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JANUARY 1976

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OAK RIDGE NATIONAL LABORATORY
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ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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ABSTRACT

An intercomparison of personnel monitoring dosimeters was conducted at Oak Ridge National Laboratory's DOSAR Facility during the period May 14-16, 1974. Ten independent laboratories and companies participated in an intercomparison of neutron and gamma-ray dosimeters used for routine personnel dosimetry. The dosimeters, which were sent through the mail, were exposed at the Health Physics Research Reactor to the same three "standardized" radiation fields which have been used for the past several years for intercomparing nuclear accident dosimeters. In addition, a 14-MeV neutron field was used as a fourth exposure configuration. The results of the intercomparison show widely varying dose estimates. The average of the reported values of neutron dose equivalent, for example, has standard deviations ranging from 47-102%.

For the past nine years the annual dosimetry intercomparisons[1,2] at the Oak Ridge National Laboratory's DOSAR Facility have provided an opportunity for laboratories in the United States and foreign countries to test dosimetry systems in simulated nuclear accident situations. These studies have been successful in developing guidelines in instrumentation and procedures and in establishing "standardized" radiation fields whose characteristics such as energy spectrum, intensity, and uniformity have been measured and accepted. The Health Physics Research Reactor (HPRR) has been used as the pulsed radiation source. The bare unshielded reactor or the reactor used with either of two shields--a 12-cm-thick Lucite shield or a 13-cm-thick steel shield--provides three different neutron and gamma-ray spectra.

Many experimenters over the years have expressed interest in using the same "standardized" radiation fields for the comparison of the response of routine personnel dosimeters used at low radiation levels typically encountered in personnel monitoring. Recently other groups, including the Nuclear Regulatory Commission (NRC), became interested in the same project. As a result, an

Intercomparison of Personnel Dosimeters was conducted during the period May 14-16, 1974, with ten groups participating. The participants included (1) Brookhaven National Laboratory, (2) Dow Chemical Company, Rocky Flats, (3) Gesellschaft für Kernforschung (GFK), Karlsruhe, Germany, (4) Lawrence Livermore Laboratory, (5) Los Alamos Scientific Laboratory, (6) Naval Ordnance Laboratory, (7) Oak Ridge National Laboratory, (8) R. S. Landauer, Jr., and Company, (9) Savannah River Laboratory and (10) Union Carbide Nuclear Division Y-12 Plant. The participants are listed in Appendix A.

The HPRR and a 14-MeV neutron generator were used to expose personnel dosimeters to mixed neutron and gamma fields. The reactor was operated in a steady-state mode at a power level of one watt for a length of time necessary to produce a radiation field with a dose range likely to be encountered in personnel monitoring. The neutron generator was operated to produce a similar range of radiation levels. Since dose equivalents of a few hundred millirem are commonly encountered, this order of magnitude was selected. In order to produce this range of radiation levels, a free air tissue kerma of approximately 40 mrad was selected for the neutron component and the reactor operating time was calculated based on this kerma. The resultant reactor runs were performed as shown in Table 1.

During the course of this intercomparison, the DOSAR Low-Energy Accelerator (DLEA) was unavailable for the production of neutrons; consequently, the 14-MeV neutron exposures were made using a small, Phillips, sealed-tube, neutron generator whose radiation field components were not as well known as those for the DLEA. In addition to the 14-MeV neutrons, there was a significant exposure due to low-energy x-rays ($E \leq 150$ keV). The reference dosimetry performed for this source was not as accurate as that for the reactor; however, since the purpose was intercomparison, this did not represent a serious problem.

All badges were placed on water-filled trunk portions of Bomab phantoms at three meters in the case of the reactor exposures and at one meter in the case of the 14-MeV exposure. When shields were used, they were placed at two meters. The placement of dosimeters on the phantoms is shown in Fig. 1, while a typical experimental arrangement with reactor and shields in place is given in Fig. 2.

Generally, the dosimeters were mailed or shipped to the DOSAR a few days in advance of the intercomparison. The dosimeters were returned in a similar manner the day after the intercomparison exposures were completed. Exceptions to this procedure were that local laboratories hand-carried their dosimeters back and forth. Because dosimeters from Karlsruhe, Germany, arrived late, it was necessary to make an additional exposure on an independent but "identical" basis. The types of dosimeters used by the participants are listed in Table 2. The participants were also provided with the calculated neutron spectra shown in Table 3, the reactor operation data shown in Table 1, and the position of their dosimeters as shown in Fig. 1.

Sulfur pellets exposed on the reactor during the intercomparison exposures gave kerma estimates for the three-meter position of 36, 42, and 35 mrad for the unshielded, steel-shielded, and Lucite-shielded runs, respectively. The count rates on the sulfur pellets were quite low, and a standard deviation of ± 20% was expected due to counting statistics and other sources of error. Based upon the neutron spectra that have been published[3] for the three exposure configurations used, the dose and dose equivalent can be calculated. Using the dose conversion factors given in Radiation Dosimetry[4] for that section of a phantom designated element 57, the dose conversion factors for the HPRR spectra were calculated and are shown in Table 4. Average quality factors determined by Murphy *et al.*[5] were used for calculating dose equivalent, and these values are also given in Table 4. Using the fission yield and the calculated leakage of the HPRR, the neutron fluence was calculated for each reactor run. By applying the previously determined dose conversion factors and average quality factors, the dose and dose equivalent were calculated and are given in Table 5.

In the case of the 14-MeV exposure, the dose equivalent was monitored by a tissue-equivalent proportional counter used in an integrating mode and placed at the approximate position of the dosimeters. This monitor indicated a dose equivalent of 325 mrem for the operation. Due to variations in the angular intensity of the radiation around the neutron generator tube, it is expected that the actual dose equivalent varied from phantom to phantom. The high x-ray exposure levels that were encountered were not anticipated, and no provision was made to monitor them. A summary of the reference values of neutron dose and dose equivalent for the four exposures is presented in Table 6.

Gamma exposures varied; but, using previous intercomparison results, gamma doses of 5.6, 4.7, and 34.5 mrad were calculated based on the number of fissions that occurred on the three respective runs during the operation of the reactor. In actuality, the dosimeters accumulated additional gamma exposure from the residual activity in the reactor core. The exposure rate at three meters from the unshielded reactor was approximately 15 mR/hr. A good estimate of the gamma dose is not possible due to the varying lengths of time the dosimeters remained in proximity to the reactor and the varying attenuation through the shields. However, it is reasonable to assume that 15-20 mrad could be added to the dose delivered during the actual reactor operation. This would suggest gamma doses of 20-25 mrad for the unshielded and steel-shielded runs and 50-55 mrad for the Lucite-shielded run.

The results of all participants are given in Tables 7 through 10 for the four exposure configurations used during the intercomparison. The averages of the participants' estimates were 453 ± 213 mrem for the bare reactor, 554 ± 346 mrem for the steel-shielded reactor, and 675 ± 687 mrem for the Lucite-shielded reactor. Several of the participants gave several dose estimates either due to the use of multiple dosimeters or due to various means of interpreting their results. The average includes all estimates that the participants claimed to be valid, even those taking into account actual knowledge of the spectra. The results of the GFK laboratory (I) are included but not averaged with the others. This is because the GFK dosimeters arrived late and had to be exposed at a different time but under "identical" conditions. The operation of the reactor should be reproducible to within a few percent, and the GFK results should be in good agreement with the others for the three reactor runs. In the case of the 14-MeV exposure, the conditions for GFK were altered by placing a lead shield around the sealed source tube to attenuate the low-energy photons (≤ 150 keV) from the accelerator. This explains the significantly smaller gamma dose reported by GFK.

A summary of the results is presented in Table 11. It is reasonable to expect a more favorable agreement between the several participating laboratories if the results of experimental devices and nonroutine dosimeters are ignored or if a selective data handling technique is used. For example, if the extreme data points for each of the phantoms in Tables 7 through 9 are excluded, the resultant average dose-equivalent estimates are 431 ± 112, 539 ± 238, and 501 ± 240 mrem, respectively. Also, if the upper and lower extremes are excluded from the 14-MeV results, the average neutron dose equivalent becomes 409 ± 154 mrem.

This adjunct study was found to be valuable to the participants, and the results were indicative of some trouble spots in the interpretation of dosimeter responses. This addition to our dosimetry intercomparison program was judged to be worthwhile, and plans are under way to continue these studies in the future.

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LIST OF TABLES

Table 1. Summary of Reactor Operations for Intercomparison

Run No.	Shield	Power	Time (min.)	Fissions
1	Unshilded	1 watt	5.0	9.25×10^{12}
2	Steel	1 watt	13.9	2.57×10^{13}
3	Lucite	1 watt	26.4	4.90×10^{13}

Table 2. Dosimeters Used by Participants

	Dosimeter Type	
Group	Neutron	Gamma
A-1	TL pair	TLD
A-2	Thorium	—
A-3	Standard interpretation	—
A-4	NTA film	Film
B	TLD albedo	TLD
C-1	TLD albedo	—
C-2	NTA film	Film
D	TLD albedo	TLD
E	TLD albedo	TLD
F-1	NTA film	Film
F-2	TLD albedo	TLD
F-3	TLD albedo	TLD
G	NTA film	Film
H	TLD albedo	TLD
I	TLD albedo	TLD
J	—	Film/TLD

Table 3. Calculation of HPRR Spectrum for NAD Intercomparisons

Group	Upper Energy (ev)	Mid Energy (ev)	N(E)ΔE*		
			No Shield	Lucite Shield	Steel Shield
1	1.49 E7	1.22 E7	9.53 E7	3.31 E7	1.35 E7
2	1.0 E7	8.19 E6	1.18 E9	3.63 E8	1.5 E7
3	6.7 E6	5.77 E6	3.43 E9	4.29 E8	3.8 E8
4	4.97 E6	3.87 E6	1.44 E10	2.58 E9	1.57 E9
5	3.01 E6	2.12 E6	3.76 E10	5.56 E9	7.94 E9
6	1.5 E6	1.16 E6	3.16 E10	3.19 E9	1.21 E10
7	9.07 E5	6.08 E5	4.61 E10	3.69 E9	3.34 E10
8	4.08 E5	2.13 E5	3.39 E10	3.08 E9	5.02 E10
9	1.11 E5	9.80 E4	2.60 E9	4.18 E8	2.13 E9
10	8.65 E4	7.64 E4	2.0 E9	3.81 E8	2.91 E9
11	6.74 E4	5.95 E4	1.5 E9	3.49 E8	1.41 E9
12	5.25 E4	4.63 E4	1.21 E9	3.24 E8	1.25 E9
13	4.09 E4	3.61 E4	9.71 E8	3.05 E8	5.61 E8
14	3.18 E4	2.81 E4	8.40 E8	2.98 E8	6.64 E8
15	2.48 E4	2.19 E4	7.35 E8	2.76 E8	2.5 E8
16	1.93 E4	1.70 E4	6.37 E8	2.66 E8	1.01 E8
17	1.50 E4	1.03 E4	1.58 E9	7.60 E8	1.14 E8
18	7.10 E3	4.88 E3	1.39 E9	7.23 E8	1.02 E8
19	3.35 E3	2.03 E3	1.62 E9	9.48 E8	1.16 E9
20	1.23 E3	8.48 E2	1.04 E9	6.97 E8	4.2 E8
21	5.83 E2	3.54 E2	1.24 E9	9.21 E8	4.47 E8
22	2.14 E2	1.47 E2	8.45 E8	6.91 E8	3.14 E8
23	1.01 E2	6.96 E1	7.76 E8	6.90 E8	2.88 E8
24	4.79 E1	3.73 E1	4.72 E8	4.59 E8	1.69 E8
25	2.90 E1	2.26 E1	4.54 E8	4.60 E8	1.67 E8
26	1.76 E1	1.37 E1	4.34 E8	4.61 E8	1.61 E8
27	1.07 E1	7.34	6.09 E8	6.93 E8	2.11 E8
28	5.04	3.93	3.82 E8	4.58 E8	1.28 E8
29	3.06	2.18	4.84 E8	6.11 E8	1.71 E8
30	1.56	1.25	3.04 E8	3.79 E8	1.12 E8
31	1.0	8.06 E-1	2.81 E8	3.41 E8	9.16 E7
32	0.65	5.41 E-1	2.42 E8	2.86 E8	7.83 E7
33	0.45	2.12 E-1	1.78 E9	2.67 E9	5.63 E8
34	0.1	2.24 E-2	3.36 E9	1.95 E10	1.09 E9
	5.0 E-3				

*This number is the area of the histogram for each energy interval.

Table 4. Dose Conversion Factors and Average Quality Factors for HPRR Spectra

Shield	Dose Conversion Factor (mrad cm^2 x 10^{-7})	$\overline{QF}$
Unshielded	25.5	9.4
Steel	17.9	9.5
Lucite	14.6	8.9

Table 5. Absorbed Dose and Dose Equivalent Calculated from HPRR Fission Yields

Reactor Run	Shield	Fissions (x 10^{-12})	Fluence (cm^{-2} x 10^7)	Dose (mrad)	Dose Equivalent (mrem)
1	Unshielded	9.25	1.82	46.4	436
2	Steel	25.7	3.11	55.7	529
3	Lucite	49.0	2.60	38.0	338

Table 6. Reference Values of Dose and Dose Equivalent

Run	Spectrum	Dose (mrad)		Dose Equivalent (mrem)	
		Calculated	Measured	Calculated	Measured
1	Unshielded HPRR	46.4	36 ± 7.2	436	—
2	Steel-shielded HPRR	55.7	42 ± 8.4	529	—
3	Lucite-shielded HPRR	38.0	35 ± 7.0	338	—
4	14 MeV	43.9	—	—	325

Table 7. Results of Personnel Dosimeter Intercomparison

May 14-16, 1974 — Bare Reactor

Group	Phantom No. 1		Phantom No. 2		Phantom No. 3	
	n (mrem)	γ (mrem)	n (mrem)	γ (mrem)	n (mrem)	γ (mrem)
F-1	140	31	140	23	160	23
F-2	952	23	865	25	921	28
F-3	662	23	594	26	512	19
E			540	20		
H	420	30	405	25	395	25
C-1			307			
C-2			307	20[a]		
D	380	23	350	23	370	23
G	220	30				
A-1	582	25				
A-2	520					
A-3	435					
A-4	350	30	350	30	350	30
B	510	22			510	22
J						35/14[b]
I			383	35		
Avg.	470	25.9	429	24.0	460	24.3

[a] mR, not mrem

[b] First number given is based on a film dosimeter, and the second number is based on a TLD.

Table 8. Results of Personnel Dosimeter Intercomparison

May 14-16, 1974 — Steel Shield

Group	Phantom No. 1		Phantom No. 2		Phantom No. 3	
	n (mrem)	γ (mrem)	n (mrem)	γ (mrem)	n (mrem)	γ (mrem)
F-1	50	19	20	19	40	19
F-2	1120	24	1112	17	1259	24
F-3	1050	22	1144	20	870	21
E			690	20		
H	565	20	690	20	620	20
C-1			378			
C-2			302	12[a]		
D	410	16	410	17	420	17
G	400	20				
A-1	612	15				
A-2	484					
A-3	223					
A-4	330	20	330	20	330	20
B	550	11			550	11
J						28/15[b]
I			402	14		
Avg.	527	18.6	564	18.1	584	19.4

[a] mR, not mrem

[b] First number given is based on a film dosimeter, and the second number is based on a TLD.

Table 9. Results of Personnel Dosimeter Intercomparison
May 14-16, 1974 — Lucite Shield

Group	Phantom No. 1		Phantom No. 2		Phantom No. 3	
	n (mrem)	γ (mrem)	n (mrem)	γ (mrem)	n (mrem)	γ (mrem)
F-1	100	89	140	89	90	89
F-2	2515	95	2437	84	2422	86
F-3	870	89	1000	83	1272	97
E			380	60		
H	405	65	405	65	425	65
C-1			443			
C-2			297	63[a]		
D	420	76	400	70	440	69
G	500	85				
A-1	431					
A-2	451					
A-3	434					
A-4	400	90	400	90	400	90
B	383	51			383	51
J						67/54[b]
I			418	65		
Avg.	628	80	656	75.5	776	74.2

[a] mR, not mrem

[b] First number given is based on a film dosimeter, and the second number is based on a TLD.

Table 10. Results of Personnel Dosimeter Intercomparison
May 14-16, 1974 — 14-MeV Neutrons

Group	Phantom No. 1		Phantom No. 2		Phantom No. 3	
	n (mrem)	γ (mrem)	n (mrem)	γ (mrem)	n (mrem)	γ (mrem)
E			390	600		
H	315	320	225	265	225	270
C-1 C-2			308 283	307[a]		
D	1600	310	1400	160	1400	120
G	100	700				
A-3 A-4	587 220	505 490	587	505	587	505
J						375
B		435				435
I			341	24[b]		
Avg.	564	460	532	367	737	341

[a]mR, not mrem [b]Source shielded with lead

Table 11. Summary of Results

Exposure Condition	Neutron Dose Equivalent (mrem)	Gamma Dose Equivalent (mrem)
Bare Reactor	453 ± 213	24.6 ± 5.9
Steel-Shielded Reactor	554 ± 346	18.1 ± 4.3
Lucite-Shielded Reactor	675 ± 687	75.1 ± 14.2
14 MeV	587 ± 501	384 ± 151

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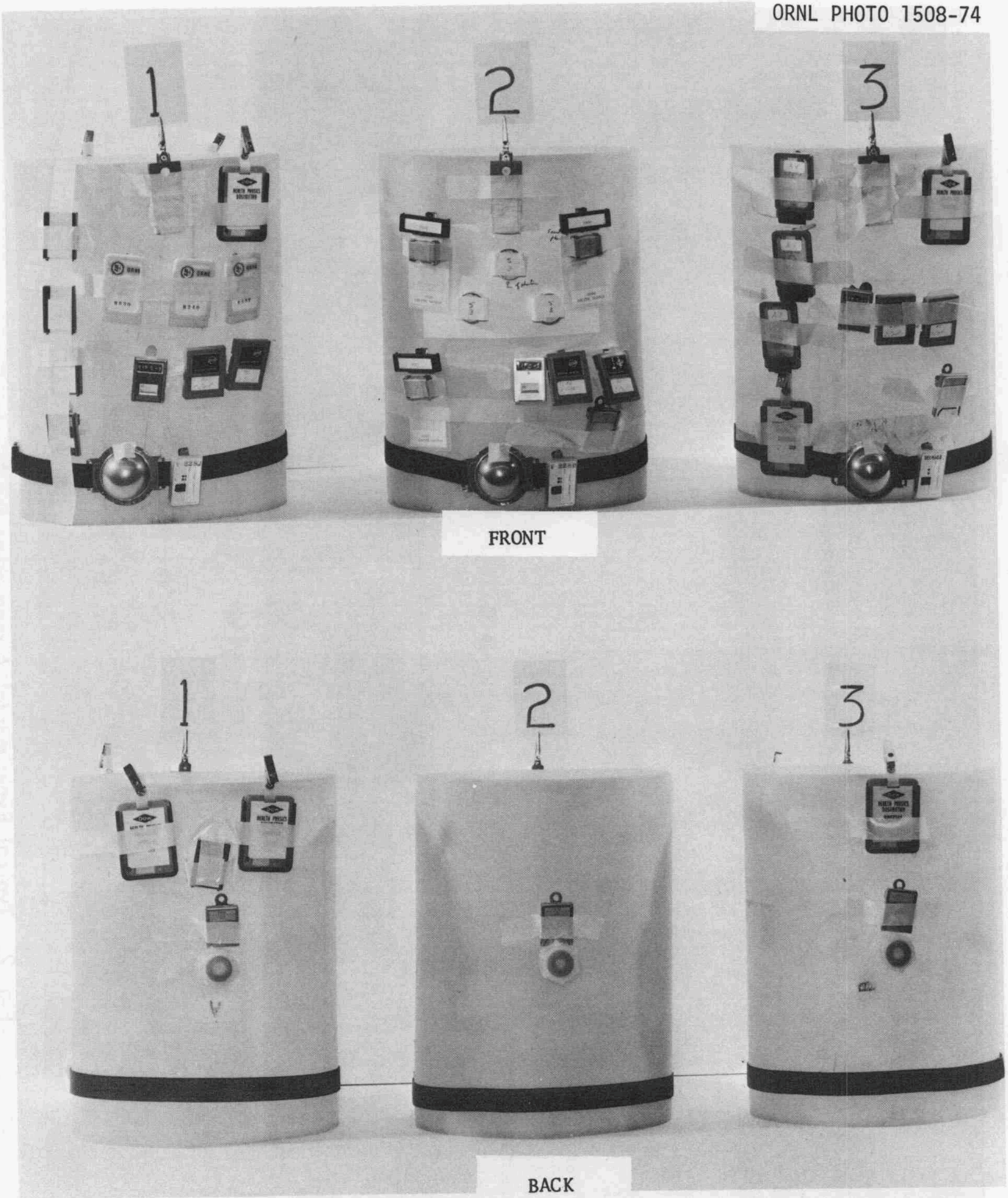

Fig. 1. Typical Placement of Dosimeters on Phantom Section

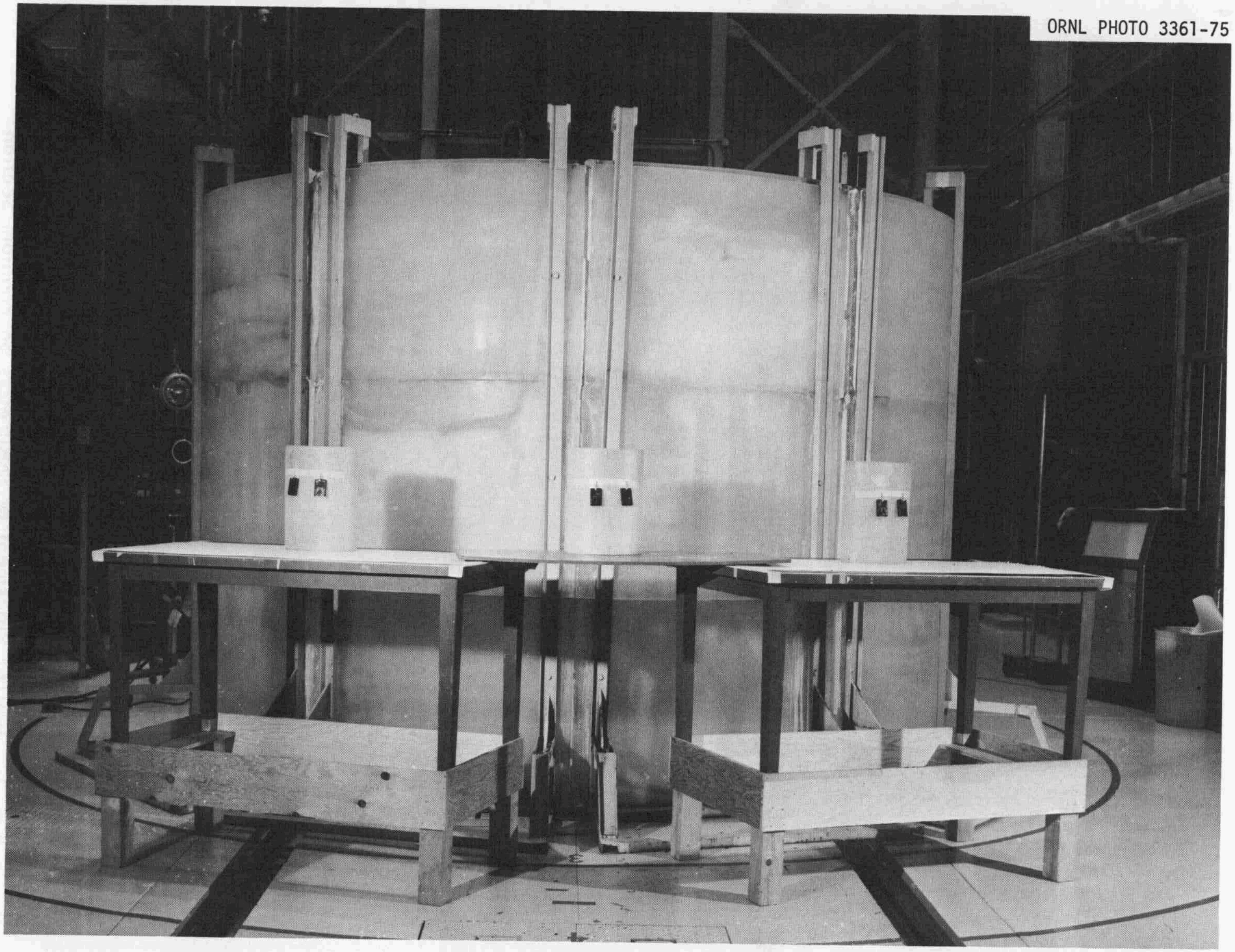

Fig. 2. Typical Experimental Arrangement for Reactor Exposures

APPENDIX A

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PERSONNEL DOSIMETER INTERCOMPARISON
May 14-16, 1974

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