27
2-27-80

ornl

MASTER

ORNL/TM-7155

**OAK
RIDGE
NATIONAL
LABORATORY**

**UNION
CARBIDE**

**Fifth Personnel Dosimetry
Intercomparison Study**

C. S. Sims

**OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A05; Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/TM-7155

Contract No. W-7405-eng-26

Health and Safety Research Division

FIFTH PERSONNEL DOSIMETRY INTERCOMPARISON STUDY

C. S. Sims

Date Published: February 1980

NOTICE This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

CONTENTS

	<u>Page</u>
LIST OF FIGURES	iv
LIST OF TABLES.	v
ACKNOWLEDGEMENTS.	vii
HIGHLIGHTS.	1
INTRODUCTION.	2
PARTICIPATION	2
EXPERIMENT DESCRIPTION.	3
DOSIMETER TYPES	4
REFERENCE DOSIMETRY	4
Sulfur Pellet Analysis	5
Tissue Equivalent Ionization Chamber (TEIC).	6
Calculations	6
RESULTS AND ANALYSIS.	7
Neutron Dose-Phantom Front	8
Gamma Dose-Phantom Front	10
Neutron Dose-Phantom Rear.	13
Gamma Dose-Phantom Rear.	13
CONCLUSIONS	14
EPILOGUE.	15
REFERENCES.	16
APPENDIX A.	39
APPENDIX B.	43
APPENDIX C.	49
APPENDIX D.	53
APPENDIX E.	57
APPENDIX F.	61

LIST OF FIGURES

	<u>Page</u>
1 Lucite shield	18
2 Concrete shield	19
3 Experimental arrangement for PDIS exposures	20

LIST OF TABLES

	<u>Page</u>
1 Summary of experimental conditions	21
2 Dosimeters as described by the participants	22
3 Reference gamma dose equivalent	23
4 Neutron dose equivalent from sulfur pellet analysis	24
5 Neutron dose equivalent from tissue equivalent ionization chamber measurements	24
6 Neutron dose equivalent from calculations	25
7 Reference neutron dose equivalent	26
8 Tabulation of reported results — PDIS 5, run 1, unshielded .	27
9 Tabulation of reported results — PDIS 5, run 2, unshielded .	28
10 Tabulation of reported results — PDIS 5, run 3, Lucite shield	29
11 Tabulation of reported results — PDIS 5, run 4, Lucite shield	30
12 Tabulation of reported results — PDIS 5, run 5, concrete shield	31
13 Tabulation of reported results — PDIS 5, run 6, concrete shield	32
14 Analysis of neutron dose equivalent results on front of phantoms	33
15 Neutron dose equivalent on front of phantoms by type of dosimeter	34
16 Analysis of gamma dose equivalent results on front of phantoms	35
17 Gamma dose equivalent on front of phantoms by type of dosimeter	36
18 Analysis of neutron dose equivalent results on rear of phantoms	37
19 Analysis of gamma dose equivalent results on rear of phantoms	38

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

ACKNOWLEDGMENTS

The intercomparison study was conducted in an orderly fashion and without problem due to the commendable efforts of M. R. Davis in handling the return of the dosimeters to the participants, H. W. Dickson in providing overall guidance to the study, L. W. Gilley in reactor operation and experimental setup, and G. R. Patterson in dosimeter preparation and evaluation.

FIFTH PERSONNEL DOSIMETRY INTERCOMPARISON STUDY

C. S. Sims

HIGHLIGHTS

The fifth in the continuing series of Personnel Dosimetry Intercomparison Studies was held March 20-22, 1979, at the Oak Ridge National Laboratory. The Health Physics Research Reactor (HPRR) served as the source of low-level radiation doses (1-15 mSv^{*} neutron, 0.1-1 mSv gamma) during six different runs using shields to provide three different neutron and gamma spectra. Participants from 29 organizations, the most in the history of the studies, exposed various types of personnel dosimeters mounted on phantoms. Typical reported dose equivalents varied by factors of 2 to 3 for neutrons and 3 to 4 for gamma-rays. Although thermoluminescent (TLD) albedo dosimeters were the most popular, track dosimeters generally provided the most accurate measurements of neutron dose equivalent. The gamma dose equivalent was most accurately measured by TLDs; however, one particular type (TLD-100) was found to be unsatisfactory (results much too high) for measurement of HPRR gamma-rays. Film was found to be unsatisfactory (results much too low) for the measurement of HPRR neutrons. It appears that more accurate measurements could be made if some participants would select dosimeters better suited to measure the various types of radiation and others would give greater attention to the response characteristics of their dosimeters and make corrections based on those characteristics and a knowledge of the spectrum being measured. Even though improved dose estimates can be made by more suitable dosimeter selection and better analysis techniques, the study

^{*}1 mSv = 100 mrem.

results are a strong indication that more research and development work is needed in mixed field radiation dosimetry.

INTRODUCTION

The fifth Personnel Dosimetry Intercomparison Study (PDIS) was conducted at the Oak Ridge National Laboratory's (ORNL) Dosimetry Applications Research (DOSAR) facility on March 20-22, 1979. This study is the latest PDIS in the continuing series¹⁻⁴ started at the DOSAR facility in 1974. The PDIS is a three day study, typically in March, where personnel dosimeters are mailed to the DOSAR facility, exposed to a range of low-level* neutron radiation doses (1-15 mSv or equivalently, 100-1500 mrem)[†] and neutron-to-gamma ratios (1:1-10:1) using the Health Physics Research Reactor (HPRR)⁵ as the radiation source, and returned to the participants for evaluation. This report is a summary and analysis of the results reported by the various participants. The participants are able to "intercompare" their results with those of others who made dose measurements under identical experimental conditions.

PARTICIPATION

Twenty-nine organizations, the most in PDIS history, participated in the March, 1979, study. Twenty-two organizations were from the United States, six were from Europe, and one was from Canada. These organizations include dosimeter vendors, national laboratories, the

*The DOSAR staff also conducts an annual Nuclear Accident Dosimetry (NAD)⁶ intercomparison study in August. Typical neutron doses in the NAD studies are in the range 0.25-8 Gy (25-800 rad).

[†]Radiation dose and dose equivalent are presented in this report in the international system of units. Conversions to the more traditional units in which the results were originally reported to the DOSAR staff are also shown.

military, universities, and utilities. A complete list of study participants and the abbreviations by which they are identified throughout the report are given in Appendix A.

Participation has been unlimited and available to any organization legitimately interested in personnel dosimetry and willing to cooperate with the DOSAR staff. The participant pays dosimeter shipping costs and agrees to expeditiously furnish measurement results to share with the other participants. Additional details relative to participation are found in Appendix B which is the letter announcing the fifth PDIS study.

EXPERIMENT DESCRIPTION

The HP RR is a small, unmoderated, fast pulse reactor. Operating in the steady state mode, the HP RR served as the radiation source for the six different exposures made during the fifth PDIS. Various dose equivalents and neutron-to-gamma ratios likely to be encountered in personnel dosimetry were produced by controlling the reactor power level and run duration and by utilizing three different shielding conditions: unshielded, a 12-cm-thick Lucite shield, and a 20-cm-thick concrete shield. Physical details of the shields are shown in Figs. 1 and 2. The two-dimensional discrete ordinates transport (DOT) code calculated neutron spectra^{6,7} for the various shielded conditions are presented in Appendices C and D.

Dosimeters were generally mounted on the front surfaces (i.e., the surfaces facing the HP RR and 3 m from it) of trunk sections of water-filled Bomab⁸ phantoms. The Bomab trunk section has an elliptical cross

section with dimensions 20 cm $\times$ 30 cm and is 40 cm high. Some participants chose to have their dosimeters mounted on the rear of the Bomab.

Figure 3 is a schematic which shows the positioning of the phantoms, the shields, and the HPRR for all six exposures made during the fifth PDIS. Table 1 is a summary of the experimental conditions. It should be noted from Table 1 that the actual neutron dose equivalents for a particular shielding configuration should be in the same ratio as the number of fissions (e.g., the dose equivalent from exposure number 2 should be eight times larger than that from exposure number 1). The gamma dose is not in this ratio due to the significant contribution of residual gamma rays from fission products at these low power levels.

DOSIMETER TYPES

The types of dosimeters used in the fifth PDIS are summarized in Table 2. The descriptions given in the table were furnished by the participants who returned the Data Report Sheet (see Appendix E). Basically, participants used two types of dosimeters, film and thermoluminescent dosimeters (TLD), for gamma dose measurements. The dosimeter types used for neutron measurements included TLD, TLD-albedo, film, and track-etch. In the remainder of this report, the dosimeters are referred to as film, TLD (for TLD and TLD-albedo), and track (for track-etch). Descriptions of these dosimeter types are readily available in the literature.^{9,10}

REFERENCE DOSIMETRY

The gamma dose and the neutron dose were measured and calculated by DOSAR personnel for each of the runs during the PDIS in order to provide

reference dosimetry. The results presented below are the staff's best estimates of the actual dose equivalent.

The gamma dose on the front of the phantoms was measured by Harshaw TLD-700 ^7LiF chips calibrated using ^{226}Ra and by a small Geiger-Mueller (G-M) tube¹¹ with a lithium shield, calibrated using ^{60}Co . In addition, the gamma dose at an air station was measured with another G-M tube and converted to dose to the phantom by using ratios of phantom dose to dose in air developed through the years at the DOSAR facility. The dose at the rear of the phantom was also measured by TLD's. All of these results are reported in Table 3.

The DOSAR staff used three different methods to determine the neutron dose equivalent for the PDIS exposures. These methods are discussed below.

Sulfur Pellet Analysis

The foundation of routine neutron dosimetry at the HPRR is a standard sized (22 g) sulfur pellet¹² located at a fixed position near the reactor core. The induced ^{32}P beta activity of the pellet is measured after an operation and can be related to the unshielded tissue kerma at an area monitoring station at any distance from the HPRR via an accurately known neutron dose vs. distance relationship developed at the DOSAR facility over 16 years of operational experience. To obtain the dose equivalent on the front of a phantom, the unshielded dose is modified by an experimentally determined shield dose attenuation factor,¹³ a factor to convert from area monitor dose to phantom dose,¹³ and an effective quality factor^{14,15} (QF) for each spectrum. The QF used for the bare

and the Lucite shielded HPRR spectra are well supported numbers.^{3,14,15} Specifically, they are effective QF associated with element 57 (a surface element) of the Auxier phantom.¹⁶ The QF for the concrete shielded HPRR is much less certain; the value* used is the average of measurements¹⁵ (11.7) and calculations¹⁷ based on a Monte Carlo determined spectrum (7.9). The dose at the rear of the phantom is estimated by applying a front-to-rear conversion factor developed from previous PDIS results. The dose equivalents determined by this method are presented in Table 4.

Tissue Equivalent Ionization Chamber (TEIC)

The DOSAR facility has recently installed a TEIC to do on-line measurements. The sensor, designated RD-1 by the manufacturer,[†] is a 7.3-cm-diam. spherical ionization chamber filled with tissue equivalent gas and having 0.16-cm-thick walls made of Shonka A-150 plastic.¹⁹ The TEIC was calibrated by the vendor using ¹³⁷Cs and checked by the DOSAR staff using ⁶⁰Co. This TEIC was used to measure the total (i.e., neutron and gamma) dose at a monitoring station in air. The neutron dose was obtained by subtracting the gamma dose as determined by the previously mentioned G-M tube. The conversion from dose in air to dose equivalent on the phantom is the same as for the sulfur pellet analysis. The results are presented in Table 5.

Calculations

The energy expended (i.e., power level $\times$ time of operation) during each run was determined from HPRR instrumentation. By knowing the energy release per fission, the number of fissions during each run was

*The value used is 9.8. It should be noted that it is standard practice¹⁸ to use QF = 10 for cases where the neutron spectrum is completely unknown.

[†]Digital Data Dosimetry (Tulsa, Oklahoma).

calculated. The neutron fluence at the location of interest (3 m from HPRR) was computed from the number of fissions and the fluence per 10^{17} fissions from the DOT code calculated spectra (see Appendices C and D). Dose conversion factors, rads per unit fluence,^{*} have been determined¹ by multiplying the fluence in each energy interval of the spectra by the element 57 dose per unit fluence in that interval as tabulated¹⁶ and summing over all intervals. The calculated fluences were multiplied by these conversion factors to give the dose for each PDIS run. The conversion to dose equivalent on the front and on the rear of the phantoms was performed using the techniques described above. These calculated data are presented in Table 6.

The reference neutron dose equivalent for each run is shown in Table 7. The reference value is taken to be the average value determined from the sulfur pellet analysis and the TEIC measurements. The calculational method determined values are not included because they are traditionally not used⁴ and because there are unresolved anomalies^{4,20} between the DOT code calculated spectra and measurements made for steel and concrete shields at the DOSAR facility.

RESULTS AND ANALYSIS

The PDIS participants reported their results on sheets provided by the DOSAR staff (see Appendix E). Tables 8-13 contain the reported dose equivalent values and Appendix F is a compilation of the participants' dosimetry related comments included on the data report sheets. The DOSAR reference values are also included in the tables for ease of comparison, but are *not* included in any of the subsequent data manipulation

^{*}Equivalent international units are shown in Table 6.

(e.g., mean reported values). Six phantoms equidistant from the HPRR were required to accommodate the dosimeters exposed during each run. Dose results have not been reported by phantom since dose variation among dosimeters on the various phantoms has been shown to be insignificant.⁴

Neutron Dose-Phantom Front

Neutron dose equivalent results from measurements made on the front of phantoms are summarized in Table 14. When all of the reported results are considered, the mean values of the dose equivalent are significantly higher (an average of about 40% for the unshielded runs, about 300% for the Lucite shielded runs, and about 250% for the concrete shielded runs) than the reference values and the standard deviations range from 108 to 201%. The median^{*} values are, however, only 6-43% higher than the reference values for the six runs. That the participants in general had difficulty in making neutron dose measurements is further evidenced by the fact that the reported results for run 3 range from 0-155.8 mSv (0-15,580 mrem) and for run 5 range from 0.27-166.9 mSv (27-16,690 mrem).

In order that the statistical analysis of the data reported might be more representative of the ability of participants to quantify neutron dose, the data have been reanalyzed with two sets of results excluded. The RPB results were excluded because no attempt was made to correct for gross spectral differences between the calibration source used and the actual measurements made. The UTAH results were excluded because their method is actually only a screening method and not intended to measure dose accurately. This reanalysis is reported in Table 14 under the

^{*} Median values as well as mean values and standard deviations are reported so that the reader may more easily understand the variation among reported dose results.

column "Subset of reported results." These data have mean values which are higher than the reference values by an average of about 10% for the unshielded runs, 35% for the Lucite shielded runs, and 40% for the concrete shielded runs. The standard deviations are 46-100% of the means (the unshielded runs have lower standard deviations than the shielded runs) and the median values differ from the reference values by 1-18%. For measurements of neutron dose equivalent performed by several groups in the range 1-15 mSv (100-1500 mrem), these data indicate that:

- (a) it is not unusual for results to differ by a factor of 2 to 3,
- (b) unshielded doses are more accurately measured than shielded doses,
- (c) the majority of the reported doses are higher than the reference dose.

A summary of the neutron dose equivalent as measured by three different types of dosimeters is presented in Table 15. The data show that film users report dose equivalents which are much lower than the actual dose in every case; in fact, only in the case of run 4 is the mean value within two standard deviations of the reference value. The mean values are less than 40% of the reference values for all cases. These low results are explained by the fact that film generally fails to respond to neutrons with energies below about 0.5 MeV (refs. 10 and 18) and has relatively low response to neutrons with energies up to about 1.2 MeV.¹⁰ This energy response also explains why the film results were slightly better for the unshielded runs than for the shielded runs. In addition, film can have a fading problem resulting in low dose values if it is not carefully packaged and read promptly after exposure to radiation.

In general, track dosimeters yielded results closer to the reference values than did the other type dosimeters. The median values were within 17% of the reference values for all cases. Except for run 1 where a single reported result was exceptionally high, the mean values for track results were within 15% of the reference values and the standard deviations were less than for the other type dosimeters. It should, however, be pointed out that no individual track dosimeter user reported results within 23% of the reference values for all runs.

The neutron dose equivalent results reported by TLD (primarily TLD albedo) users are very good for the unshielded runs (i.e., runs 1 and 2). As determined from Table 15, the median values for these runs are within 14% of the reference values and the mean values are within 11% of the reference values. In contrast, the TLD results for the shielded runs (i.e., runs 3-6) are not good. The mean and median values for these runs are higher than the reference values by factors of 1.6-2.0.* When a shield is placed between the HPRR and the dosimeters, the dosimeters are exposed to neutrons of lower average energy than if they are unshielded. It is probable that the relatively high dose equivalents reported for the shielded runs are due to the fact that TLD-albedo dosimeters are "extremely energy dependent and *overrespond severely* to low energy neutrons."¹⁰ The relative response of a TLD-albedo dosimeter increases by about a factor of 10 as the neutron energy drops from 2 MeV to 0.2 MeV.⁹

Gamma Dose-Phantom Front

Gamma dose equivalent results from measurements made on the front of phantoms are summarized in Table 16. When all reported results are

*The reader is reminded that this analysis *does not* include the extremely high TLD results from RPB and UTAH.

considered, the mean values of the dose equivalent for the six runs are higher than the reference values by factors of 2.6-8.1 and have standard deviations of 124-165%. The median values vary from 1.0-2.9 times the reference values.

The IRA group did not know the neutron sensitivity of their gamma dosimeter system and UW obviously (reported values 7.5-33 times the reference value) had difficulty in dose determination. Groups specifying use of TLD-100 dosimeters (which are relatively neutron sensitive) generally reported very high results indicating insufficient correction for the neutron response. The IRA, UW, and specified TLD-100 data were subsequently omitted from the reported values and the statistical analysis of the data redone and included in Table 16 as a "Subset of reported results." These data should be more representative of the overall participant ability to measure gamma dose. The means are higher than the reference values by factors of 1.2-2.6 and have standard deviations of 39-172%. The median values vary from 0.9-1.9 times the reference values. For gamma dose equivalents in the range 0.1-1 mSv (10-100 mrem), measured in the presence of a larger neutron dose, these data indicate that almost all reported dose values are larger than the reference dose and that it is not unusual for results to differ by a factor of 3 to 4.

A summary of the gamma dose equivalent as measured by various dosimeter types is presented in Table 17. Film did not provide good measurements of the gamma dose equivalent. In contrast to the film-measured neutron dose equivalent, the gamma results were generally high:

the median values ranged from 0.9 to 4.1 times the reference values for the six runs and the mean values were 1.9-3.8 times the reference values. Almost all radiation monitoring film is somewhat sensitive to neutrons. Tests²¹ conducted on eight commercial film types used to measure gamma-rays showed that they were, on the average, four times^{*} more sensitive to thermal neutrons (on a gray or a rad basis) than to ⁶⁰Co gamma-rays. The fast neutron response (per gray or rad) averaged only about 5%[†] of the gamma response. Depending on the type of film used in the PDIS and whether or not the users corrected for such neutron sensitivity, this sensitivity could be a significant contributor to the high gamma doses reported.

The TLD gamma dose measurements (without IRA, UW, and TLD-100 user data) are also presented in Table 17. They are generally much closer to the reference values than the film results, but are somewhat high: the median values range from 0.9-1.6 times the reference values while the means are 0.8-1.7 times the reference values for all runs except number 2 where a single exceptionally high result biased the remaining data. In every case, the mean values were within one standard deviation of the reference value.

Table 17 also includes the gamma dose equivalent as measured by TLD-100 users. It is readily seen why these results were omitted from the overall data analysis as being nonrepresentative of the general ability to measure gammas in the presence of neutrons: the means and medians are higher than the reference values by factors of about 3.5 for

*Some individual types were ten times more sensitive.

†One individual type had a fast neutron response which was 23% of the gamma response.

the unshielded runs, 5.5 for the Lucite shielded runs, and 10 for the concrete shielded runs. The TLD-100 dosimeters respond to neutrons as well as to gamma-rays.* The gamma dose can be grossly overestimated unless careful spectrum-dependent corrections are made. As is observed in the PDIS data, the amount of overestimation is known to increase as the percentage of low energy neutrons increases.²²

Neutron Dose-Phantom Rear

Neutron dose equivalent results from measurements made on the rear[†] of the phantoms are summarized in Table 18. As is the case for measurements on the fronts of the phantoms, the film results are lower than the reference values and the TLD results are higher. No further statements about these data are presented because of the lack of enough data to provide statistical significance and the fact that the RPB TLD results (known to be calibrated to a distinctly different spectrum) are the only TLD measurements reported for three of the six runs.

Gamma Dose-Phantom Rear

Gamma dose equivalent results from measurements made on the rear of the phantoms are summarized in Table 19. For most cases, the means are within one standard deviation of the reference values. That would normally be an indication of good data, but here it is due to very large standard deviations. These data are presented for completeness of reporting, but are not used to draw conclusions because of the relatively few results reported. In addition, the values in Table 19 include UW

*The TLD-100 material is natural lithium fluoride and contains 7.5% of the ⁶Li isotope which is extremely sensitive to thermal neutrons.

[†]The rear of the phantom is the surface the greatest distance from the HPRR (see Fig. 3).

values (as previously mentioned, UW obviously had measurement difficulty) and, as could be expected, exceptionally high values from a TLD-100 user.

CONCLUSIONS

Conclusions based on the results of the fifth PDIS are:

- 1) Interest in radiation dosimetry intercomparison studies is increasing.
- 2) The most popular types of personnel dosimeters are TLD-albedo for neutron measurements and TLD for gamma measurements.
- 3) For measurements of neutron dose equivalent in the 1-15 mSv (100-1500 mrem) range, it is not unusual for results reported by various groups to differ by a factor of 2 to 3.*
- 4) Neutron dose equivalents are much more accurately measured in the unshielded runs than in the shielded ones.
- 5) About 55% of the reported neutron dose equivalent values are higher than the reference dose. This is an indication that there is no real bias among the results as a whole.
- 6) The mean and median values of neutron dose equivalent measurements reported by users of film dosimeters are less than 40% of the reference dose. This indicates that film is inadequate for this application.
- 7) Track dosimeters, in general, provided more accurate neutron dose equivalent measurements than did TLD or film.
- 8) For gamma dose equivalent measurements in the 0.1-1 mSv (10-100 mrem) range with relatively large numbers of neutrons

*This is true even after the "far out" data have been omitted.

present, it is not unusual for reported results to differ by a factor of 3 to 4.*

- 9) About 80% of the reported gamma dose equivalent values are higher than the reference dose. This is probably primarily due to a failure to account properly for the neutron sensitivity of the gamma dosimeters used in the study.
- 10) In general, TLD measurements of the gamma dose equivalent are more accurate than film measurements.
- 11) Gamma dose equivalents are slightly more accurately measured in the unshielded runs than in the shielded ones.
- 12) The TLD-100 dosimeters are generally unsuitable for the measurement of gamma dose equivalent in mixed neutron-gamma radiation fields.

EPILOGUE

It is hoped that the PDIS study participation and the results presented in this report will encourage and challenge many groups to learn more about the limitations of their dosimetry systems. It appears that several groups could significantly improve the accuracy of their results by using dosimeter types more suited to the measurement of particular types of radiation or by giving greater attention to the response characteristics of their dosimeters and making corrections based on those characteristics and knowledge of the spectrum being measured. Improved dose estimates can be obtained in the manner suggested, but the "bottom line" is this: more research and development work is needed in mixed field radiation dosimetry.

*This is true even after the "far out" data have been omitted.

REFERENCES

1. H. W. Dickson, W. F. Fox, and F. F. Haywood, *1974 Intercomparison of Personnel Dosimeters*, ORNL/TM-4786 (January 1976).
2. L. W. Gilley, H. W. Dickson, and D. J. Christian, *1976 Intercomparison of Personnel Dosimeters*, ORNL/TM-5672 (December 1976).
3. L. W. Gilley and H. W. Dickson, *Third Personnel Dosimetry Intercomparison Study*, ORNL/TM-6114 (January 1979).
4. H. W. Dickson, *Fourth Personnel Dosimetry Intercomparison Study*, ORNL/TM-7137 (in preparation).
5. J. A. Auxier, "The Health Physics Research Reactor," *Health Phys.* 11, 89-93 (1965).
6. C. S. Sims, *Fifteenth Nuclear Accident Dosimetry Intercomparison Study: August 14-22, 1978*, ORNL/TM-6554 (May 1979).
7. J. W. Poston, J. R. Knight, and G. E. Whitesides, "Calculation of the HPRR Neutron Spectrum for Simulated Nuclear Accident Conditions," *Health Phys.* 26, 217-221 (1974).
8. F. W. Sanders and J. A. Auxier, "Neutron Activation of Sodium in Anthropomorphic Phantoms," *Health Phys.* 8, 371-379 (1962).
9. T. P. Barton and C. E. Easterly, *Neutron Personnel Dosimetry Considerations for Fusion Reactors*, ORNL/TM-6756 (July 1979).
10. R. V. Griffith, D. E. Hankins, R. B. Gammage, L. Tommasino, and R. V. Wheeler, "Recent Developments in Personnel Neutron Dosimeters - A Review," *Health Phys.* 36, 235-260 (1979).
11. E. B. Wagner and G. S. Hurst, "A Geiger-Mueller γ -Ray Dosimeter with Low Neutron Sensitivity," *Health Phys.* 5, 20-26 (1961).
12. D. R. Johnson and J. W. Poston, *Radiation Dosimetry Studies at the Health Physics Research Reactor*, ORNL-4113 (June 1967).

13. C. S. Sims and H. W. Dickson, "Nuclear Accident Dosimetry Intercomparison Studies at the Health Physics Research Reactor: A Summary (1965-1978)," *Health Phys.* 37, 687-699 (1979).
14. M.S.S. Murthy, R. C. Bhatt, and S. S. Shinde, "Estimation of Quality Factor and RBE for Degraded Fission Neutron Spectra," *Health Phys.* 27, 9-17 (1974).
15. C. S. Sims, H. W. Dickson, and L. W. Gilley, "Neutron Quality Factor Measurements at the Oak Ridge National Laboratory's Dosimetry Applications Research Facility," to be published in *Health Physics*.
16. J. A. Auxier, W. S. Snyder, and T. D. Jones, "Neutron Interactions and Penetration in Tissue," *Radiation Dosimetry*, Vol. 1, p. 275, ed. by F. H. Attix and W. C. Roesch, Academic Press, New York (1968).
17. H. W. Dickson, Unpublished hand calculations using a Monte Carlo calculated spectrum for the concrete shielded HPRR (1979).
18. International Commission on Radiation Units and Measurements, *Radiation Protection Instrumentation and Its Application*, ICRU Report 20 (1971).
19. L. J. Goodman, "Density and Composition Uniformity of A-150 Tissue-Equivalent Plastic," *Phys. Med. Biol.* 23, 4 (1978).
20. C. S. Sims and H. W. Dickson, "Health Physics Research Reactor Spectrum Measurements with Threshold Detector Units," to be published in *Health Physics*.
21. Robert J. Smith and Ralph F. Benck, "Thermal and Fast Neutron Effects on Dosimeter Films," *Health Phys.* 9, 473-484 (1963).
22. Dale E. Hankins, "Evaluation of the Fast Neutron Dose Equivalent Using the Thermal Neutron Response of LiF TL Material," *Health Phys.* 31, 170-173 (1976).

ORNL-DWG 70-4828A

(a) VIEW FROM
BEHIND SHIELD

(b) VIEW LOOKING DOWN FROM ABOVE SHIELD

Fig. 1. Lucite shield.

ORNL-DWG 77-9402A

Fig. 2. Concrete shield.

ORNL-DWG 79-19734

Fig. 3. Experimental arrangement for PDIS exposures.

Table 1. Summary of experimental conditions

Exposure number	Date of exposure	Start time ^a	Exposure duration, s	Reactor power, w	$10^{-13} \times$ number of fissions	Shield thickness and type	Shield distance from reactor, m	Distance from reactor to front of phantom, ^b m
1	3/20/79	1031	503	0.20	0.31	None		3
2	3/20/79	1312	537	1.50	2.50	None		3
3	3/21/79	0923	508	6.00	9.45	12-cm Lucite	2	3
4	3/21/79	1122	576	2.00	3.57	12-cm Lucite	2	3
5	3/21/79	1405	524	6.00	9.75	20-cm concrete	1	3
6	3/22/79	0912	466	1.50	2.17	20-cm concrete	1	3

^aEastern Standard Time.

^bThe horizontal centerlines of the reactor and of the phantom sections on which the dosimeters were mounted were 1.5 m above the concrete floor for all exposures.

Table 2. Dosimeters as described by the participants

Group ^a	Neutron dosimeter	Gamma dosimeter
ANL	TLD-albedo	TLD
BMI	P-1 type film	LiF TLD and film
BUMED	LiF TLD	LiF TLD
CERN	Film	Film
DOSAR	See reference dosimetry section	
EIC	TLD-100	TLD-100
EUR-LUX		
FERMI		
GAC		Harshaw TLD and film
GFK	TLD albedo, recoil track	TLD-700
IRA		TLD
IRD-CS	Track with Th and U	CaSO ₄ :Dy TLD
KSU	Film (Rad. Det. Co.)	Film (Rad. Det. Co.)
LAND	Neutrak, CR-39	
ND		Landauer film badges
NRPB	Neutron emulsion	
OPPD	Harshaw TLD-600	Harshaw TLD-700
PPPL	Landauer H-1 film badge	Landauer H-1 film badge
REECO	⁶ Li/ ⁷ Li; Cd-encased	⁶ Li/ ⁷ Li; Cd-encased
RFP	TLD albedo	TLD-700
RMC		
RPB	TLD albedo	LiF-100 (TLD)
SK		
SLA	TLD albedo	LiF TLD
TVA	⁶ LiF TLD albedo	TLD-700
UCD	Film badge	Film badge
UTAH	TLD-100 LiF	TLD-100 LiF
UW		Rad. Det. Co. TLD badge
YALE	Landauer Gardray	Landauer Gardray

^aIdentifying acronyms are defined in Appendix A.

Table 3. Reference gamma dose equivalent

Run Number	Phantom front			Reference gamma dose equivalent, ^b 10 ⁻⁵ Sv (average of three methods)	Phantom rear Reference gamma dose equivalent, ^b 10 ⁻⁵ Sv (TLD measured)
	Gamma dose equivalent, 10 ⁻⁵ Sv ^a		Inferred from G-M in air		
	TLD	G-M on phantom			
1	10.7	9.0	12.8	11	5
2	34.5	30.4	33.2	33	17
3	102.0	86.6	103.0	97	29
4	25.6	34.1	41.7	34	10
5	32.3	42.9	38.7	38	10
6	7.9	9.6	9.7	9	3

^a1 mrem = 10^{-5} Sv.

^bRounded to the nearest whole number.

Table 4. Neutron dose equivalent from sulfur pellet analysis

Run	Unshielded dose at area monitor, 10^{-5} Gy	Shield factor	Shielded dose at area monitor, 10^{-5} Gy	Area monitor to phantom dose conversion	Quality factor	Dose equivalent on phantom front, 10^{-5} Sv	Phantom front to rear conversion	Dose equivalent on phantom rear, 10^{-5} Sv
1	14			1.04	9.4	137	0.16	22
2	108			1.04	9.4	1055	0.16	169
3	387	0.152	58.8	1.03	8.9	539	0.21	113
4	149	0.152	22.7	1.03	8.9	208	0.21	44
5	329	0.185	60.9	1.20	9.8	716	0.19	136
6	76	0.185	14.1	1.20	9.8	165	0.19	31

Note: 1 mrad = 10^{-5} Gy, 1 mrem = 10^{-5} Sv.

Table 5. Neutron dose equivalent from tissue equivalent ionization chamber measurements

Run	Measured neutron and gamma dose at area monitor, 10^{-5} Gy	Measured gamma dose at area monitor, 10^{-5} Gy	Inferred neutron dose at area monitor, 10^{-5} Gy	Area monitor to phantom dose conversion	Quality factor	Dose equivalent on phantom front, 10^{-5} Sv	Phantom front to rear conversion	Dose equivalent on phantom rear, 10^{-5} Sv
1	22.7	7.7	15.0	1.04	9.4	147	0.16	23
2	139.4	20.0	119.4	1.04	9.4	1167	0.16	187
3	132.2	74.7	57.5	1.03	8.9	527	0.21	111
4	52.2	30.2	22.0	1.03	8.9	202	0.21	42
5	97.4	30.2	57.2	1.20	9.8	673	0.19	128
6	19.8	7.6	12.2	1.20	9.8	143	0.19	27

NOTE: 1 mrad = 10^{-5} Gy, 1 mrem = 10^{-5} Sv.

Table 6. Neutron dose equivalent from calculations

Run	Energy expended during run as determined by HPRR instrumentation, w-min	Number of fissions ^a	Neutron fluence at phantom front, n/cm ²	Dose conversion factor ^b 10 ⁻⁵ Gy-cm ² /n	Dose, 10 ⁻⁵ Gy	Quality factor	Dose equivalent on phantom front, 10 ⁻⁵ Sv ^c	Phantom front to rear conversion	Dose equivalent on phantom rear, 10 ⁻⁵ Sv
1	1.68	0.31×10^{13}	0.61×10^7	25.5×10^{-7}	15.6	9.4	147	0.16	24
2	13.42	2.50×10^{13}	4.90×10^7	25.5×10^{-7}	125.0	9.4	1175	0.16	188
3	50.80	9.45×10^{13}	5.04×10^7	14.6×10^{-7}	73.6	8.9	655	0.21	138
4	19.22	3.57×10^{13}	1.90×10^7	14.6×10^{-7}	27.7	8.9	247	0.21	52
5	52.38	9.74×10^{13}	9.74×10^7	13.5×10^{-7}	131.5	9.8	1289	0.19	245
6	11.64	2.17×10^{13}	2.17×10^7	13.5×10^{-7}	29.3	9.8	287	0.19	55

^a 3.7×10^{10} fissions = 1 W-s.

^b1 mrad = 10⁻⁵ Gy.

^c1 mrem = 10⁻⁵ Sv.

Table 7. Reference neutron dose equivalent

Run	Reference neutron dose equivalent, 10^{-5} Sv ^a	
	Phantom front	Phantom rear
1	142	23
2	1112	178
3	533	112
4	205	43
5	695	132
6	154	29

^a1 mrem = 10^{-5} Sv.

Table 8. Tabulation of reported results - PDIS 5, run 1, unshielded

Group ^a	Neutron dosimeter	Neutron dose equivalent, ^b 10 ⁻⁵ Sv				Gamma dosimeter	Gamma dose equivalent, ^b 10 ⁻⁵ Sv			
		1 ^c	2	3	average		1	2	3	average
ANL	TLD	164	164	159	162	TLD	13	13	12	13
BMI										
BUMED	TLD	188	203	176	189	TLD	11	13	13	12
CERN	Film	30	60	0 ^d	45/0 ^d	Film	10	10	10 ^d	10/10 ^d
DOSAR	Reference				142/23 ^d	Reference				11/5 ^d
EIC	TLD	88	105	84	92	TLD	33	20	37	30
EUR-LUX										
FERMI										
GAC						Film/TLD	0/7	0/10	0 ^d /0 ^d	0/3, 0 ^d /0 ^d
GFK	TLD/Track	137	155	100	131	TLD	7	6		7
IRA						TLD	105	95	105	102
IRD-CS	Track	500	400		450	TLD	0	0		0
KSU	Film	40	80		60	Film	10	10		10
LAND	Track/Track	138/ ^e	166/ ^e	193/ ^e	166/163 ^e					
ND						Film	130			130
NRPB	Film	95	65	55	72					
OPPD	TLD	211	197	185	198	TLD	10	11	9	10
PPPL	Film	0	0	0	0	Film	0	30	30	20
REECO	TLD	179	170	186	178	TLD	12	14	15	14
RFP	TLD	277	294	257	276	TLD	10	8	9	9
RMC										
RPB	TLD	960	50 ^d		960/50 ^d	TLD	60	60 ^d		60/60 ^d
SK										
SLA	TLD	90	80	60	77	TLD	10	10	10	10
TVA	TLD	104	115	123	114	TLD	11	9	10	10
UCD										
UTAH	TLD	320 ^f	370 ^f	190 ^f	290 ^f	TLD	29	36	40 ^d	35
UW						TLD	80	85	0 ^d	83/0 ^d
YALE										

^aIdentifying acronyms are defined in Appendix A.^bThe dose equivalent is background corrected. The values are reported in units of mrem (i.e., 10⁻⁵ Sv).^cEach group was allowed to expose three dosimeters per run.^dDosimeter on rear of phantom (i.e., side not facing HP RR). All others were on front of phantom.^eReported average of three CR-39 dosimeters.^fReported in mrad, but converted to mrem using OF = 10 per ref. 18.

Table 9. Tabulation of reported results - PDIS 5, run 2, unshielded

Group ^a	Neutron dosimeter	Neutron dose equivalent, ^b 10 ⁻⁵ Sv				Gamma dosimeter	Gamma dose equivalent, ^b 10 ⁻⁵ Sv			
		1 ^c	2	3	average		1	2	3	average
ANL	TLD	1070	1179	1179	1143	TLD	73	63	66	69
BMI						TLD + Film	440	562	430	477
BUMED	TLD	1323	1567	1273 ^d	1388	TLD	48	53	43	47
CERN	Film	400	400	160 ^d	400/160 ^d	Film	40	40	30 ^d	40/30 ^d
DOSAR	Reference				1112/178 ^d	Reference				33/17 ^d
EIC	TLD	1029	857	890	925	TLD	93	72	80	82
EUR-LUX										
FERMI										
GAC						Film/TLD	90/30	80/29	0 ^d /11 ^d	85/30, 0 ^d /11 ^d
GFK	TLD, Track	923	979	740	881	TLD	27	24		26
IRA						TLD	700	720	700	707
IRD-CS										
KSU	Film	420	410		415	Film	45	45		45
LAND	Track/Track	1159/ ^e	214/ ^e	1214/ ^e	1196/1048 ^e					
ND						Film	70			70
NRPB	Film	780	610	630	673					
OPPD	TLD	1586	1537	1794	1639	TLD	51	43	47	47
PPPL	Film	210	150	130	163	Film	70	90	80	80
REECO	TLD	1300	1210 ^d	1190 ^d	1233 ^d	TLD	71	70 ^d	64 ^d	68 ^d
RFP	TLD	356 ^d	343 ^d	321 ^d	340 ^d	TLD	13 ^d	14 ^d	16 ^d	14 ^d
RMC										
RPB	TLD	7800	1570 ^d		7800/1570 ^d	TLD	240	80 ^d		240/80 ^d
SK										
SLA	TLD	680 ^d	550 ^d	720 ^d	650 ^d	TLD	60 ^d	50 ^d	40 ^d	50 ^d
TVA	TLD	908	866	838	871	TLD	35	34	32	34
UCD										
UTAH	TLD	2430 ^f	3370 ^f	3780 ^f	3190 ^f	TLD	160	0	0	53
UW						TLD	115 ^d	500 ^d		500/115 ^d
YALE	Film	0 ^d	0 ^d		0 ^d	Film	0 ^d	0 ^d	0	0 ^d

^aIdentifying acronyms are defined in Appendix A.^bThe dose equivalent is background corrected. The values are reported in units of mrem (i.e., 10⁻⁵ Sv).^cEach group was allowed to expose three dosimeters per run.^dDosimeter on rear of phantom (i.e., side not facing HP RR). All others were on front of phantom.^eReported average of three CR-39 dosimeters.^fReported in mrad, but converted to mrem using QF = 10 per ref. 18.

Table 10. Tabulation of reported results -- PDIS 5, run 3, Lucite shield

Group ^a	Neutron dosimeter	Neutron dose equivalent, ^b 10 ⁻⁵ Sv				Gamma dosimeter	Gamma dose equivalent, ^b 10 ⁻⁵ Sv			
		1 ^c	2	3	average		1	2	3	average
ANL	TLD	1690	1932	1992	1871	TLD	172	180	186	179
BMI	Film	20	380	40	147	TLD + film	120	110	100	110
BUMED	TLD	1081	1025	984	1030	TLD	124	122	127	124
CERN										
DOSAR	Reference				533/112 ^d	Reference				97/29 ^d
EIC	TLD	467	451	374	431	TLD	351	468	413	411
EUR-LUX										
FERMI										
GAC						Film/TLD	250/77	250/77	75 ^d /27 ^d	250/77, 75 ^d /27 ^d
GFK	TLD, Track	420	647	573	547	TLD	73	42		58
IRA						TLD	2050	2060	2090	2067
IRD-CS	Track	550	450		500	TLD	0	0		0
KSU										
LAND	Track/Track	722/ ^e	413/ ^e	619/ ^e	585/531 ^e					
ND						Film				160
NRPB	Film	420	380	320	373					
OPPD	TLD	955	106	1059	1040	TLD	91	94	105	97
PPPL	Film	140	0	0	47	Film	220	180	190	197
REECO	TLD	902	920	918	913	TLD	145	149	146	147
RFP	TLD	1097	1359	1427	1294	TLD	128	116	103	116
RMC										
RPB	TLD	15580	2540 ^d		15580/2540 ^d	TLD	790	190 ^d		790/190 ^d
SK										
SLA	TLD	430	500	570	500	TLD	80	60	60	67
TVA	TLD	805	1080	1218	1034	TLD	97	103	93	98
UCD										
UTAH	TLD	10700 ^f	8010 ^f	6220 ^f	8310 ^f	TLD	388	525	744	552
UW						TLD	1600	1700	1350	1550
YALE	Film	0	0		0	Film	140	130		135

^aIdentifying acronyms are defined in Appendix A.^bThe dose equivalent is background corrected. The values are reported in units of mrem (i.e., 10⁻⁵ Sv).^cEach group was allowed to expose three dosimeters per run.^dDosimeter on rear of phantom (i.e., side not facing HPRR). All others were on front of phantom.^eReported average of three CR-39 dosimeters.^fReported in mrad, but converted to mrem using QF = 10 per ref. 18.

Table 11. Tabulation of reported results - PDIS 5, run 4, Lucite shield

Group ^a	Neutron dosimeter	Neutron dose equivalent, ^b 10 ⁻⁵ Sv				Gamma dosimeter	Gamma dose equivalent, ^b 10 ⁻⁵ Sv			
		1 ^c	2	3	average		1	2	3	average
ANL	TLD	743 ^d	793 ^d	721 ^d	751 ^d	TLD	72 ^d	69 ^d	70 ^d	70 ^d
BMI	Film	23 ^d	20 ^d	20 ^d	20 ^d	TLD + film	10 ^d	10 ^d	10 ^d	10 ^d
BUMED	TLD	385	398	447	410	TLD	52	50	52	51
CERN										
DOSAR	Reference				205/43 ^d	Reference				34/10 ^d
EIC	TLD	183	210	160	186	TLD	113	160	168	147
EUR-LUX										
FERMI										
GAC						Film/TLD	80/32	100/35	0 ^d /8 ^d	90/34, 0 ^d /8 ^d
GFK	TLD, Track	173	262	140	192	TLD	28	17		23
IRA						TLD	780	760	750	763
IRD-CS										
KSU										
LAND	Track/Track	258/ ^e	206/ ^e	253/ ^e	241/209 ^e					
ND										
NRPB	Film	110	150	150	137					
OPPD	TLD	345	346	438	368	TLD	41	50	44	45
PPPL										
REECO	TLD	375 ^d	364 ^d	358 ^d	369 ^d	TLD	62 ^d	54 ^d	59 ^d	58 ^d
RFP	TLD	86 ^d	70 ^d	71 ^d	76 ^d	TLD	16 ^d	17 ^d	15 ^d	16 ^d
RMC										
RPB	TLD	4910	880 ^d		4910/880 ^d	TLD	320	80 ^d		320/80 ^d
SK										
SLA	TLD	330 ^d	200 ^d	230 ^d	253 ^d	TLD	10 ^d	20 ^d	20 ^d	17 ^d
TVA	TLD	237	255	386	293	TLD	43	40	33	39
UCD										
UTAH	TLD	5810 ^f	4720 ^f	3900 ^f	4810 ^f	TLD	0	296	181 ^d	159
UW						TLD	600	550	0 ^d	575/0 ^d
YALE	Film	0	0	--	0	Film	50	50		50

^aIdentifying acronyms are defined in Appendix A.^bThe dose equivalent is background corrected. The values are reported in units of mrem (i.e., 10⁻⁵ Sv).^cEach group was allowed to expose three dosimeters per run.^dDosimeter on rear of phantom (i.e., side not facing HPRR). All others were on front of phantom.^eReported average of three CE-39 dosimeters.^fReported in mrad, but converted to mrem using OF = 10 per ref. 18.

Table 12. Tabulation of reported results — PDIS 5, run 5, concrete shield

Group ^a	Neutron dosimeter	Neutron dose equivalent, ^b 10 ⁻⁵ Sv				Gamma dosimeter	Gamma dose equivalent, ^b 10 ⁻⁵ Sv			
		1 ^c	2	3	average		1	2	3	average
ANL	TLD	1656	1645	1677	1659	TLD	122	128	124	125
BMI	Film	20	40	20	27	TLD + film	10	10	40	20
BUMED	TLD	653	669	601	641	TLD	70	64	56	63
CERN	Film	35	180	30 ^d	108/30 ^d	Film	80	70	40 ^d	75/40 ^d
DOSAR	Reference				695/132 ^a	Reference				38/10 ^d
EIC	TLD	570	375	510	485	TLD	158	192	306	219
EUR-LUX										
FERMI										
GAC						Film/TLD	150/48	100/49	40 ^d /NM ^d	125/49, 40 ^d /NM ^d
GFK	TLD, Track	468	611	170	416	TLD	32	23		28
IRA						TLD	1510	1550	1570	1543
IRD-CS	Track	450	650		550	TLD	0	0		0
KSU										
LAND	Track/Track	661/ ^e	592/ ^e	696/ ^e	650/874 ^e					
ND						Film	130			130
NRPB	Film	420	310	300	343					
OPPD	TLD	3634	3212	3765	3537	TLD	63	59	25	49
PPPL	Film	0	0	80	27	Film	140	120	140	133
REECO	TLD	1200	1120	1230	1183	TLD	73	77	74	75
RFP	TLD	2310	1429	1887	1875	TLD	61	62	51	58
RMC										
RPB	TLD	16690	2570 ^d		16690/2570 ^d	TLD	1080	150 ^d		1080/150 ^d
SK										
SLA	TLD	1490	1470	1430	1463	TLD	40	30	40	37
TVA	TLD	1065	1505	932	1167	TLD	47	42	47	45 ^f
UCD									NM ^f	NM ^f
UTAH	TLD	5040 ^g	5270 ^g	4890 ^g	6400 ^g	TLD	587 ^g	185 ^g	432	401
UW						TLD	0 ^d	0 ^d	1250	1250/0 ^d
YALE										

^aIdentifying acronyms are defined in Appendix A.^bThe dose equivalent is background corrected. The values are reported in units of mrem (i.e., 10⁻⁵ Sv).^cEach group was allowed to expose three dosimeters per run.^dDosimeter on rear of phantom (i.e., side not facing HPRR). All others were on front of phantom.^eReported average of three CR-39 dosimeters.^fNM = No TLD measurement taken.^gReported in mrad, but converted to mrem using QF = 10 per ref. 18.

Table 13. Tabulation of reported results - PDIS 5, run 6, concrete shield

Group ^a	Neutron dosimeter	Neutron dose equivalent, ^b 10 ⁻⁵ Sv				Gamma dosimeter	Gamma dose equivalent, ^b 10 ⁻⁵ Sv			
		1 ^c	2	3	average		1	2	3	average
ANL	TLD	345 ^d	363 ^d	382 ^d	364 ^d	TLD	29 ^d	25 ^d	23 ^d	26 ^d
RMI	Film	27 ^d	20 ^d	20 ^d	20 ^d	TLD + film	10 ^d	10 ^d	10 ^d	10 ^d
BUMED	TLD	163	159	154	161	TLD	14	15	14	14
CERN	Film	57	70	10 ^d	60/10 ^d	Film	20	30	10 ^d	25/10 ^d
DOSAR	Reference				154/29 ^d	Reference				9/3 ^d
EIC	TLD	94	99	94	96	TLD	62	68	75	68
EUR-LUX										
FERMI										
GAC						Film/TLD	40/12	40/15	0 ^d /4 ^d	40/14, 0 ^d /4 ^d
GFK	TLD, Track	120	156	200	159	TLD	6	6		6
IRA						TLD	380	385	395	387
IRD-CS										
KSU										
LAND	Track/Track	174/ ^e	118/ ^e	66/ ^e	119/235 ^e					
ND										
NRPB	Film	60	75	45	60					
OPPD	TLD	807	850	837	831	TLD	11	9	16	12
PPPL	Film	0	0	0	0	Film	40	30	40	37
REECO	TLD	245 ^d	259 ^d	256 ^d	255 ^d	TLD	17 ^d	19 ^d	20 ^d	19 ^d
RFP	TLD	52 ^d	57 ^d	77 ^d	62 ^d	TLD	4 ^d	5 ^d	6 ^d	5 ^d
RMC										
RPB	TLD	3570	570 ^d		3570/570 ^d	TLD	100	100 ^d		100/100 ^d
SK										
SLA	TLD	220 ^d	260 ^d	260 ^d	247 ^d	TLD	10 ^d	10 ^d	10 ^d	10 ^d
TVA	TLD	312	300	340	317	TLD	12	13	12	12
UCD										
UTAH	TLD	1800 ^f	1870 ^f	2190 ^f	1950 ^f	TLD	103 ^d	86 ^d	40 ^d	76 ^d
UW						TLD	0 ^d	0 ^d	260 ^d	260/0 ^d
YALE	Film	0 ^d	0 ^d		0 ^d	Film	0 ^d	0 ^d		0 ^d

^aIdentifying acronyms are defined in Appendix A.^bThe dose equivalent is background corrected. The values are reported in units of mrem (i.e., 10⁻⁵ Sv).^cEach group was allowed to expose three dosimeters per run.^dDosimeter on rear of phantom (i.e., side not facing HPRR). All others were on front of phantom.^eReported average of three CR-39 dosimeters.^fReported in mrad, but converted to mrem using QF = 10 per ref. 18.

Table 14. Analysis of neutron dose equivalent results
on front of phantoms

Run	Neutron dose equivalent, 10^{-5} Sv (i.e., mrem)		
	Reference	All reported results ^a	Subset of reported results ^{a,b}
1	142	163, 201 $\pm$ 217 (108)	147, 148 $\pm$ 106 (72)
2	1112	1048, 1531 $\pm$ 1871 (122)	925, 921 $\pm$ 422 (46)
3	533	566, 1930 $\pm$ 3879 (201)	539, 678 $\pm$ 493 (73)
4	205	293, 990 $\pm$ 1727 (174)	241, 287 $\pm$ 194 (68)
5	695	762, 2116 $\pm$ 3948 (187)	646, 938 $\pm$ 896 (96)
6	154	198, 584 $\pm$ 996 (171)	160, 221 $\pm$ 221 (100)

^aValues reported are median, mean $\pm \sigma$ ($\% \sigma$).

^bThis subset omits results reported by RPB and UTAH.

Table 15. Neutron dose equivalent on front of phantoms by type of dosimeter

Run	Neutron dose equivalent, 10^{-5} Sv (i.e., mrem)			
	Reference	Film ^a	Track ^a	TLD ^a
1	142	53, 44 $\pm$ 32 (73)	166, 260 $\pm$ 165 (63)	162, 157 $\pm$ 62 (39)
2	1112	408, 413 $\pm$ 208 (50)	1122, 1122 $\pm$ 105 (9)	1143, 1154 $\pm$ 290 (25)
3	533	97, 142 $\pm$ 166 (117)	531, 539 $\pm$ 43 (8)	1030, 962 $\pm$ 450 (47)
4	205	69, 69 $\pm$ 97 (141)	225, 225 $\pm$ 23 (10)	368, 367 $\pm$ 191 (52)
5	695	68, 126 $\pm$ 149 (118)	650, 691 $\pm$ 166 (24)	1183, 1381 $\pm$ 958 (69)
6	154	60, 40 $\pm$ 35 (88)	177, 177 $\pm$ 82 (46)	255, 312 $\pm$ 248 (79)

^aResults do not include RPB and UTAH values. Values reported are median, mean $\pm \sigma$ (% σ).

Table 16. Analysis of gamma dose equivalent results
on front of phantoms

Run	Gamma dose equivalent, 10^{-5} Sv (i.e., mrem)		
	Reference	All reported results ^a	Subset of reported results ^{a,b}
1	11	11, 29 ± 36 (124)	10, 18 ± 31 (172)
2	33	69, 150 ± 200 (133)	47, 86 ± 119 (138)
3	97	141, 359 ± 536 (149)	116, 121 ± 61 (50)
4	34	64, 173 ± 227 (131)	50, 51 ± 20 (39)
5	38	75, 275 ± 453 (165)	58, 67 ± 43 (64)
6	9	26, 73 ± 108 (148)	17, 21 ± 11 (52)

^aValues reported are median, mean $\pm \sigma$ ($\% \sigma$).

^bThis subset omits results reported by IRA, UW, and those using TLD-100.

Table 17. Gamma dose equivalent on front of phantoms by type of dosimeter

Run	Gamma dose equivalent, 10^{-5} Sv (i.e., mrem)			
	Reference	Film ^a	TLD ^{a,b}	TLD-100 ^a
1	11	10, 34 $\pm$ 54 (159)	10, 9 $\pm$ 4 (44)	35, 42 $\pm$ 16 (38)
2	33	70, 64 $\pm$ 20 (31)	47, 100 $\pm$ 153 (153)	82, 125 $\pm$ 101 (81)
3	97	179, 186 $\pm$ 50 (27)	98, 98 $\pm$ 48 (49)	522, 574 $\pm$ 195 (34)
4	34	65, 65 $\pm$ 35 (54)	45, 46 $\pm$ 16 (35)	159, 209 $\pm$ 97 (46)
5	38	125, 97 $\pm$ 49 (51)	49, 53 $\pm$ 33 (62)	401, 567 $\pm$ 454 (80)
6	9	37, 34 $\pm$ 8 (24)	14, 15 $\pm$ 6 (40)	76, 81 $\pm$ 17 (21)

^aResults do not include IRA and UW values. Values reported are median, mean $\pm \sigma$ ($\% \sigma$).

^bResults do not include those reported by TLD-100 users.

Table 18. Analysis of neutron dose equivalent results on rear of phantoms

Run	Neutron dose equivalent, 10^{-5} Sv (i.e., mrem)			
	Reference	All reported results ^a	Film ^a	TLD ^a
1	23	25, 25 ± 35 (140)	0 ^b	50 ^b
2	178	340, 544 ± 622 (114)	80, 80 ± 113 (141)	650, 853 ± 640 (75)
3	112	2540 ^b		2540 ^b
4	43	165, 307 ± 395 (129)	20 ^b	253, 403 ± 422 (105)
5	132	1300, 1300 ± 1796 (138)	30 ^b	2570 ^b
6	29	41, 152 ± 225 (148)	10, 10 ± 10 (100)	247, 293 ± 257 (88)

^aValues reported are median, mean $\pm \sigma$ ($\% \sigma$).

^bOnly one measurement reported.

Table 19. Analysis of gamma dose equivalent results on rear of phantoms

Run	Gamma dose equivalent, 10^{-5} Sv (i.e., mrem)			
	Reference	All reported results ^a	Film ^a	TLD ^a
1	5	0, 14 ± 26 (186)	5, 5 ± 7 (140)	0, 20 ± 35 (175)
2	17	22, 38 ± 42 (111)	0, 10 ± 17 (170)	50, 54 ± 44 (81)
3	29	75, 97 ± 84 (87)	75 ^b	109, 109 ± 115 (106)
4	10	10, 19 ± 28 (147)	5, 5 ± 7 (140)	16, 24 ± 32 (133)
5	10	40, 58 ± 64 (110)	40, 40 ± 0 (0)	75, 75 ± 106 (141)
6	3	5, 15 ± 32 (213)	5, 5 ± 6 (120)	5, 24 ± 43 (179)

^aValues reported are median, mean $\pm \sigma$ (% σ).

^bOnly one measurement reported.

APPENDIX A

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Study Participants

<u>Name</u>	<u>Affiliation</u>	<u>Identifying abbreviation</u>
W. E. Bleiler	Argonne National Laboratory 9700 South Cass Avenue Argonne, IL 60439	ANL
George Kirsch	Battelle Memorial Institute Columbus Laboratories 505 King Avenue Columbus, OH 43201	BMI
K. Goebel J. Dutrannois	CERN European Organization for Nuclear Research Ch 1211 Geneve 23 Suisse, Switzerland	CERN
Frantisek Spurney	Czechoslovak Academy of Sciences Institute of Radiation Dosimetry Na Truhlarce 39/2a 18086 Praha 8, Czechoslovakia	IRD-CS
H. W. Dickson L. W. Gilley G. R. Patterson C. S. Sims	Dosimetry Applications Research Oak Ridge National Laboratory P. O. Box X, Building 7710 Oak Ridge, TN 37830	DOSAR
E. Geiger Rose Marie Tauche	Eberline Instrument Corporation P. O. Box 2108 Santa Fe, NM 87501	EIC
Paul Lovendale	Fermilab Batavia Road Batavia, IL 60510	FERMI
J. R. Ortman Billy Short	Goodyear Atomic Corporation P. O. Box 628 Piketon, OH 45661	GAC
J. F. Valley	Institut de Radiophysique Appliquee Centre Universitaire 1015 Lausanne Switzerland	IRA
M. Oberhofer	Joint Research Center Ispra Establishment Euratom C. C. R. 21020 Ispra (Varese) Italy	EUR-LUX

<u>Name</u>	<u>Affiliation</u>	<u>Identifying abbreviation</u>
John P. Lambert	Kansas State University Office of Campus Safety Ward Hall Manhattan, KS 66506	KSU
B. Burgkhardt E. Piesch	Kernforschungszentrum Karlsruhe GmbH Postfach 3640, D 7500 Karlsruhe 1 Federal Republic of Germany	GFK
Richard Oswald Robert Wheeler	R. S. Landauer, Jr., & Co. Division of Technical Operations Incorporated Glenwood Science Park Glenwood, IL 60425	LAND
L. G. Beuchler G. H. Zeman	National Naval Medical Center Bureau of Medicine and Surgery Dosimetry Center Radiological Safety Service Bethesda, MD 20014	BUMED
D. T. Bartlett	National Radiological Protection Board, Harwell Didcot Oxfordshire OX11 0RQ United Kingdom	NRPB
E. A. Ulicny	Notre Dame Radiation Laboratory Notre Dame, IN 46556	ND
D. K. Bruening L. G. Sealock	Omaha Public Power District 1623 Harney Omaha, NE 68102	OPPD
Joseph R. Stencel	Princeton University Plasma Physics Laboratory James Forrestal Campus P. O. Box 451 Princeton, NJ 08540	PPPL
David Katzman Stephen M. Kim	Radiation Management Corporation 3508 Market Street Philadelphia, PA 19104	RMC
R. P. Bradley	Radiation Protection Bureau Brookfield Road Ottawa, Ontario K1A 1C1 Canada	RPB

<u>Name</u>	<u>Affiliation</u>	<u>Identifying abbreviation</u>
Billy Smith Mike Lantz	Reynolds Electric and Engineering Company P. O. Box 14400 Las Vegas, NV 89114	REECO
R. B. Falk C. R. Lagerquist J. R. Pennock	Rockwell International Rocky Flats Plant P. O. Box 464 Golden, CO 80401	RFP
D. J. Thompson	Sandia Laboratories Albuquerque, NM 87115	SLA
J. St. Germain	Sloan Kettering Memorial Hospital 411 East 67th Street New York, NY 10021	SK
John L. Lobdell Bob Powers	Tennessee Valley Authority Muscle Shoals, AL 35660	TVA
Art Perez	University of California-Davis Office of Environmental Health and Safety Davis, CA 95616	UCD
T. R. Downard	University of Utah Radiological Health Department 100 Orson Spencer Hall Salt Lake City, UT 84112	UTAH
Michael Baumann	University of Wisconsin-Madison Safety Department, Room 103 1410 Johnson Drive Madison, WI 53706	UW
John Flynn G. R. Holēman	Yale University Health Physics Division 314 Wright Nuclear Structure Laboratory, West New Haven, CT 06520	YALE

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

APPENDIX B

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

PDIS Announcement Letter

OAK RIDGE NATIONAL LABORATORY

OPERATED BY
UNION CARBIDE CORPORATION
NUCLEAR DIVISION

POST OFFICE BOX X
OAK RIDGE, TENNESSEE 37830

The Fifth Personnel Dosimetry Intercomparison Study (PDIS) will be held at the Oak Ridge National Laboratory's Dosimetry Applications Research (DOSAR) facility on March 20, 21, and 22, 1979. The Health Physics Research Reactor (HPRR) will be the source of neutron and gamma radiation for the experiments. Participants' personnel dosimeters will be located on water-filled Bomab phantoms. The dosimeters will be exposed to a range of doses and neutron-to-gamma ratios which could be encountered in personnel monitoring. The attachment to this letter contains details and limitations related to the various exposures.

Participants are expected to mail their dosimeters to the DOSAR facility where the staff will conduct the irradiation experiments. The dosimeters will be returned to the participants for evaluation as soon as possible after exposure. Participants agree to provide the staff with their final dose estimates by July 2, 1979 (102 days after the study) so that the results may be tabulated and distributed in a timely fashion. One of the past shortcomings of the PDIS has been the long time the participants have had to wait for published results. The DOSAR staff is committed to correcting this shortcoming so that these studies will be even more valuable to participants as they test their ability to accurately monitor neutron and gamma dose.

If a dosimeter will be activated to $> .002 \mu\text{Ci/g}$ when exposed to a fast neutron fluence of 10^8 n/cm^2 , the participant must fill out and send us either ERDA form 375 or 391, as appropriate, in order for us to be able to ship the dosimeters back promptly. If you wish to participate and do not have such a form, let us know and we will send you some. In filling out the form, be sure to specify each element in the dosimeter and its activity if the activity will exceed $.002 \mu\text{Ci/g}$.

Fifth Personnel Dosimetry
Intercomparison Study (PDIS)

2

There is no fee for participation in the study. Expenses to you will include mailing costs (both ways) and, if your dosimeters are activated in excess of the above stated limit, a small (about \$65) isotope handling fee imposed by the laboratory shipping department. (Please contact us about how such a fee can be paid). If you plan to participate in the study, please let us know by March 5 and send your dosimeters so they will arrive no later than March 15. If you have any questions or suggestions, please write or call us at 615/574-5860 or 5851 (FTS: 624-5860 or 5851).

Sincerely yours,

A handwritten signature in black ink, appearing to read "C. S. Sims". The signature is written in a cursive, slightly stylized font.

Dr. C. S. Sims
Health and Safety Research Division

CSS:md

Attachment

ATTACHMENT

Exposure Information

There will be six exposures, two different total doses (no single dose will exceed 1.5 rem) for each of three shielding configurations.

<u>Exposure number</u>	<u>Shield type</u>
1	none
2	none
3	12-cm Lucite
4	12-cm Lucite
5	20-cm concrete
6	20-cm concrete

The DOSAR staff will mount a maximum of three dosimeters per participant per exposure. In addition, participants may choose to send a maximum of three background dosimeters. The maximum number (and the number recommended by the staff) of dosimeters allowed each participant is 21 (i.e., $3 \times 6 + 3$). The dosimeters should be labelled as follows:

Example:

This label identifies the dosimeter as belonging to the DOSAR facility. It is to be mounted on the front of the phantom for exposure no. 3. It is DOSAR dosimeter no. 2 for that exposure. (If DOSAR exposes 3 dosimeters on the front of phantoms for exposure no. 3, they will be 3F-1, 3F-2, and 3F-3).

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

APPENDIX C

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

HPRR spectra: Unshielded and through 12-cm Lucite

Group	Upper energy (eV)	Mid- energy (eV)	$N(E)\Delta E^a$, n/cm ²	
			No shield	Lucite shield
1	1.49E7	1.22E7	9.53E7	3.31E7
2	1.00E7	8.19E6	1.18E9	3.63E8
3	6.70E6	5.77E6	3.43E9	4.29E8
4	4.97E6	3.87E6	1.44E10	2.58E9
5	3.01E6	2.12E6	3.76E10	5.56E9
6	1.50E6	1.16E6	3.16E10	3.19E9
7	9.07E5	6.08E5	4.61E10	3.69E9
8	4.08E5	2.13E5	3.39E10	3.08E9
9	1.11E5	9.80E4	2.60E9	4.18E8
10	8.65E4	7.64E4	2.00E9	3.81E8
11	6.74E4	5.95E4	1.50E9	3.49E8
12	5.25E4	4.63E4	1.21E9	3.24E8
13	4.09E4	3.61E4	9.71E8	3.05E8
14	3.18E4	2.81E4	8.40E8	2.98E8
15	2.48E4	2.19E4	7.35E8	2.76E8
16	1.93E4	1.70E4	6.37E8	2.66E8
17	1.50E4	1.03E4	1.58E9	7.60E8
18	7.10E3	4.88E3	1.39E9	7.23E8
19	3.35E3	2.03E3	1.62E9	9.49E8
20	1.23E3	8.48E2	1.04E9	6.97E8
21	5.83E2	3.54E2	1.24E9	9.21E8
22	2.14E2	1.47E2	8.45E8	6.91E8
23	1.01E2	6.96E1	7.76E8	6.90E8
24	4.76E1	3.73E1	4.72E8	4.59E8
25	2.90E1	2.26E1	4.54E8	4.60E8
26	1.76E1	1.37E1	4.34E8	4.61E8
27	1.07E1	7.34	6.09E8	6.93E8
28	5.04	3.93	3.82E8	4.58E8
29	3.06	2.18	4.84E8	6.11E8
30	1.56	1.25	3.04E8	3.79E8
31	1.00	8.06E-1	2.81E8	3.41E8
32	0.65	5.41E-1	2.43E8	2.86E8
33	0.45	2.12E-1	1.78E9	2.67E9
34	0.10	2.24E-2	3.36E9	1.95E10
	5.0E-3			
Total fluence at 3 m from HPRR for 10 ¹⁷ fissions, n/cm ²			19.61E10	5.33E10

^aThis number is the area of the histogram for each energy interval.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

APPENDIX D

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

HPRR spectra: Unshielded and through 20-cm concrete

Group	Mid-energy (eV)	ΔE (eV)	$N(E)\Delta E^a$, n/cm ²	
			No shield	Concrete shield
1	1.32E7	1.36E7	2.16E9	5.15E8
2	5.62E6	1.63E6	4.08E9	9.60E8
3	3.90E6	1.80E6	1.43E10	2.36E9
4	2.25E6	1.50E6	3.77E10	9.12E9
5	1.20E6	6.00E5	3.27E10	4.57E9
6	6.50E5	5.00E5	4.73E10	9.35E9
7	2.64E5	2.72E5	3.06E10	7.54E9
8	1.07E5	4.33E4	4.85E9	2.28E9
9	7.90E4	1.20E4	1.28E9	6.96E8
10	6.25E4	2.10E4	2.36E9	1.72E9
11	4.85E4	7.00E3	8.48E8	6.84E8
12	3.75E4	1.50E4	1.81E9	1.80E9
13	2.75E4	5.00E3	6.87E8	7.80E8
14	2.10E4	8.00E3	1.24E9	1.55E9
15	1.50E4	4.00E3	7.64E8	1.06E9
16	1.05E4	4.97E3	1.21E9	1.86E9
17	5.52E3	5.03E3	1.94E9	3.41E9
18	2.08E3	1.85E3	1.76E9	3.60E9
19	8.50E2	6.00E2	1.10E9	2.46E9
20	3.80E2	3.40E2	1.35E9	3.31E9
21	1.55E2	1.10E2	9.65E8	2.60E9
22	74.2	51.7	8.22E8	2.31E9
23	39.2	18.3	5.30E8	1.57E9
24	23.5	13.0	5.97E8	1.84E9
25	13.5	7.00	5.23E8	1.67E9
26	7.50	5.00	5.96E8	1.95E9
27	4.03	1.95	4.42E8	1.50E9
28	2.32	1.46	6.47E8	2.30E9
29	1.30	0.59	4.14E8	1.68E9
30	0.825	0.35	3.51E8	1.39E9
31	0.550	0.20	3.09E8	1.24E9
32	0.275	0.35	1.02E9	4.14E9
33	0.050	0.10	4.50E9	1.63E10
Total fluence at 3 m from HPRR for 10 ¹⁷ fissions, n/cm ²			20.18E10	10.01E10

^aThis represents the area of the histogram for each energy interval.

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

APPENDIX E

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

Post Experiment Letter and Data Report Sheet

OAK RIDGE NATIONAL LABORATORY

OPERATED BY
 UNION CARBIDE CORPORATION
 NUCLEAR DIVISION

POST OFFICE BOX X
 OAK RIDGE, TENNESSEE 37830

The Fifth Personnel Dosimetry Intercomparison Study was held on March 20, 21, and 22, 1979 at the Oak Ridge National Laboratory's Dosimetry Applications Research (DOSAR) facility. Twenty-nine (29) organizations exposed dosimeters during the study. Your dosimeters were shipped from the laboratory on March 23.

Data related to the Health Physics Research Reactor radiation exposures is in the following table:

<u>Exposure Number</u>	<u>Shield</u>	<u>Date of Exposure</u>	<u>Time of Start of Exposure, EST</u>	<u>Duration of Exposure, sec</u>
1	none	3/20/79	1031	503
2	none	3/20/79	1312	537
3	12-cm Lucite	3/21/79	0923	508
4	12-cm Lucite	3/21/79	1122	576
5	20-cm concrete	3/21/79	1405	524
6	20-cm concrete	3/22/79	0912	466

In order for the study to be of maximum value to each participant, publication of the results should not be unnecessarily delayed. We look forward to receiving your results on the enclosed Data Report Sheet as soon as possible, but certainly before July 2, 1979. Your participation is appreciated.

Sincerely,

A handwritten signature in dark ink, appearing to read "C. S. Sims". The signature is fluid and cursive, with the first letters of the first and last names being capitalized and prominent.

Dr. C. S. Sims
 Health & Safety Research Division

CSS:md

Enclosure

FIFTH PERSONNEL DOSIMETRY INTERCOMPARISON STUDY

Data Report Sheet

Organization _____ Type of neutron dosimeter _____
 Person reporting _____
 Date _____ Type of gamma dosimeter _____

Dosimeter * Designation	Background corrected dose equivalent, mrem		Dosimeter * Designation	Background corrected dose equivalent, mrem	
	neutron	gamma		neutron	gamma
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

Other Comments (e.g., Quality factor used): _____

Please return this sheet as soon as possible (before July 2, 1979) to:

C. S. Sims
 Oak Ridge National Laboratory
 Health & Safety Research Division
 P. O. Box X, Bldg. 7710
 Oak Ridge, TN 37830

* If you followed the requested dosimeter label format, please report 1F1, 1F2, 1R3, etc.
 If you did not follow that, please report the number on the dosimeter (e.g., 72-340)
 which we have recorded.

APPENDIX F

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

PARTICIPANT COMMENTS RELATED TO THEIR DOSIMETERS^a AND MEASUREMENTS

Along with the dose results, some groups reported additional data and made comments about their dosimetry. These data and comments are reproduced in this appendix and are valuable as aids to understanding the various dose measurement, calibration, and calculational techniques used by the participants.

BMI^b — One of the three background dosimeters yielded a gamma dose of 320 mrem. The others were <10 mrem.

CERN — Neutron calibration was done with a plutonium-beryllium source.

GFK — The effective neutron energy based on correlation between albedo response and albedo dosimeter readings was 590 keV for the unshielded cases, 400 keV for the Lucite shielded cases, and 300 keV for the concrete shielded cases. The GFK track dosimeter was calibrated with a ²⁵²Cf source.

IRA — Our dosimeter is used for the measurement of beta and gamma radiation. We have not studied its sensitivity to neutrons through the ⁶Li(n,α)³H reaction. The doses are interpreted as gamma doses. The background is about 70 mrem.

IRD-CS — The detectors were etched electrochemically. The precision was about ±25%. The quality factor was taken from NCRP38.

^aParticipant furnished descriptions of their dosimeters are in Table 2 of this report. The dose equivalent unit used by participants in these comments is mrem: 1 mrem = 10⁻⁵ Sv.

^bIdentifying acronyms are defined in Appendix A.

LAND - The Neuttrak dosimeters were calibrated using the HPRR.

The CR-39 dosimeters were calibrated using an americium-beryllium spectrum and are not corrected for the associated reactor spectrum used in the intercomparison.

NRPB - The dosimeters were calibrated with an americium-beryllium source. A fluence to dose equivalent conversion factor of $3.7 (10^{-8}) \text{ rem-cm}^2\text{-m}^{-1}$ (ICRP 21) was used for that source.

OPPD - The badges used to monitor the background dose indicated a relatively high background neutron dose. The average neutron background dose of 98 mrem was calculated by assuming the neutrons causing the background dose had the same spectrum as the no shield spectrum. This is the most conservative method for calculating the background neutron dose. If the background neutrons are assumed to have the same spectrum as the Lucite moderated spectrum, the average background neutron dose reduces to 31 mrem. The Lucite moderated beam has an average energy of $2.8 (10^6) \text{ eV}$. If the actual background neutron beam had an average energy which was less than the Lucite moderated beam, the actual dose would be even less than 31 mrem.

REECO - The analytical difficulty of this experiment lies in determining the proper calibration factors. Previous research by Dale E. Hankins on this badge was our only lead to these values. This system's accuracy and precision will be concluded from this experiment, although there is already evidence that the precision is good. This will be proved by the results of the two doses per pulse.* If the system is incorrect by say

* It is presumed that REECO means the two steady state runs per shielding configuration.

30% on exposure 3, then it should also be off by approximately 30% on exposure 4. The same should hold true for pairs 1-2 and 5-6 if the precision is to be found good. Other initial evidence is the uniformity of the three measurements in each exposure and the consistency of the four TLDs in each badge.

The gamma determinations are quite secondary in importance to this study for us because this dosimeter was not designed for gamma dosimetry. Due to the complications of a neutron exposure to a cadmium badge (i.e., the neutron-gamma reaction), gamma calibration factors for each pulse had to be obtained from previous research by Dale E. Hankins.

As a final note of interest to you, our background badges (B-1, B-2, and B-3) registered a positive neutron dose. Although the spectra involved in this dose are unknown, the measurements indicate a dose of less than 20 mrem. The following is a list of our background badge readouts as compared to readouts from badges stored in a lead pig at the Nevada Test Site from anneal to readout. The higher ^6Li readouts are apparent in the badges sent to the experiment.

TLD readouts (in nc)									
B-1		B-2		B-3		Onsite control 1		Onsite control 1	
^6Li	^7Li	^6Li	^7Li	^6Li	^7Li	^6Li	^7Li	^6Li	^7Li
6.084	4.145	6.293	4.846	6.305	5.428	4.182	3.838	3.569	4.054
6.356	4.585	6.338	5.383	6.194	5.342	4.002	4.097	3.541	3.880
6.023	4.605	6.719	6.543	6.201	5.263	4.154	4.292	3.449	
5.793	4.492	6.715	5.705	6.203	5.199	3.868	4.103	4.221	4.133
Average:									
6.064	4.457	6.516	5.619	6.226	5.308	4.052	4.083	3.695	4.122

RPB - Interpretation of the registered neutron exposures was made using a plutonium-beryllium source. No corrections were made for spectral differences as we are interested in determining the degree of overresponse for the dosimeter when exposed to these "softer" spectra.

TVA - A quality factor of 10 was used for the fast neutron component of the dose.

UTAH - The neutron dose is reported in mrad. We have no means of determining the energy of the neutrons detected and cannot assign a quality factor. The TLD method used is a screening method only and is not suitable for personnel dosimetry applications.

INTERNAL DISTRIBUTION

1-2.	Central Research Library	15.	L. B. Holland
3.	Document Reference Section	16.	S. V. Kaye
4-5.	Laboratory Records Department	17.	Al King
6.	Laboratory Records, ORNL R.C.	18.	W. T. Mullins
7.	ORNL Patent Office	19.	G. R. Patterson
8.	J. A. Auxier	20.	P. S. Rohwer
9.	S. J. Cotter	21.	M. T. Ryan
10.	H. W. Dickson	22.	T. L. Rucker
11.	R. B. Gammage	23.	C. S. Sims
12.	L. W. Gilley	24.	C. M. West
13.	E. D. Gupton	25.	D. C. Parzyck
14.	F. F. Haywood	26-40.	DOSAR files

EXTERNAL DISTRIBUTION

41. R. E. Alexander, U.S. Nuclear Regulatory Commission, 5650 Nicholson Lane, Rockville, MD 20555
42. D. T. Bartlett, National Radiological Protection Board, Harwell Didcot, Oxfordshire OX11 0RQ, United Kingdom
43. Michael Baumann, University of Wisconsin-Madison, Safety Department, Room 103, 1410 Johnson Drive, Madison, WI 53706
44. L. G. Beuchler, National Naval Medical Center, Bureau of Medicine and Surgery Dosimetry Center, Radiological Safety Service, Bethesda, MD 20014
45. W. E. Bleiler, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439
46. R. P. Bradley, Radiation Protection Bureau, Brookfield Road, Ottawa, Ontario K1A 1C1, Canada
47. D. K. Bruening, Omaha Public Power District, 1623 Harney, Omaha, NE 68102
48. B. Burgkhardt, Kernforschungszentrum Karlsruhe, Postfach 3640, 7500 Karlsruhe, Federal Republic of Germany
49. Rick Cummings, Battelle Pacific Northwest Laboratories, P.O. Box 999, Richland, WA 99352
50. Jan Cusimano, Department of Energy-RESL, Idaho Operations Office, 550 Second Street, Idaho Falls, ID 83401
51. Howard Delafield, Environmental and Medical Sciences Division, AERE, Harwell, Oxfordshire, England OX11 0RA
52. T. R. Downard, University of Utah, Radiological Health Department, 100 Orson Spencer Hall, Salt Lake City, UT 84112
53. J. Dutrannois, CERN, European Organization for Nuclear Research, CH 1211 Geneve 23, Suisse, Switzerland
54. Great Ehrlich, Room C-210, Radiation Physics Building, National Bureau of Standards, Washington, DC 20234

55. Roger Falk, Rockwell International, Rocky Flats Plant,
P. O. Box 464, Golden, CO 80401
56. Judith Foulke, U.S. Nuclear Regulatory Commission, 7915 Eastern
Avenue, Room 1014, Silver Spring, MD 20555
57. John Flynn, Yale University, Health Physics Division, 314
Wright Nuclear Structure Laboratory, West, New Haven CT 06520
58. Eric Geiger, Eberline Instrument Corporation, P.O. Box 2108,
Santa Fe, NM 87501
59. J. St. Germain, Sloan Kettering Memorial Hospital, 411 East
67th Street, New York, NY 10021
60. K. Goebel, CERN, European Organization for Nuclear Research
CH 1211 Geneve 23, Suisse, Switzerland
61. Richard Griffith, Lawrence Livermore Laboratory, L383, P.O.
Box 808, Livermore, CA 94550
62. D. E. Hankins, Lawrence Livermore Laboratory, L383, P.O. Box
808, Livermore, CA 94550
63. G. R. Holeman, Yale University, Health Physics Division, 314
Wright Nuclear Structure Laboratory, West, New Haven, CT 06520
64. Dave Katzman, Radiation Management Corporation, 3508 Market
Street, Science Center Building No. 2, Philadelphia, PA 19104
65. Stephen M. Kim, Radiation Management Corporation, 3508 Market
Street, Philadelphia, PA 19104
66. George Kirsch, Battelle Memorial Institute, Columbus Laboratories,
505 King Avenue, Columbus, OH 43201
67. C. R. Lagerquist, Rockwell International, Rocky Flats Plant,
P.O. Box 464, Golden, CO 80401
68. John P. Lambert, Kansas State University, Office of Campus
Safety, Ward Hall, Manhattan, KS 66506
69. Mike Lantz, Reynolds Electric and Engineering Company, P.O.
Box 14400, Las Vegas, NV 89114
70. John L. Lobdell, Tennessee Valley Authority, Muscle Shoals,
AL 35660
71. Paul Lovendale, Fermilab, Batavia Road, Batavia, IL 60510
72. Wayne Lowder, Environmental Monitoring Laboratory, Department
of Energy, 376 Hudson Street, New York, NY 10014
73. A. C. Lucas, The Harshaw Chemical Company, 6801 Cochran Road,
Solon, OH 44139
74. S. A. McGuire, Office of Standards Development, U.S. Nuclear
Regulatory Commission, Washington, DC 20555
75. M. Oberhofer, Joint Research Center, Ispra Establishment,
Euratom C.C.R., 21020 Ispra (Varese), Italy
76. J. R. Ortman, Goodyear Atomic Corporation, P.O. Box 628,
Piketon, OH 45661
77. Richard Oswald R. S. Landauer, Jr., and Company, Division of
Technical Operations, Incorporated, Glenwood Science Park,
Glenwood, IL 60425
78. J. R. Pennock, Rockwell International, Rocky Flats Plant,
P.O. Box 464, Golden, CO 80401
79. Art Perez, University of California-Davis, Office of Environ-
mental Health and Safety, Davis, CA 95616
80. E. Piesch, Kernforschungszentrum Karlsruhe GmbH, Postface 3640,
D 7500 Karlsruhe 1, Federal Republic of Germany

81. Phillip Plato, School of Public Health, University of Michigan, Ann Arbor, MI 84106
82. Bob Powers, Tennessee Valley Authority, Muscle Shoals, AL 35660
83. W. M. Quam, EG&G, 130 Robin Hill Road, Goleta, GA 93017
84. Robert B. Schwartz, U.S. Department of Commerce, National Bureau of Standards, RADP B119, Washington, DC 20234
85. L. G. Sealock, Omaha Public Power District, 1623 Harney, Omaha, NE 68102
86. Billy Short, Goodyear Atomic Corporation, P.O. Box 628, Piketon, OH 45661
87. Billy Smith, Reynolds Electric and Engineering Company, P.O. Box 14400, Las Vegas, NV 89114
88. Frantisek Spurney, Czechoslovak Academy of Sciences, Institute of Radiation Dosimetry, Na Truhlárce 39/2a, 18086 Praha 8, Czechoslovakia
89. Joseph R. Stencel, Princeton University, Plasma Physics Laboratory, James Forrestal Campus, P.O. Box 451, Princeton, NJ 08540
90. Rose Marie Tauche, Eberline Instrument Corporation, P.O. Box 2108, Santa Fe, NM 87501
91. D. J. Thompson, Sandia Laboratories, Albuquerque, NM 87115
92. E. A. Ulicny, Notre Dame University, Radiation Laboratory, Notre Dame, IN 46556
93. Ed Vallario, U.S. Department of Energy, Division of Operational and Environmental Safety, Mail Stop E201, Washington, DC 20545
94. J. F. Valley, Institut de Radiophysique Appliquée, Centre Universitaire, 1015 Lausanne, Switzerland
95. B. Waldeskog, IAEA, Dosimetry Section, Division of Life Sciences, Karntner Ring 11, P.O. Box 590, A-1011 Vienna, Austria
96. Robert V. Wheeler, R. S. Landauer, Jr., and Company, Division of Technical Operations, Incorporated, Glenwood Science Park, Glenwood, IL 60425
97. R. W. Wood, Division of Pollutant Characterization and Safety Research, Department of Energy, Washington, DC 20545
98. C. N. Wright, Savannah River Laboratory, Aiken, South Carolina 29802
99. G. H. Zeman, National Naval Medical Center, Bureau of Medicine and Surgery Dosimetry Center, Radiological Safety Service, Bethesda, MD 20014
100. Office of Assistant Manager, Energy Research and Development, Department of Energy, Oak Ridge Operations Office, Oak Ridge, TN 37830
- 101-127. Technical Information Center, Department of Energy, Oak Ridge, TN 37830