10^{10}	$.034\times10^{10}$				
^{198}Au	3.1×10^{6}	$.94\times10^{6}$	2.0×10^{10}	$.033\times10^{10}$				
^{64}Cu		1.4×10^{5}			3.1×10^{10}			
^{115m}In	1.9×10^{5}	2.0×10^{5}				6.5×10^{10}		209
^{32}S							2.3×10^{10}	
LOCATION AIR- 3 METER DISTANCE								
^{116m}In	$.69\times10^{8}$	$.26\times10^{8}$	$.36\times10^{10}$	$.017\times10^{10}$				
^{198}Au	$.61\times10^{6}$	$.30\times10^{6}$	$.58\times10^{10}$	$.021\times10^{10}$				
^{64}Cu		$.65\times10^{5}$			4.1×10^{10}			
^{115m}In	1.8×10^{5}	1.8×10^{5}				6.0×10^{10}		210
^{32}S							1.9×10^{10}	

TABLE C-7 (CONT'D)

LOCATION CONCRETE BLOCK- 6 METER DISTANCE

DETECTOR	Disintegrations Min-gm of isotope		Neutrons/cm^2					Rad Neutrons
	Bare Foil	Cd. Cov. Foil	.025 to .3 eV	.3 to 10 eV	.3 eV to 1 MeV	> .5 keV	> 2.9 MeV	
^{116m}In	$.65 \times 10^8$	$.27 \times 10^8$	19×10^{10}	$.006 \times 10^{10}$				
^{198}Au	$.56 \times 10^6$	$.31 \times 10^6$	$.29 \times 10^{10}$	$.013 \times 10^{10}$				
^{64}Cu		$.58 \times 10^5$			2.1×10^{10}			
^{115m}In	$.69 \times 10^5$	$.68 \times 10^5$				2.3×10^{10}		89
^{32}S							$.64 \times 10^{10}$	

TABLE C-8

1. Values of parameters for calculating ϕth using gold.

count/γ @ 412 keV - .051;	A = 197
γ/dis @ 412 keV = .95;	f_D = 1
$T_{1/2}$ = 2.33 x 10^5 sec.;	f_{sa} = 1
σth = 98 x 10^{-24} cm^2;	C = 2 for the human body
	= 1.63 for concrete
	= 1.0 for air

2. Values of parameters for calculating ϕth using ^{116m}In.

count/γ @ 1293 keV = .015;	A = 115
γ/dis @ 1293 keV = .8;	f_D = 1.17 for cadmium covered forks
$T_{1/2}$ = 3.24 x 10^3 sec.;	f_{sa} = 1
σth = 157 x 10^{-24} cm^2;	C = same as for gold

3. Values of parameters for calculating ϕepi using gold.

Same as 1. above except ϕepi = 2600 x 10^{-24} cm^2

4. Values of parameters for calculating ϕepi using ^{116m}In.

Same as 2. above except ϕepi = 2600 x 10^{-24} cm^2

5. Values of parameters for calculating ϕcu using ^{64}Cu.

Count/γ @ 511 keV - .04;	A = 63
γ/dis @ 511 keV = .38;	f_D = 1
$T_{1/2}$ = 4.59 x 10^4 sec.;	f_{sa} = 1
σ = .15 x 10^{-24} cm^2;	C = same as for gold

6. Values of parameters for calculating ϕIn using ^{115m}In.

Count/γ @ 335 keV = .063;	A = 115
γ/dis @ 335 keV = .50;	f_D = 1
$T_{1/2}$ = 1.66 x 10^4 sec.;	f_{sa} = 1
σ = .225 x 10^{-24} cm^2;	C = 1

7. ϕS = .061 x 10^{10}x (Counts/min-gm of ^{32}S).

TABLE C-9

3A COINS-PULSE 3-13CM STEEL SHIELD-ZERO TIME 1029

	Time	Nickel (mr/hr)	Quarter (mr/hr)	Dime (mr/hr)	Penny (mr/hr)
(July 25)	1131	2.0	2.0	1.0	1.5
	1325	1.9	1.4	1.0	1.1
	1430	1.7	1.15	0.9	1.1
	1533	1.4	1.1	0.85	1.0
	1630	1.25	0.7	0.8	0.9
	1836	1.0	0.8	0.7	0.8
	1938	0.95	0.75	0.65	0.8
	2029	0.85	0.65	0.65	0.75
	2290	0.65	0.6	0.5	0.75
	2429	0.6	0.6	0.45	0.7
(July 26)	0829	0.3	0.32	0.25	0.33
	1405	0.22	0.2	0.17	0.25

Nickel = $T_{\frac{1}{2}}$ = 7.9 hrs. Intercept = 2.17
Quarter = $T_{\frac{1}{2}}$ = 9.12 hrs. Intercept = 1.585
Dime = $T_{\frac{1}{2}}$ = 9.9 hrs. Intercept = 1.19
Penny = $T_{\frac{1}{2}}$ = 11.0 hrs. Intercept = 1.430

TABLE C-10
PULSE 3

x	Dime y	Nickel	Quarter	Penny
4.02	0.9	1.7	1.15	1.1
5.07	0.85	1.4	1.1	1.0
6.02	0.8	1.25	0.7	0.9
8.12	0.7	1.0	0.8	0.8
9.15	0.65	0.95	0.75	0.8
10.8	0.65	0.85	0.65	0.75
12.8	0.5	0.65	0.6	0.75
14.0	0.45	0.6	0.6	0.7
22.0	0.25	0.3	6.32	0.33
27.60	0.17	0.22	0.2	0.25
b	-0.0721	-0.0857	-0.0682	-0.062
a	1.241	2.084	1.381	1.408
$T_{1/2}$	9.6 hrs.	8.09 hrs.	10.2 hrs.	11.2 hrs.

TABLE C-11

4A COINS-PULSE 4-ZERO TIME 1034

	Time	Dime (mr/hr)	Penny (mr/hr)	Quarter (mr/hr)	Nickel (mr/hr)	Half-Dollar (mr/hr)	Dollar (mr/hr)
(July 26)	1138	2.0	2.1	2.3	3.3	3.4	4.1
	1205	1.8	2.15	2.15	3.5	2.7	3.9
	1326	1.55	1.95	1.95	2.95	2.35	3.2
	1434	1.5	1.8	1.8	2.5	2.1	2.85
	1529	1.3	1.7	1.6	2.4	1.85	2.6
	1840	1.0	1.5	1.25	1.8	1.4	1.9
	2035	0.9	1.35	1.15	1.5	1.2	1.5
	2230	0.85	1.2	1.0	1.2	1.05	1.3
	2430	0.75	1.2	0.95	1.15	0.9	1.15
(July 27)	0731	0.4	0.75	0.65	0.8	0.7	0.75
	0931	0.29	0.7	0.55	0.7	0.55	0.65
	1118	3.3	3.3	3.5	4.4	4.3	5.0
	$T_{1/2}$	8.2 hr.	13.9 hr.	11.7 hr.	10.3 hr.	10.7 hr.	9.0 hr.

TABLE C-12

QUICK SORT DATA IN COUNTS/MIN. FROM A 1" DIAMETER GM DETECTOR

BURST 1

TIME Hours	TIME Min.	JN BADGE	JN CLIP	PCD DOSIMETER	PCD CLIP	QUARTER	DIME	NICKEL	PENNY
					LOCATION A AT 3 METERS				
0	30	$4x10^4$	$1x10^3$	$>10^5$	$1x10^3$	$1.5x10^3$	$5.5x10^2$	$3x10^3$	$8x10^2$
1	30	$2.5x10^4$	$.75x10^3$	$8.5x10^4$	$6x10^2$	$1x10^3$	$5x10^2$	$2x10^3$	$6.5x10^2$
					LOCATION B				
0	45	$1.5x10^4$	$4.5x10^2$	---	---	---	---	---	---
					LOCATION C AT 3 METERS				
0	40	$1x10^4$	$3.5x10^2$	---	---	$4.5x10^2$	$2x10^2$	$4x10^2$	$3x10^2$
1	35	$5x10^3$	$2x10^2$	---	---	---	---	---	---
					LOCATION G AT 3 METERS				
0	47	---	---	$3x10^4$	$3.5x10^2$	---	---	---	---
0	49	---	---	---	---	$4x10^2$	$2x10^2$	$4x10^2$	$2.5x10^2$
					LOCATION F AT 3 METERS				
0	55	---	---	---	---	$1.5x10^2$	$4x10^2$	$2x10^2$	$7x10^2$
					LOCATION H AT 3 METERS				
0	51	---	---	$6.5x10^4$	$3.5x10^2$	---	---	---	---

TABLE C-12
(CONT'D)

QUICK SORT DATA IN COUNTS/MIN. FROM A 1" DIAMETER GM DETECTOR

BURST 1

TIME Hours	TIME Min.	JN BADGE	JN CLIP	PCD DOSIMETER	PCD CLIP	QUARTER	DIME	NICKEL	PENNY
NEW MULTIPURPOSE DOSIMETER									
					LOCATION A				
0	30	4.5×10^2	7×10^2	---	---	---	---	---	---
0	90	---	6.5×10^2	---	---	---	---	---	---
					LOCATION B				
0	47	2×10^2	---	---	---	---	---	---	---
					LOCATION C				
0	40	2×10^2	3×10^2	---	---	---	---	---	---

TABLE C-13

QUICK SORT DATA IN COUNTS/MIN. FROM A 1" DIAMETER GM DETECTOR

BURST 2

TIME Hours	TIME Min.	JN BADGE	JN CLIP	PCD DOSIMETER	PCD CLIP	QUARTER	DIME	NICKEL	PENNY
				LOCATION A AT 3 METERS					
0	44	$4x10^4$	---	$1x10^5$	---	$1.5x10^4$	$5.5x10^3$	$6.5x10^3$	$5.5x10^3$
1	02	$3.1x10^4$	---	$4.8x10^4$	---	---	---	---	---
1	09	---	---	---	---	$6x10^3$	$2.5x10^3$	$2.6x10^3$	$2x10^3$
1	59	$1.2x10^4$	---	$2.5x10^4$	---	---	---	---	---
2	3	---	---	---	---	$5.5x10^3$	$2.3x10^3$	$2.3x10^3$	$1.8x10^3$
2	17	$1.3x10^4$	---	---	---	---	---	---	---
				LOCATION B					
0	48	$1.4x10^4$	---	---	---	---	---	---	---
1	7	$1x10^4$	---	---	---	---	---	---	---
1	58	$4.7x10^3$	---	---	---	---	---	---	---
				LOCATION C AT 3 METERS					
0	37	$5x10^3$	---	---	---	---	---	---	---
0	40	---	---	---	---	$2x10^3$	$1.5x10^3$	$1.5x10^3$	$1x10^3$
1	12	---	---	---	---	$7.5x10^2$	$4x10^2$	$6x10^2$	$3.5x10^2$
1	57	$4.5x10^3$	---	---	---	---	---	---	---
2	6	---	---	---	---	$5x10^2$	$3.5x10^2$	$6x10^2$	$3x10^2$

TABLE C-13

(CONT'D)

QUICK SORT DATA IN COUNTS/MIN. FROM A 1" DIAMETER GM DETECTOR

BURST 2

TIME Hours	TIME Min.	JN BADGE	JN CLIP	PCD DOSIMETER	PCD CLIP	QUARTER	DIME	NICKEL	PENNY
				LOCATION F AT 3 METERS					
0	56	---	---	---	---	$8x10^2$	$3.2x10^2$	$3x10^2$	$2.5x10^2$
1	15	---	---	---	---	$5.7x10^2$	$2.5x10^2$	$2.3x10^2$	$<1.5x10^2$
2	14	---	---	---	---	$5x10^2$	$1.8x10^2$	$1.9x10^2$	$<1.5x10^2$
				LOCATION G AT 3 METERS					
0	51	---	---	$4.5x10^4$	---	$3.5x10^3$	$1.5x10^3$	$3.8x10^3$	$1.6x10^3$
1	6	---	---	$3x10^4$	---	---	---	---	---
1	13	---	---	---	---	$2x10^3$	$1.3x10^3$	$3.4x10^3$	$1x10^3$
2	10	---	---	---	---	$2x10^3$	$1x10^3$	$2.7x10^3$	$7.2x10^3$
				LOCATION H AT 5 METERS					
0	48	---	---	$1.5x10^4$	---	---	---	---	---
1	4	---	---	$1.3x10^4$	---	---	---	---	---

TABLE C-14

QUICK SORT DATA IN COUNTS/MIN. FROM A 1" DIAMETER GM DETECTOR

BURST 3

TIME		JN		PCD					
Hours	Min.	BADGE	CLIP	DOSIMETER	CLIP	QUARTER	DIME	NICKEL	PENNY
0	33	---	---	---	---	2.2×10^4	1.5×10^4	2.1×10^4	1.5×10^4
0	38	---	---	6×10^4	5.5×10^3	---	---	---	---
0	42	3.4×10^4	3.2×10^3	---	---	---	---	---	---
2	04	1.6×10^4	2.2×10^3	---	---	---	---	---	---
2	16	---	---	---	3×10^3	---	---	---	---
2	24	---	---	---	---	3.1×10^3	---	---	---
2	31	---	---	---	---	---	1.5×10^3	---	---
2	37	---	---	---	---	---	---	3.7×10^3	---
2	44	---	---	---	---	---	---	---	1.1×10^3
3	27	8.5×10^3	2.5×10^3	---	---	---	---	---	---
3	29	---	---	---	2.2×10^3	---	---	---	---
				LOCATION B					
0	45	2.5×10^4	1.5×10^3	---	---	---	---	---	---
2	06	3.2×10^3	1.5×10^3	---	---	---	---	---	---
3	37	1.4×10^3	1×10^3	---	---	---	---	---	---

TABLE C-14

(CONT'D)

QUICK SORT DATA IN COUNTS/MIN. FROM A 1" DIAMETER GM DETECTOR

BURST 3

TIME		JN		PCD					
Hours	Min.	BADGE	CLIP	DOSIMETER	CLIP	QUARTER	DIME	NICKEL	PENNY
				LOCATION C AT 3 METERS					
0	36	---	---	---	---	4.8×10^3	3.8×10^3	2.4×10^3	2.5×10^3
0	43	8.4×10^3	7×10^2	---	---	---	---	---	---
1	58	---	---	---	---	8×10^2	---	---	---
2	02	---	---	---	---	---	7.5×10^2	---	---
2	08	2.3×10^3	8.5×10^2	---	---	---	---	4.7×10^2	---
2	14	---	---	---	---	---	---	---	3.7×10^2
3	42	9×10^2	5×10^2	---	---	---	---	---	---
				LOCATION F AT 3 METERS					
0	55	---	---	---	---	1.1×10^4	2×10^3	7.3×10^3	2.5×10^3
3	13	---	---	---	---	4×10^3	---	---	---
3	16	---	---	---	---	---	1.1×10^3	---	---
3	23	---	---	---	---	---	---	4×10^3	---
3	29	---	---	---	---	---	---	---	1.4×10^3

TABLE C-14

(CONT'D)

QUICK SORT DATA IN COUNTS/MIN. FROM A 1" DIAMETER GM DETECTOR

BURST 3

TIME Hours	TIME Min.	JN BADGE	JN CLIP	PCD DOSIMETER	PCD CLIP	QUARTER	DIME	NICKEL	PENNY
				LOCATION G AT 3 METERS					
0	48	---	---	$2x10^4$	$1.5x10^3$	---	---	---	---
0	49	---	---	---	---	$1.4x10^3$	$1.1x10^3$	$1.4x10^3$	$1.1x10^3$
2	18	---	---	---	$1.2x10^3$	---	---	---	---
3	38	---	---	---	$7.5x10^2$	---	---	---	---
4	2	---	---	---	---	450-500	300-350	700-750	300-350
				LOCATION H AT 6 METERS					
0	47	---	---	$1.5x10^4$	$1.2x10^3$	---	---	---	---
2	16	---	---	---	$6.5x10^2$	---	---	---	---
3	43	---	---	---	$5x10^2$	---	---	---	---
BNW MULTIPURPOSE DOSIMETER									
				LOCATION A					
0	38	---	$3.4x10^3$	---	---	---	---	---	---

TABLE C-15

QUICK SORT DATA IN COUNTS/MIN. FROM A 1" DIAMETER GM DETECTOR

BURST 4

TIME		JN		PCD					
Hours	Min.	BADGE	CLIP	DOSIMETER	CLIP	QUARTER	DIME	NICKEL	PENNY
				LOCATION A AT 3 METERS					
0	38	8.2×10^4	8×10^3	$>10^5$	---	---	---	---	---
0	50	---	---	---	---	1.2×10^4	6×10^3	9.5×10^3	5×10^3
0	52	5.2×10^4	---	1×10^5	---	---	---	---	---
0	59	---	---	---	---	8×10^3	4.5×10^3	8.5×10^3	3×10^3
1	28	---	---	8.5×10^4	6.8×10^3	---	---	---	---
2	36	1.25×10^4	5.5×10^3	---	---	---	---	---	---
				LOCATION B					
0	43	1.5×10^4	---	---	---	---	---	---	---
0	54	1.5×10^4	---	---	---	---	---	---	---
2	36	3×10^3	---	---	---	---	---	---	---
				LOCATION C AT 6 METERS					
0	44	2.6×10^4	4×10^3	---	---	---	---	---	---
0	55	2.2×10^4	---	---	---	---	---	---	---
1	01	---	---	---	---	2.8×10^3	1.2×10^3	2.2×10^3	1.2×10^3
2	36	5×10^3	---	---	---	---	---	---	---

TABLE C-15

(CONT'D)

QUICK SORT DATA IN COUNTS/MIN. FROM A 1" DIAMETER GM DETECTOR

BURST 4

TIME		JN		PCD					
Hours	Min.	BADGE	CLIP	DOSIMETER	CLIP	QUARTER	DIME	NICKEL	PENNY
				LOCATION F AT 3 METERS					
1	02	---	---	---	---	$6x10^3$	$2.2x10^3$	$1.2x10^3$	$2.6x10^3$
				LOCATION G AT 3 METERS					
0	56	---	---	$2x10^4$	---	---	---	---	---
2	24	---	---	---	$1.2x10^3$	---	---	---	---
				LOCATION H AT 6 METERS					
0	58	---	---	$2.5x10^4$	---	---	---	---	---
1	15	---	---	$2.2x10^4$	---	---	---	---	---
2	24	---	---	---	$9x10^2$	---	---	---	---

APPENDIX D

LOS ALAMOS SCIENTIFIC LABORATORY

REPRESENTATIVE: D. E. HANKINS

Albedo-neutron dosimeters of the type being placed on personnel at the DP facility were used in this study. The information desired in this study included the following:

1. We had not checked this particular dosimeter design for the effect of having the dosimeter located at small distances away from the body, similar to those distances expected during the actual wearing of the dosimeter.
2. We needed more data to determine how accurately a gallon jug can be used to approximate a manikin.
3. The response of dosimeters located on the backside of the manikin with respect to the source had not been adequately studied and the effect of distance of the dosimeter from the backside of the phantom was desired.
4. We had not studied the response of bare TLD's to gamma rays and thermal neutrons when located at the same position on a phantom as the albedo-neutron dosimeters and were particularly interested in the ^{7}Li TLD response inside and outside the albedo dosimeter.
5. Additional points were desired to complete the drawing of a curve to be used to determine the calibration factor for the albedo-neutron dosimeters from data obtained with the 9- and 3-in. spheres.

6. Information was desired that could be of use in an accidental criticality and the effect of steel shielding on the dosimeter response had not been studied to date and was unknown.

Gold foils were used inside the 3- and 9-in. spheres. Since these foils had not been used in this manner previously, the first burst was used as a calibration. The GM instrument brought from LASL did not function properly and the gold foils were counted by DOSAR personnel on their NaI crystal.

To provide dose estimates for the intercomparison, we used our existing curve for the 3- and 9-in. sphere ratio vs. dosimeter response. This curve provided accurate results. Additional points will be added from the results obtained in this study but no change in the curve will result. This study helps to confirm the accuracy of the curve.

The results obtained during the intercomparison are given in Table D-1. At this time the most accurate neutron doses are given in Table D-1 in the "Previous Intercomparison Expected Results" line. ORNL was having some difficulties with counters and some of their early results must be revised. The ORNL gamma-ray results are good and will not change. Our gamma-ray results are consistently higher than theirs. While at ORNL, we exposed some of our TLD's to one of their sources. Our preexposed TLD's and the ORNL exposures agreed to within 2.4%. The high gamma-ray doses we obtained are unexplained at present and should be investigated further.

The effect of moving the dosimeter away from the body was significant only for the steel shield of Burst 3, where a consistent

drop was noted as the dosimeters were moved away from the phantom. The general statement that the dosimeters do not have to be held tightly against the body is still valid, however, since the change is normally within a few percent.

Dosimeters on the back of a person record ∿21% of the dose. Dosimeters located 3 cm from the phantom on the back indicated an increase of about 6% compared to the dosimeters at contact.

The gallon-jug data was low for all bursts except the lucite-shielded Burst 2. It would appear that the gallon jug would average a few percent low for most applications. More data is desired before the percentage low can be stated.

Several ratios of sphere data and doses are given in Table D-1. These ratios should be the same if the dosimeters are following the response of the spheres perfectly. The ratio of the 3- to 9-in. sphere varied from 1.34 to 0.56 for the extremes of Bursts 2 and 4. For unshielded bursts, the calibration factor changes from 0.275 to 0.54 for distances of 1 to 9.85 m, which would give an accuracy of ±33% if a single factor were used. For the extremes of this intercomparison, the calibration factor varied from 0.275 to 0.75 and the use of a single calibration factor would not be reasonable.

The neutron doses reported for the intercomparison were corrected for the known overresponse of the sphere resulting from the shielded bursts. A QF of 9.5 was used for the fast-neutron doses.

The preliminary results indicated we were high on the thermal-neutron dose on the man. An incorrect calibration factor had been used which did not correct for thermal-neutron return from the

phantom. These results have been revised and good agreement now exists.

The ^{7}Li TLD's located in the dosimeters gave a higher reading than the ^{7}Li TLD's located on the man. This must be due to gamma rays produced by the capture of neutrons in cadmium. This result was unexpected since our dosimeters placed on personnel at DP had a ^{7}Li reading in the dosimeter of about one-third the gamma-ray dose reported by the film badge. We did not plant ^{7}Li TLD's in the DP badge at that time. This apparent discrepancy must be investigated further.

TABLE D-1

RESULTS OBTAINED AT ORNL 1972 INTERCOMPARISON

LASL RESULTS	Burst 1 Bare	Burst 2 Lucite Shield	Burst 3 Steel Shield	Burst 4 Bare
Gamma in air			15.5 rads	13.8 rads
Gamma on man	83 rads	56 rads	41.1 rads	26.5 rads
Fast neutron on man				
9.85 m	270 rem 28.4 rads	380 rem 40 rads		
3 m	2451 rem 258 rads		1239 rem 130 rads	
6 m				695 rem 73 rads
Corrected for sphere response		37.8 rads	114 rads	
Thermal neutron on man		8.2 rem 2.7 rads	6.8 rem 2.3 rads	3.92 rem 1.3 rads
in air			1.79 rem 0.60 rads	1.03 rem 0.34 rads
Sphere neutron dose		352 rem 37 rads	1276 rem 134 rads	
1 m				15,600 rem 1640 rads
6 m				634 rem 67 rads

TABLE D-1

(CONT'D)

RESULTS OBTAINED AT ORNL 1972 INTERCOMPARISON

ORNL RESULTS	Burst 1 Bare	Burst 2 Lucite Shield	Burst 3 Steel Shield	Burst 4 Bare
Gamma in air	39 R	34 R	11 R	
Gamma on man	73 R	52 R	25 R	
Fast neutron dose	256 rads	34 rads	114 rads	
Blood sodium	245 rads	46 rads	139 rads	
Previous Intercomparison Expected Results (1970)				
Gamma in air	39 rads	33.6 rads	11.8 rads	
6 m				10.1 rads
Fast neutron dose	264 rads	37 rads	114 rads	
6 m				69 rads
All Previous Intercomparisons				
Gamma in air	39 rads	34 R	11.7 R	
6 m				10.2 rads
Fast neutron dose	273 rads	38 rads	107 rads	
6 m				72 rads
With dosimeter at contact	2628 rem +7%	380 rem 0%	1318 rem +6%	717 rem +3%

TABLE D-1

(CONT'D)

	Burst 1 Bare	Burst 2 Lucite Shield	Burst 3 Steel Shield	Burst 4 Bare
1 cm	2343 rem -4%	392 rem +3%	1256 rem +1%	696 rem 0%
2 cm	2426 rem -1%	379 rem 0%	1212 rem -2%	685 rem -1%
3 cm	2410 rem -2%	367 rem -3%	1170 rem -6%	682 rem -2%
Dosimeter on side 3 m	1259 and 900 rem			
On back of phantom contact	508 rem -3%	73 rem -4%	272 rem -3%	
3 cm	544 rem +3%	79 rem +4%	285 rem +2%	
average	526 rem 55 rads	76 rem 8.0 rads	279 rem 29.4 rads	
Percent of front	21%	20%	23%	
Dosimeter on gal jugs				
1 m				15,000 rem 1580 rads
3 m	2361 rem 248 rads	405 rem 42.6 rads	1184 rem 125 rads	

TABLE D-1

(CONT'D)

	Burst 1 Bare	Burst 2 Lucite Shield	Burst 3 Steel Shield	Burst 4 Bare
6 m				617 rem 65 rads
9.85 m	270 rem 28 rads			
Percent deviation from on man				
3 m	-4%	+6%	-4%	
6 m				-11%
Ratios				
9- to 3-in.-sphere data				
1 m				1.34
3 m	0.98	0.51 left 0.61 right 0.56 ave.	0.74	
6 m				0.87
9.85 m	0.76			

	Spheres	Doses	Spheres	Doses	Spheres	Doses	Spheres	Doses
indicated doses								
1st to 2nd burst			6.97	6.82[a]				
1st to 3rd burst					1.92	1.98[b]		
3 to 9.85 m	8.7	9.1[c]						

TABLE D-1
(CONT'D)

	Spheres	Doses	Spheres	Doses	Spheres	Doses	Spheres	Doses
1st to 4th burst								
1 m							0.156	0.163[c]
6 m							3.87	3.53[d]

[a]ORNL doses 5.82

[b]ORNL doses 7.52

[c]ORNL Report 4113 indicates 8.9

[d]ONRL Report 4113 indicates 0.132 and 3.75

APPENDIX E

NAVAL ORDNANCE LABORATORY

REPRESENTATIVE: F. M. TOMNOVEC

Enclosed are the final results of the experiment conducted by NOL at the ORNL Ninth Intercomparison of Nuclear Accident Dosimetry Systems. The system used is the Navy DT-518/PD Accident Dosimeter (See Figure E-1). Three dosimeters were normally exposed on the phantom at each position. After exposure, one each dosimeter was processed at the Oakland Naval Hospital, Oakland, California; the National Naval Medical Center, Bethesda Maryland; and the Naval Ordnance Laboratory, White Oak, Silver Springs, Maryland.

The data is presented in four tables (E-1 through E-4) with the neutron dose in Rads, the gamma dose is in equivalent ^{60}Co exposure; that is, the LiF has been calibrated to ^{60}Co. The dose is the surface dose incident on the phantom. After the final results of this intercomparison, we will adjust our calibration to read the dose at the median of the phantom. The data presented in the tables are the average and where there are more than three readings a standard deviation and the error of the mean value at one deviation is given.

The most obvious comment one can make from this data is that in Pulse 2, the initial screening dose is extremely high, because of the thermal neutrons from the shield. Exposures made in the sideways position also yield initial high screening values. The screening value is supposed to represent the total dose (gamma and neutron).

FUNCTIONAL DESCRIPTION

The Detector, Radiac DT-518/PD, is a passive type nuclear dosimeter capable of detecting and recording, for later readout, fast neutron radiation exposures from 10 to 50,000 rem (with a quality factor of 10) and gamma-ray doses from 1 to 10,000 rem. Three materials within the DT-518/PD determine radiological exposure: (1) two indium foil discs record neutron radiation exposure for quick evaluation of dose significance; (2) two sulfur tablets record fast neutron dose, and (3) a quantity of 30 mg of thermoluminescent powder (TLD-700) records gamma and X-ray dose. These materials are capsulated in a plastic tube which is secured inside a stainless steel tube which is fastened, at time of issue, to a film badge holder and worn by the user as a personnel accident dosimeter. The detector capsule is removed from the steel tube at the time of suspected radiation exposure for a determination of recorded dose. A replacement capsule is obtained from a new DT-518/PD drawn from the Navy supply system; the outer steel tube of the new unit is not used. The DT-518/PD is non-self indicating; separate readout instruments are required to determine the amount of radiation dose recorded. Additional information on the design and calibration of the DT-518/PD can be obtained in reference (1).

Preliminary screening of the indium foils by field facilities requires a Radiac Set, type AN/PDR-27 ("J" through "R" series).

The sulfur tablets and TLD powder are processed only at the medical facilities listed in the first paragraph. A determination of the beta activity contained in the sulfur is made with a Geiger-Mueller (GM) type counting system. These data are standardized in a

neutron flux of known intensity. This counting process requires a system consisting of: (1) a Computer-Indicator, Radiac CP-792/UD, or equal (2) a lead shield counting set-up with internal GM counter tube; and, (3) an electrostatic voltmeter high voltage monitor, 0-1500 volt range, 1% full scale accuracy, Sensitive Research Model ESD, or equal.

Measurement of gamma and X-ray dose recorded by the TLD powder requires a Con-Rad TLD System, manufactured by Controls for Radiation, Inc., 130 Alewife Brook Parkway, Cambridge, Massachusetts 02140.

Conversion of Screening Data

It is important that field facilities be able to make a gross estimate of the radiation dose received by personnel involved in a nuclear accident. An estimated dose received by personnel may be made by converting screening readings obtained with the AN/PDR-27 Radiacmeter into dose equivalence. The readings are convertible to units of rem by the equation:

$$mR/h \times 100 \times (F) = rem, \pm 50\%$$

In the above equations the value of mR/h is the net screening reading, and the value of the factor (F) is obtained from the graph of Figure E-2.

In Figure E-2, the value of (F) is related to the decay of the relatively short half-life of the isotope measured during the screening and therefore increases with time after exposure. The number of hours after exposure (Time of Screening) is determined by the time when the gross screening reading was made.

The above relationships are valid for both bare and shielded critical assemblies.

REFERENCE LITERATURE

(1) Report NRDL-LR-68-87: The Design and Calibration of a Navy Accident Dosimeter.

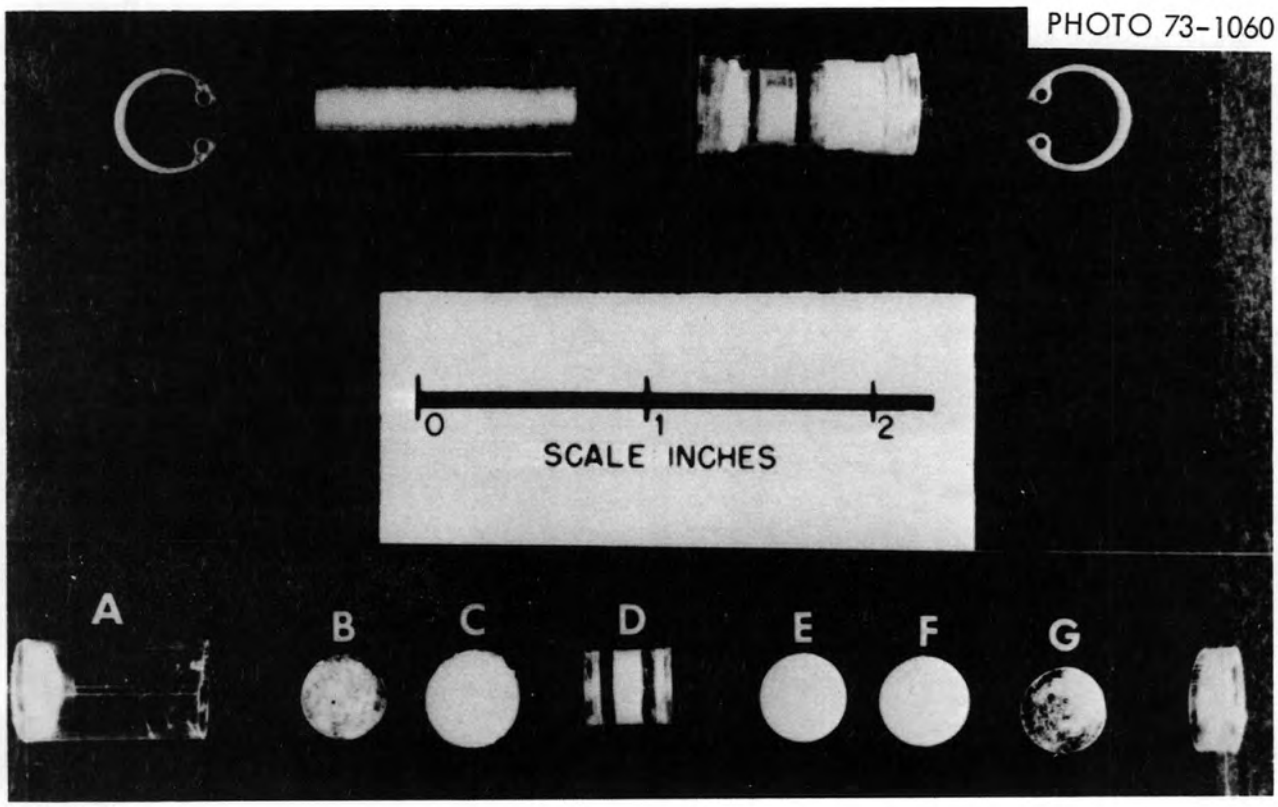


Figure E-1. RADIAC DT-518/PD Detector

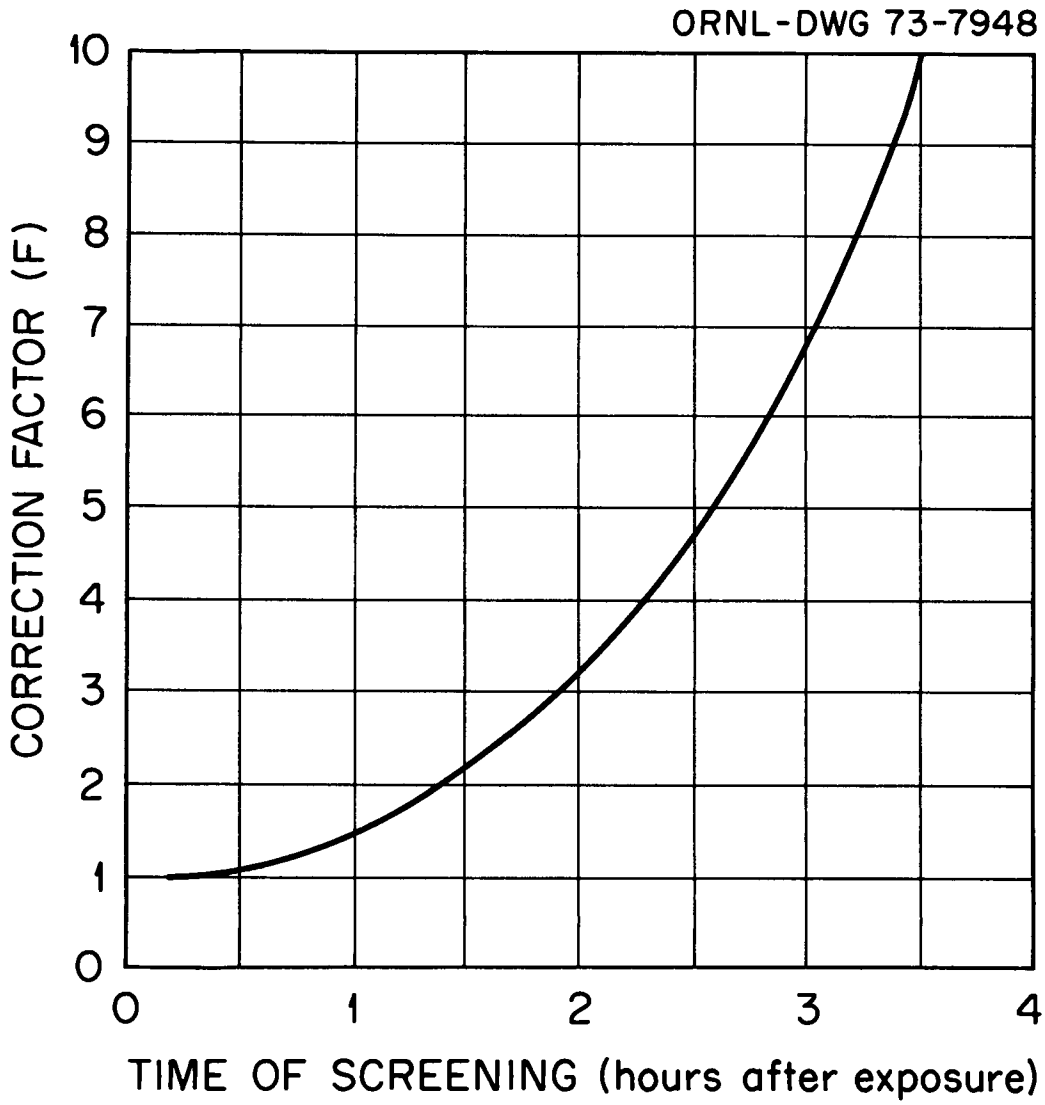
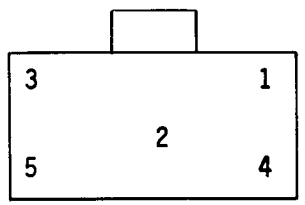


Figure E-2. Correction Factors (F) for AN/PDR-27 Meter Readings as a Function of Time after Exposure

TABLE E-1

PULSE 1 UNMODERATED

	Neutron Dose (Rads)	Gamma (Rads) ^{60}Co Equivalent	Total Rads	Initial Screening (Rads)
AIR MEASUREMENT AT 3 METERS				
(3) Detectors	213.0 +2.8% -4.7%	39.2 +7.1% -4.1%	252.2	
PHANTOM FACING SOURCE				
Ave. (9) Detectors on front, position 1, 2, 3	231.8, σ = 5.0, $\frac{\sigma}{\bar{n}}$ = 2.2%	89.4, σ = 7.5 $\frac{\sigma}{\bar{n}}$ = 8.3%	321.2	380
Ave. (9) Detectors on back, position 1, 2, 3	25.2, σ = 3.2, $\frac{\sigma}{\bar{n}}$ = 14%	39.7, σ = 1.4 $\frac{\sigma}{\bar{n}}$ = 3.4%	64.9	127
PHANTOM SIDEWAYS TO SOURCE				
Ave. (3) Detectors on right side nearest source, position 3	228.0 +2.6% -2.0%	63.5 +3.9% -7%	291.5	260
Ave. (3) Detectors on center of chest, position 2	214.5 +7% -10%	54.7 +6.0% -6.8%	269.2	150
Ave. (3) Detectors on left side furthest from source, position 1	43.3 +35% -21%	32.0 +11% -14%	75.3	100



Possible Detector Positions on Phantom

TABLE E-2

PULSE 2 MODERATED BY 12-CM HYDROGENOUS SHIELD

	Neutron Dose (Rads)	Gamma (Rads) ^{60}Co Equivalent	Total Rads	Initial Screening (Rads)
AIR MEASUREMENT AT 3 METERS				
(1) Detector	38.0 ± 20%	25.3 ± 10%	63.3	
PHANTOM FACING SOURCE				
Ave. (6) Detectors on front, position 1, 2	38.3, σ = 3.0 $\frac{\sigma}{\bar{n}}$ = 7.8%	60.0, σ = 3.4, $\frac{\sigma}{\bar{n}}$ = 5.6%	98.3	285
Ave. (6) Detectors on back, position 2	40 $^{+8\%}_{-11\%}$	24.3 $^{+21\%}_{-18\%}$	28.3	35
PHANTOM SIDEWAYS TO SOURCE				
Ave. (3) Detectors on center of chest, position 2	35.0 $^{+2.5\%}_{-2.2\%}$	39.7 $^{+17.4\%}_{-12.9\%}$	74.7	160

TABLE E-3

PULSE 3 MODERATED BY 13-CM STEEL SHIELD

	Neutron Dose (Rads)	Gamma Dose Rads (^{60}Co Equivalent)	Total Rads	Initial Screening (Rads)
AIR MEASUREMENT AT 3 METERS				
(1) Detector	33.6 ± 10%	21 ± 10%	54.6	
PHANTOM FACING SOURCE				
Ave. (9) Detectors on front, position 2. 2. 4	38.5, σ = 2.6 $\frac{\sigma}{\pi}$ = 7%	39.6, σ = 4.5, $\frac{\sigma}{\pi}$ = 11.4%	78.1	196
Ave. (3) Detectors on back, position 2	5.1 $^{+3\%}_{-5\%}$	18.8 $^{+11.7\%}_{-6.9\%}$	23.9	63
PHANTOM SIDEWAYS TO SOURCE				
Ave. (3) Detectors on right side nearest source, position	33.7 $^{+5.6\%}_{-8.2\%}$	28.1 $^{+3.2\%}_{-3.9\%}$	61.8	212
Ave. (3) Detectors on center of chest, position 2	28.8 $^{+3.4\%}_{-6.1\%}$	30.1 $^{+16.3\%}_{-12.3\%}$	58.9	200
Ave. (3) Detectors on left beltline furthest from source, position 4	12.9 $^{+2.6\%}_{-2.6\%}$	20.2 $^{+6.4\%}_{-5.9\%}$	33.1	128
AGAINST FACE OF CONCRETE BLOCKS				
2' x 2' x 2' at 6 meters				
1 Detector	9.9 ± 10%	6.9 ± 10%	16.8	

TABLE E-4

PULSE 4 UNMODERATED

	Neutron Dose Rads	Co Equivalent	Total Rads	Initial Screening (Rads)
AIR MEASUREMENT AT 3 METERS				
(3) Detectors	215.5 $^{+4.9\%}_{-2.7\%}$	37.3 $^{+7.2\%}_{-6.2\%}$	252.8	
PHANTOM FACING SOURCE - 3 METERS				
Ave. (6) Detectors on front, position 2, 4	225.2, $\sigma = 7.2$ $\frac{\sigma}{\bar{n}} = 3.2\%$	87, $\sigma = 5.1$ $\frac{\sigma}{\bar{n}} = 5.8\%$	312.2	390
Ave. (3) Detectors on back, position 2	22.6, $^{+6.3\%}_{-7.3\%}$	37.5, $^{+9.3\%}_{-6.4\%}$	60.1	117
PHANTOM FACING SOURCE - 6 METERS				
Ave. (6) Detectors on front, position 2, 4	58.5, $\sigma = 3.1$ $\frac{\sigma}{\bar{n}}$ 5.2%	25.8, $\sigma = 2.8$, $\frac{\sigma}{\bar{n}} = 10.7\%$	84.3	154
Ave. (3) Detectors on back, position 2	6.3 $^{+23\%}_{-12\%}$	12.3 $^{+11.3\%}_{-10.6\%}$	18.6	37
AGAINST FACE OF CONCRETE BLOCKS				
2' x 2' x 2' at 6 meters				
Ave. (2) Detectors	68.5 ± 1.9%	17.8 ± 1.4%	86.3	

APPENDIX F

SAVANNAH RIVER LABORATORY

REPRESENTATIVES: J. E. HOY AND C. N. WRIGHT

SRP/SRL CRITICALITY DOSIMETER

The SRP/SRL criticality neutron dosimeter (CND) is designed basically as a personnel dosimeter although it is also used as an area dosimeter. Activation of included materials (see Figure F-1) enables measurement of neutron fluence in five energy intervals from 0.0 eV to greater than 10 MeV. Gamma dose is measured by three thermoluminescent dosimeters of ^{7}LiF powder. The neutron energy intervals and material used for measurement of each are:

<u>0.0 eV to 0.5 eV</u> and <u>0.5 eV to 2 eV</u>

Bare and cadmium-shielded indium foils

<u>2 eV to 1 MeV</u>

Copper foil

<u>1 MeV to 3.0 MeV</u>

Indium-115m less fluence above 3 MeV as determined by sulfur.

<u>Greater than 3 MeV</u>

Sulfur

In addition to the materials listed the CND contains a vial of sodium fluoride. Comparison of the sodium activity induced in this vial with that induced in the blood sodium, both suitably corrected for spectral influence, allows determination of the dosimeter placement on the wearer's body relative to the exposing source.

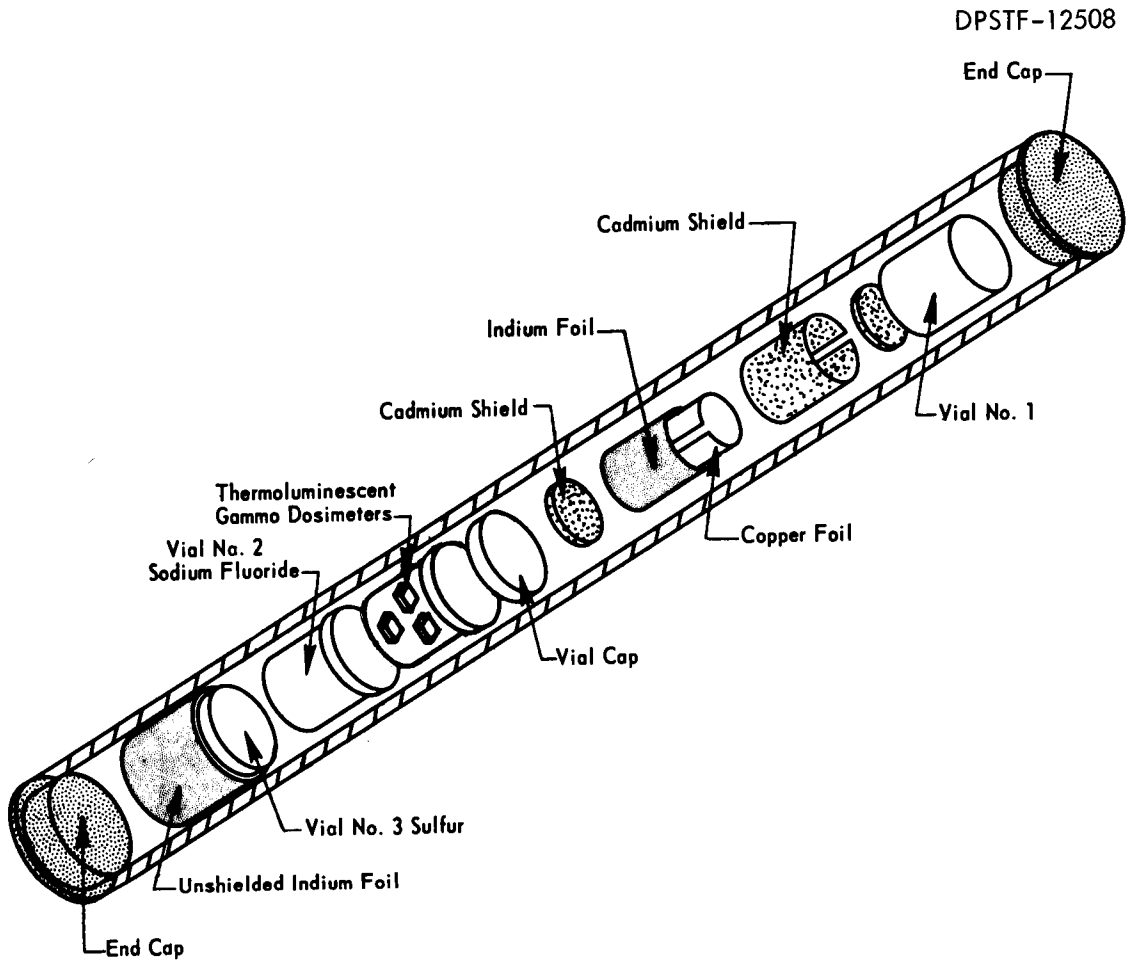


Figure F-1. SRP Criticality Dosimeter

APPENDIX G

GOODYEAR ATOMIC CORPORATION

OAK RIDGE GASEOUS DIFFUSION PLANT

OAK RIDGE NATIONAL LABORATORY

UNION CARBIDE CORPORATION (Y-12 PLANT)

AREA MONITORING STATION

The ORNL NAD Area Monitoring Station is comprised of a neutron energy threshold detector, and a pair of metaphosphate glass blocks.

Threshold Detector

This is seen in Figure 1. Fission foils of Pu, Np, and U, are enclosed in a B_4C sphere whose thickness is 1 cm. Bare gold and cadmium-covered gold foils are used in addition to determine thermal neutron fluence. A sulfur pellet is used to determine neutron fluence above 2.5 MeV.

Energy Threshold	Cross Section
At Thermal Energy	98 b
1 keV	1.8 b
750 keV	1.6 b
1.5 MeV	0.55 b
2.5 MeV	0.23 b

Energy Interval	Dose Conversion Factor
At Thermal Energy	2.4×10^{-11}
0.001 - 0.75 MeV	1.4×10^{-9}
0.75 - 1.5 MeV	2.4×10^{-9}
1.5 - 2.5 MeV	3.0×10^{-9}
2.5 MeV and Above	3.8×10^{-9}

Gamma Rays

Gamma-ray dose is measured using Toshiba FD-P8-1 glass blocks. These glass blocks are 50 percent Al $(PO_3)_3$, and 50 percent $LiPO_3$ with $AgPO_3$ added. In mixed fields of neutrons and gamma rays, these blocks are exposed inside a ^6Li container lined with 0.040" Sn for a more independent energy response at low photon energies.

PERSONNEL MONITORING

The ORNL Badge-Meter is a combination identification, routine monitoring, and radiation accident monitoring device for personnel use. See Figure 2.

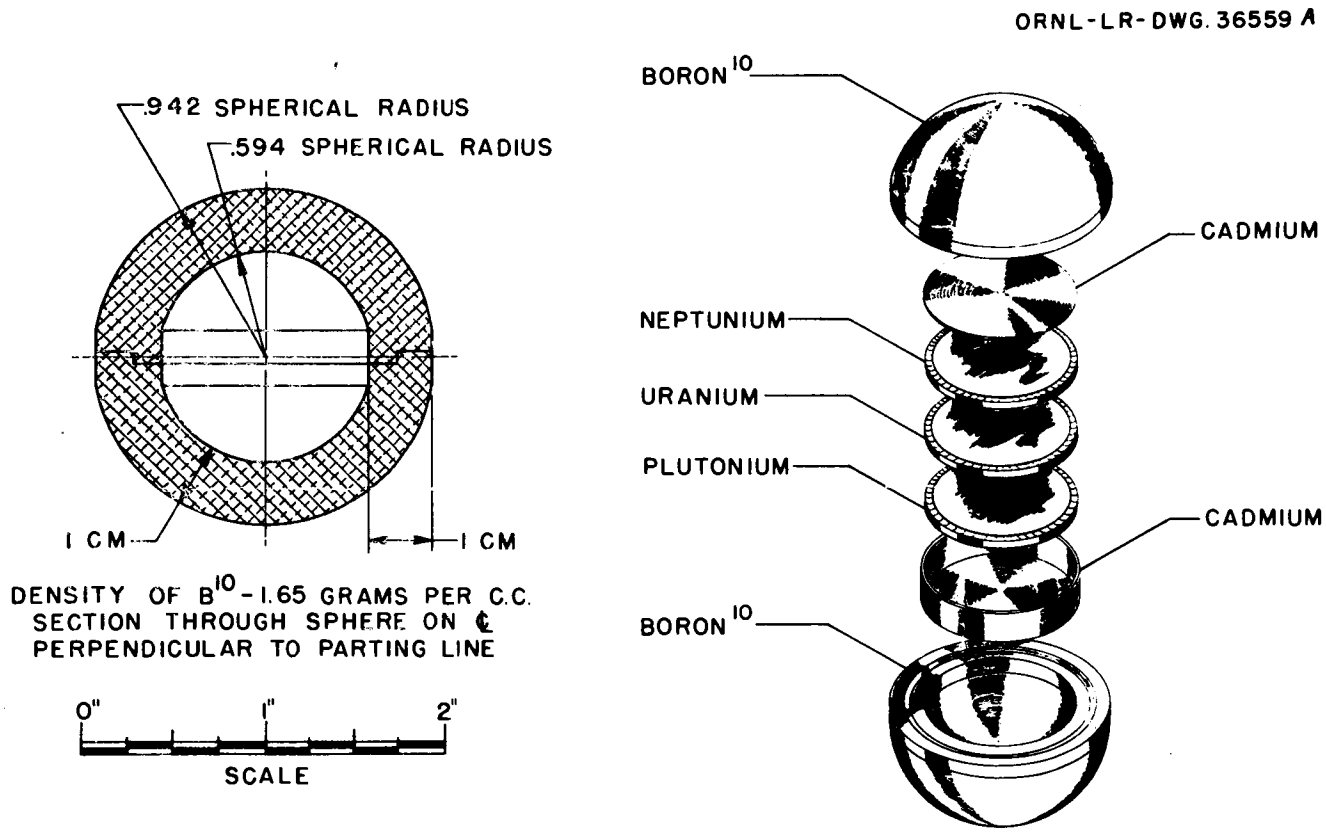


Figure G-1. Exploded View of the Hurst Threshold Detector Unit

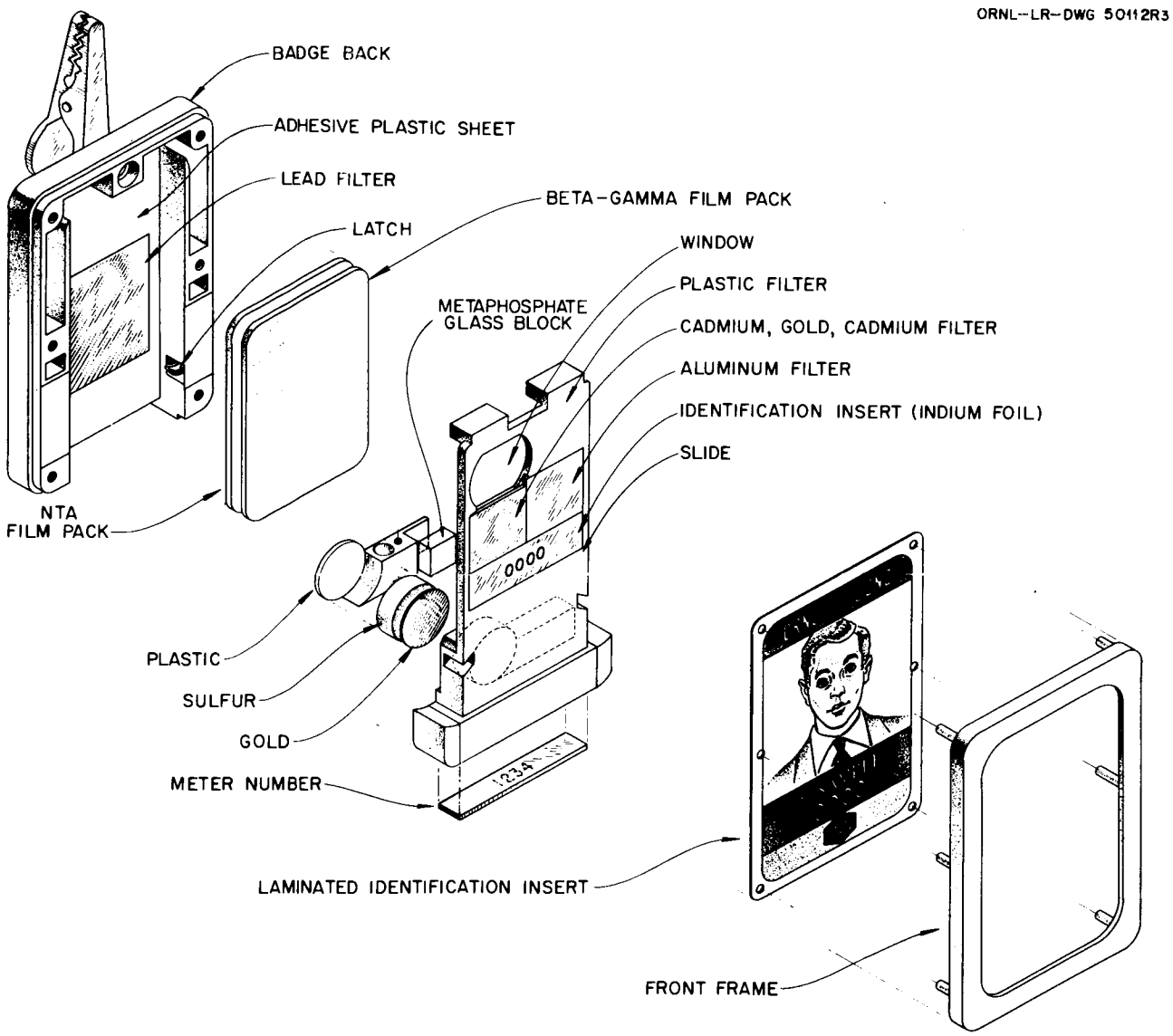


Figure G-2. Exploded View of the ORNL Security Badge Pass Meter

APPENDIX H

R. S. LANDAUER, JR. & COMPANY (PARTICIPATION BY MAIL)

REPRESENTATIVE: R. V. WHEELER, ASSISTANT MANAGING DIRECTOR

Following are the results of our recent criticality detector test. Since our counting system is not accurately calibrated for the foils used, I would not be surprised if significant errors resulted in the interpretation of the neutron dose.

Burst #1	Dosimeters #1, 2 and 3	65.8 Rad neutron
		15.6 Rad gamma
		81.4 Rad
Burst #2	Dosimeters #4, 5 and 6	19.3 Rad neutron
		Minimal Rad gamma
		19.3 Rad
Burst #3	Dosimeters #7, 8 and 9	63.4 Rad neutron
		8.0 Rad Gamma
		71.4 Rad

A cross sectional display of the criticality dosimeter which specifies the location and dimensions of the foils used is shown in Figure H-1. Specifically, they include the following:

1. Bare Gold
2. Cadmium Wrapped Gold
3. Indium
4. Sulfur
5. Silver Activated Phosphate Glass

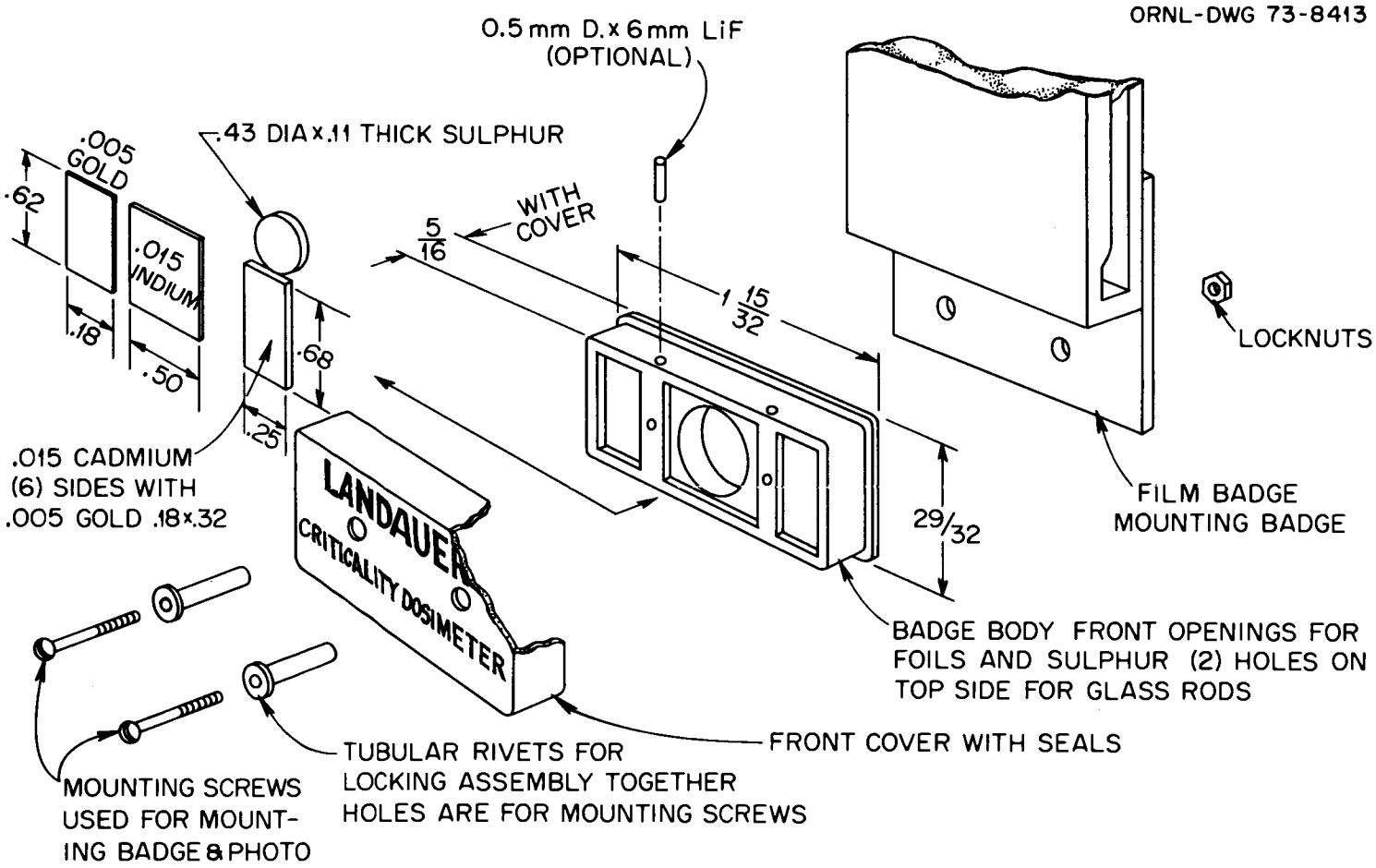


Figure H-1. Exploded View of the Landauer Criticality Dosimeter

APPENDIX I

RADIATION DETECTION COMPANY (PARTICIPATION BY MAIL)

REPRESENTATIVE: EUGENE TOCHILIN, VICE PRESIDENT

This summarizes the neutron and gamma-ray measurements obtained with our criticality film badge. Criticality badge A is our normal badge and contains the following detectors.

1. Bare gold foil 1/4" x 1/4" sqare, 0.005" thick
2. Indium foil 11/16" x 11/16" square, 0.005" thick in front of the Pb filter
3. 0.5 gram sulfur in the form of 3 sulfur pellets
4. 30 mg of encapsulated LiF powder

Badge B was identical to A except that the indium foil was located above the film in the area containing the gold, sulfur and TLD detectors. Badge C contained no indium. These three configurations allowed us to determine if the activated indium foil was significantly influencing the gamma-ray reading obtained under the lead filter.

There was not detectable difference between gamma-ray readings obtained from Badges A, B, or C for the three bursts during which the badges were exposed. It is therefore concluded that thermal neutron activation of the indium foil has negligible effect on film blackening relative to that produced by the accompanying gamma rays.

Badges A, B, and C were exposed together for shots 1, 2, and 4. The results obtained are the average of three dosimeter readings, which agreed to within 10 percent.

Table I-1 summarizes the thermal neutron and sulfur fast neutron measurements obtained with the calibrated gold and sulfur detectors,

counted with a GM counter. Column 3 gives the gold thermal neutron measurements used to determine the thermal neutron response of film. Column 4 gives the thermal neutron fluence assuming a cadmium ratio of 3.0. The cadmium ratio ranges from about 2.5 to 6 for reactor excursions depending upon the amount of moderation encountered. An assumed ratio of 3.0 gives a value accurate to ±20% within these extreme limits. Column 5 gives the fast neutrons above an assumed sulfur threshold energy is 2.9 MeV, with an effective cross section of 300 millibarns. Column 6 is the sulfur rads based on 3.1 rads per 10^9 sulfur n/cm^2. The fast neutron dose is obtained by assuming that the sulfur dose is 20% of the total fast neutron dose (this assumption holds reasonably well for a bare reactor or one moderated with hydrogen, but not for other materials). It is apparent that one needs some information on the leakage spectrum before a fast neutron dose can be assigned from sulfur measurements.

TABLE I-1

THERMAL AND FAST NEUTRON FLUENCE MEASURED WITH GOLD AND SULFUR DETECTORS IN RDC CRITICALITY FILM BADGE

Burst No.	Dosimeter No.	Gold n/cm^2	Thermal Neutron n/cm^2	Sulfur[a] n/cm^2	Sulfur[b] n/cm^2	Fast[c] Neutron rads
1	1-A, B, C	1.8×10^{10}	1.3×10^{10}	1.8×10^{10}	56.5	283
2	2-A, B, C	2.1×10^{10}	1.6×10^{10}	3.7×10^{9}	11.5	58
4	4-A, B, C	7.6×10^{9}	5.6×10^{9}	2.1×10^{10}	65	325

[a]Assume effective threshold energy of 2.9 MeV and effective cross section of 300 millibarns.

[b]Based on 3.1 rads per 10^9 sulfur n/cm^2

[c]Assume sulfur dose is 20% of fast neutron dose

Note: Bursts 1 and 4 were unmoderated

Burst 2 had a 12 cm Lucite shield between the reactor and and the dosimeter

TABLE I-2

FILM AND LiF GAMMA-RAY MEASUREMENTS IN RDC

CRITICALITY FILM BADGE

Dosimeter Number	Film R	Corrected[a] Film R	LiF R	Corrected[b] LiF R
1-A, B, C	46	39	50	38
2-A, B, C	37	34	44	36
4-A, B, C	44	35	52	43

[a]Film readings corrected as follows:

100 rads fast neutrons produce 2.0 equivalent R

10^{10} thermal gold n/cm^2 produce 3.5 equivalent R

[b]LiF readings corrected as follows:

100 rads fast neutrons produce 2.0 equivalent R

10^{10} thermal n/cm^2 produce 1.1 equivalent R

APPENDIX J

ORNL - DOSAR EXPERIMENTAL DOSIMETER

The use of TSEE dosimeters for fast neutron dosimetry in mixed radiation fields is based upon the detection of recoil protons from external radiators in contact with the dosimeter. The front face of one ceramic BeO detector is covered with a polyethylene layer, while a second dosimeter is covered with a non-hydrogenous, low-Z material such as graphite or teflon. After proper calibration, the difference between the polyethylene-covered dosimeter and the teflon - covered dosimeter gives an indication of the fast neutron dose. The response of the teflon covered dosimeter indicates the magnitude of the gamma-ray dose. For high dose levels encountered under accident conditions the dosimeters are evaluated by use of an ionization chamber-type TSEE counter.

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