30
5-29-85 J.D. (2)

DR-1032-4

ornl

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

ORNL-6173

Twenty-First Nuclear Accident Dosimetry Intercomparison Study: August 6-10, 1984

R. E. Swaja
G. E. Ragan
C. S. Sims

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL--6173

DE85 012076

Contract No. DE-AC05-84OR21400

Health and Safety Research Division

Twenty-first Nuclear Accident Dosimetry Intercomparison Study: August 6-10, 1984

R. E. Swaja

G. E. Ragan

C. S. Sims

Date Published - May 1985

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY

TABLE OF CONTENTS

List Of Tables

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of the following people in making this intercomparison a success: L. F. Amburn in handling administrative details and manuscript preparation; E. G. Bailiff in operating the reactor and assisting with experimental setup; T. L. Chou, P. A. Scofield, and J. E. Wofford in obtaining DOSAR dose estimates and assisting with experimental work; and G. R. Patterson in evaluating reference dosimetry.

We also acknowledge R. W. Wood, Director of the Physical and Technological Research Division, U.S. Department of Energy, for funding this work.

TWENTY-FIRST NUCLEAR ACCIDENT DOSIMETRY INTERCOMPARISON STUDY:

AUGUST 6-10, 1984

R. E. Swaja

G. E. Ragan

C. S. Sims

Highlights

The twenty-first in a series of nuclear accident dosimetry (NAD) intercomparison (NAD) studies was conducted at the Oak Ridge National Laboratory's Dosimetry Applications Research Facility during August 6-10, 1984. The Health Physics Research Reactor operated in the pulse mode was used to simulate three criticality accidents with different radiation fields. Participants from five organizations measured neutron doses between 0.53 and 4.36 Gy and gamma doses between 0.19 and 1.01 Gy at area monitoring stations and on phantoms. About 75% of all neutron dose estimates based on foil activation, hair activation, simulated blood sodium activation, and thermoluminescent methods were within ± 25% of reference values. Approximately 86% of all gamma results measured using thermoluminescent (TLD-700 or $CaSO_4$) systems were within ± 20% of reference doses which represents a significant improvement over previous studies. Improvements observed in the ability of intercomparison participants to estimate neutron and gamma doses under criticality accident conditions can be partly attributed to experience in previous NAD studies which have provided practical tests of dosimetry systems, enabled participants to improve evaluation methods, and standardized dose reporting conventions.

INTRODUCTION

The twenty-first in a series[1-6] of nuclear accident dosimetry (NAD) intercomparison studies was conducted at the Oak Ridge National Laboratory's (ORNL) Dosimetry Applications Research (DOSAR) Facility during August 6-10, 1984. Participants measured neutron doses between 0.53 and 4.36 Gy and gamma doses between 0.19 and 1.01 Gy at area monitoring locations (air stations) and on phantoms for three simulated criticality accidents. These accidents were simulated by operating the Health Physics Research Reactor (HPRR)[7] in the pulse mode with and without spectral modifying shields. Results of individual agencies were compared with those of other participants who made similar measurements under identical conditions and to reference doses based on reactor characteristic data. This week-long study also included lectures, discussions, and demonstrations on subjects concerning neutron activation principles, foil activation analysis, biological dosimetry, accident dose conventions, medical aspects of radiation accidents, analysis of the Japanese bomb survivor data, and problems associated with nuclear accident monitoring at participating facilities. The intercomparison study program is included in Appendix A of this report.

PARTICIPATION

A total of 15 people from 5 different organizations participated in this study. Four agencies reported final dose estimates. Appendix B lists individual participants, their affiliations, mailing addresses, and the abbreviations used in this report to identify participating organizations.

DESCRIPTION OF EXPERIMENTS

A summary of experimental conditions for the three pulses considered in this study is given in Table 1. The three pulses had fission yields between 6.12 to 9.05 x 10^{16} fissions for the HPRR with the following shield conditions: unshielded, shielded with 20-cm of concrete, and shielded with 13-cm of steel. Details of the shield construction and associated neutron and gamma spectra have been reported in the literature[8].

Accident dosemeters were mounted on ring stands or tables for area monitoring station measurements and on BOMAB[9] phantoms for personnel monitoring. Dosemeters at air stations and phantom centerlines were located 3 m from the reactor vertical centerline. Horizontal centerlines of the HPRR, area monitors, and personnel dosemeters were positioned 1.5 m above the floor. All phantoms were arranged with their fronts facing the HPRR. One phantom was filled with a saline solution with a sodium content approximating that found in human blood (1.5 mg/ml). The activated saline solution was made available to particiants after each pulse for dose measurements based on simulated blood sodium activation analysis[9–10]. Two other phantoms used for personnel monitoring studies were filled with tap water.

DOSEMETERS USED IN THE INTERCOMPARISON

A general description of the types of radiation dosemeters used in this study and the abbreviations used to identify them are given below. Neutron doses were measured using foil activation systems or thermoluminescent dosemeters (TLD's) at air stations and foil activation, TLD, TLD-albedo, sodium activation, or hair activation on phantoms. All gamma measurements were made using thermoluminescent dosemeters with TLD-700 (^{7}LiF) or $CaSO_4$ phosphors. Detailed descriptions of the accident dosimetry systems and evaluation methods are available in the literature[11–12].

Neutron Dosemeters

1. Foil Activation Systems (Act) – Some materials (e.g., gold copper, indium, sulfur) become radioactive when exposed to neutrons. By measuring the activity of exposed foils, neutron fluences over differential energy ranges can be estimated for the incident spectrum. Associated neutron doses can be obtained by applying fluence-to-dose conversion factors to the estimated fluences and summing over the range of energies encompassed by the activation foils. Some activation systems also use foils made of

fissionable materials (e.g., plutonium, neptunium, uranium) which have fission cross sections with thresholds at different neutron energies. These systems are called Threshold Detector Units (TDU's) and are generally used for area monitoring.

2. Thermoluminescent (TLD) and TLD-albedo dosemeters - In some substances metastable states are produced when these materials are irradiated and, upon heating, light is emitted in proportion to the absorbed dose. For neutron monitoring, two types of TL materials, one sensitive to gammas (^{7}LiF) and the other sensitive to neutrons and gammas (^{6}LiF), are simultaneously exposed to the simulated nuclear accident radiation fields. The response due to neutrons can be determined after both chips are analyzed. The thermoluminescent neutron systems considered in this study were of the direct interaction (TLD) type, which respond mostly to directly incident neutrons, and the TLD-albedo type, which respond mostly to neutrons reflected from the body. Both systems are also used for routine personnel neutron monitoring.

3. Sodium Activation (NaAct) - Samples from irradiated, saline-filled phantoms are analyzed for ^{24}Na activity by any of a variety of counting techniques. The dose received by a phantom is proportional to the activity per unit volume of solution.

4. Human Hair Activation (HAct) - Samples of human hair are analyzed for ^{32}P activity following irradiation. This method is used to determine the dose due to neutrons with energies greater than the ^{32}S(n,p) threshold of about 2.5 MeV. The total neutron dose can be determined if the fast neutron dose fraction is known.

Gamma Dosemeters

All gamma dosemeters used in this study were TLD's containing TLD-700 or $CaSO_4$ phosphors. These dosemeters are also used for routine gamma personnel monitoring at participating agencies.

REFERENCE DOSIMETRY

Reference neutron and gamma doses in air and on phantoms are given in Tables 2 and 3, respectively. Reference neutron doses in air (Table 2) were obtained using fission yields determined by measuring the ^{32}P beta activity in a 22 gram sulfur pellet located at a fixed position near the reactor core and applying dose-per-fission conversion factors at 3 m from the reactor for the various HPRR spectra[8]. Reference neutron doses in air are given in terms of wet tissue kerma [13] and element 57 absorbed dose[14] with the capture gamma component excluded. Element 57 refers to the central volume element of a tissue-equivalent cylindrical phantom used to calculate the average absorbed dose per unit incident neutron fluence. Neutron dose in volume element 57 is the highest for all volume elements in the phantom and represents the expected maximum measured value for each exposure in this study. Reference neutron doses at air stations varied from 0.53 to 4.15 Gy for this study. Reference gamma doses in air were obtained by dividing neutron kerma in air by the neutron-to-gamma dose ratio at 3 m from the reactor. The neutron-to-gamma dose ratio is based on measured results from the first nineteen NAD intercomparison studies. For this intercomparison, reference gamma doses at air stations varied from 0.19 to 0.59 Gy.

The reference neutron and gamma doses on phantoms given in Table 3 were calculated by multiplying doses in air by appropriate air-to-phantom conversion factors developed from measured results of the first nineteen NAD intercomparison studies. These factors were applied only to neutron kerma and gamma dose values since element 57 dose already represents the absorbed dose in a particular volume element of a tissue equivalent phantom. Reference neutron and gamma doses on phantoms ranged from 0.64 to 4.36 Gy and from 0.33 to 1.01 Gy, respectively, for this study. For comparison with measured results, reference neutron doses will be given in terms of wet tissue kerma at air stations and element 57 absorbed dose on phantoms[1].

MEASUREMENT RESULTS AND ANALYSIS

Tables 4-9 summarize final results of measurements reported by participants for the Twenty-first NAD Study. Air station results including neutron and gamma dose estimates, neutron-to-gamma dose ratios, and detection systems are given in Tables 4-6 for each reporting agency. Tables 7-9 summarize results of measurements made on phantoms for each organization. Data contained in these tables include neutron doses, gamma doses, and the basis for the reported dose estimates.

Table 10 summarizes results of neutron dose measurements at air stations and on phantoms based on data shown in Tables 4-9. The table gives average measured neutron doses and experimental standard deviations about the mean for each basic dosemeter type (foil activation, blood sodium and/or hair activation, and TLD and TLD-albedo systems) and for the composite of all measurements. Reference values given in terms of wet tissue kerma for air station results and element 57 absorbed dose for phantom measurements are also included.

Average measured neutron doses normalized to the reference values and associated percent standard deviations about the mean (in parenthesis) based on data shown in Table 10 are given in Table 11 for each basic dosemeter type and for the composite of all measurements.

Normalized doses indicate the accuracy of the mean of a set of measurements relative to the reference value. Standard deviation about the mean is a measure of precision and reflects agreement among individual measurements of the same dose.

Considering all dosemeter types (column labeled "All"), neutron doses were underestimated by an average of about 11% for air stations and 15% for phantom measurements. With the exception of the air station results for the concrete-shielded pulse, average neutron doses were about 15% lower than reference values. No significant variations in average measurement accuracy with neutron spectrum average energy or neutron-to-gamma dose ratio is observable based on the results obtained for the composite of all measurements. Standard deviations associated with these data were lower for air stations (average = 11% of the mean) than for phantoms (average = 17%). For each pulse, measurements made at air stations were equally precise or more precise than corresponding measurements made on phantoms.

Neutron dose measurements at air stations were made using foil activation methods (the most popular type of area monitor used in this study) or TLD systems. Average activation-measured neutron doses varied between 0.81 to 1.00 times the reference values (average = 0.90) with the magnitude increasing with increasing neutron spectrum softness (i.e., decreasing mean energy). Associated standard deviations averaged 11% of the means for the three pulses. Since only one agency reported air station results based on TL monitors, no detailed analysis of the data is possible. However, TLD-measured neutron doses were within 25% of reference values for all three pulses.

With regard to phantom measurements, personnel accident dosemeters based on foil activation produced average neutron doses which varied from 0.71 to 0.82 times reference values (average = 0.78). Associated standard deviations varied from 12 to 22% of the means with an average of 16% for the three pulses. Average results obtained for blood sodium and hair activation varied between 0.79 and 0.95 times reference doses (average = 0.87) with an average standard deviation of 13% of the mean. The TLD and TLD-albedo personnel dosemeters, which were used by two agencies, provided average neutron doses between 0.89 and 0.98 times reference values (average = 0.94) with an average standard deviation of 17% of the mean. Thus, of the basic systems used to estimate personnel neutron doses in this study, TL and albedo systems provided the most accurate estimates (within 11% of references) followed by blood sodium and/or hair activation (within 21% of references) and foil activation (within 29% of references). This indicates that TL-based neutron dosemeters used for routine personnel monitoring can provide accurate dose estimates under accident conditions.

Table 12 summarizes average gamma dose measurements at air stations and on phantoms, associated experimental standard deviations about the mean, reference doses, and measured and reference neutron-to-gamma dose ratios (D_n/D_γ) at air stations for each of the three pulses. All gamma measurements were made using either ^{7}LiF (TLD-700) or $CaSO_4$ phosphors. Measured dose ratios are within one experimental standard deviation of the reference values for all three pulses.

Average measured gamma doses normalized to the reference values and associated percent standard deviations from the mean (in parenthesis) for air station and phantom locations are given in Table 13. Average measured results were within 14% and 7% of the reference values for air stations and phantoms, respectively. Most accurate measurements were obtained for the unshielded pulse while least accurate were obtained for the steel-shielded spectrum. Air station measurements were more precise (average standard deviation = 9% of the mean) than corresponding phantom results (average standard deviation = 17% of the mean) for each pulse. These results indicate that personnel gamma dosemeters are capable of providing very accurate and precise estimates of gamma doses under accident conditions.

Measured and reference phantom-to-air station dose ratios are given in Table 14 for neutrons and gammas. Neutron doses measured on phantoms are larger than air stations due to neutrons reflected from the phantom. Gamma doses on phantoms are higher than at air stations because of the contribution of gamma rays from neutron capture reactions in hydrogen in phantom materials. In all cases, measured phantom-to-air dose ratios are within one experimental standard deviation of reference results.

DOSEMETER PERFORMANCE RELATIVE TO REGULATORY CRITERIA

Guidelines[15-16] for criticality accident dosimetry suggest accuracies of ± 25% for neutron dose and ± 20% for gamma dose measurements. Table 15 summarizes the performance of neutron and gamma measurements made in this study relative to these criteria for air stations, phantoms, and the composite of all measurements. Data shown in the table include the number of measurements reported, the number satisfying the appropriate criterion, and the percent of results satisfying the criterion (in parenthesis).

A total of 75% of all neutron measurements was within ± 25% of reference values. Participants had greater success satisfying the guidelines at air stations where a total of 91% of the results was within ± 25% of references compared to 70% of the phantom measurements. The same degree of success was exhibited for unshielded and shielded spectrum measurements which indicated 77% and 76% of the results, respectively, meeting the criterion. This performance is consistent with that observed in the most recent intercomparisons[1-3] which produced about 75% of all neutron measurements within the suggested limits.

With regard to gamma data, 86% of all reported results was within ± 20% of reference values. All measurements made at air stations satisfied the criterion while 75% of the phantom results was within the limits. Gamma measurement performance exhibited in this study is considerably improved over that found in the most recent intercomparisons[1-3] which produced only 39% of the gamma dose estimates within ± 20% of reference values.

CONCLUSIONS

Results of the Twenty-first NAD Intercomparison indicated that 75% of all neutron measurements and 86% of all gamma measurements made under simulated criticality accident conditions satisfied suggested accident dosimetry guidelines relative to reference doses. Neutron doses measured at air stations using foil activation systems, the most popular type used in this study, provided average neutron doses within 20% of reference values for all three pulses. Foil activation and blood sodium and/or hair neutron activation measurements on phantoms provided results within 30% of references for the simulated criticality accidents. Neutron dose estimates based on TLD or TLD-albedo systems which are also used for personnel monitoring were within 25% of reference values for areal and phantom measurements. Gamma dose estimates based on TLD-700 or $CaSO_4$ phosphors were within 14% of references for all pulses and monitoring locations. Improvements observed in the ability of intercomparison participants to estimate neutron and gamma doses under accident conditions can be partly attributed to experience in previous NAD studies which have provided practical tests of dosimetry systems, enabled participants to improve evaluation methods, and standardized dose reporting conventions.

RECOMMENDATIONS

The number of participating agencies in the past few NAD studies has been relatively consistent at about six organizations per intercomparison. This number represents a slight decrease in total number of participants relative to the Fifteenth through Eighteenth NAD Intercomparisons. Based on discussions with dosimetrists at agencies which maintain accident monitoring systems, interest in these intercomparisons is still great but travel funding has decreased significantly at most participating facilities. To provide a relatively high number of participants (at least eight agencies) and to ensure significant interaction among accident dosimetrists, the DOSAR staff should consider conducting these intercomparisons every two years instead of annually. Significant interest in the Criticality Accident Dosimetry Training Course sponsored by the DOSAR staff is also indicated. This course could be conducted during the years between NAD intercomparisons.

References

1. R. E. Swaja, R. T. Greene, and C. S. Sims, 1983 International Intercomparison of Nuclear Accident Dosimetry Systems at Oak Ridge National Laboratory, ORNL-6164 (1985).

2. R. T. Greene, C. S. Sims, and R. E. Swaja, Nineteenth Nuclear Accident Dosimetry Intercomparison Study: August 9-13, 1982, ORNL/TM-8698 (November 1983).

3. R. E. Swaja, C. S. Sims, and R. T. Greene, Eighteenth Nuclear Accident Dosimetry Intercomparison Study: August 20-14, 1981, ORNL/TM-8281 (November 1982).

4. R. E. Swaja and R. T. Greene, Seventeenth Nuclear Accident Dosimetry Intercomparison Study; August 22-15, 1980, ORNL/TM-7696 (April 1981).

5. C. S. Sims and R. E. Swaja, Sixteenth Nuclear Accident Dosimetry Intercomparison Study: August 13-17, 1979, ORNL/TM-7596 (December 1980).

6. 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, 687-99 (1979).

7. J. A. Auxier, "The Health Physics Research Reactor," Health Phys. 11, 89-93 (1965).

8. C. S. Sims and G. G. Killough, Reference Dosimetry for Various Health Physics Research Reactor Spectra, ORNL/TM-7748 (July 1981).

9. F. W. Sanders and J. A. Auxier, "Neutron Activation of Sodium in Anthropomorphous Phantoms," Health Phys. 8, 371-79 (1962).

10. D. R. Davy, L. H. Peshori, and J. W. Poston, "Sodium - 24 Production in Saline-Filled Phantoms under Neutron Irradiation," Health Phys. 12 1353-56 (1966).

11. H. J. Delafield, J. A. Dennis, and J. A. B. Gibson, Nuclear Accident Dosimetry, AERE-R7485-7 (1973).

12. D. E. Hankins, A Study of Selected Criticality Dosimetry Methods, LA-3910 (June 1968).

13. International Commission on Radiation Units and Measurements, "Neutron Fluence, Neutron Spectra, and Kerma," ICRU Report 13 (September 1969).

14. J. A. Auxier, W.S. Snyder, and T. D. Jones, "Neutron Interactions and Penetrations in Tissue," Rad. Dosimetry 1, 275 (1968).

15. American National Standards Institute, "Dosimetry for Criticality Accidents," ANSI N13.3-1969 (1969).

16. U. S. Atomic Energy Commission Manual, "Nuclear Accident Dosimetry Program," AEC-0545 (May, 1984).

Table 1. Summary of experimental conditions[a]

Pulse No.	Date	Eastern Daylight Time	Pulse yield,[b] 10^{16} fissions	Shield	Reactor to shield distance, m
1	8/7/84	1020	9.05	None	–
2	8/8/84	1020	6.12	20-cm concrete	1
3	8/9/84	1023	8.38	13-cm steel	2

[a]Dosemeters at area monitoring stations were located 3 m from the centerline of the HPRR. The centerlines of phantoms on which personnel dosemeters were exposed were 3 m from the centerline of the HPRR.

[b]Based on sulfur pellet activation analysis.

Table 2. Reference neutron and gamma doses at air stations

Pulse No.	Shield	Pulse yield, 10^{16} fissions	Neutron dose, 10^{-2} Gy[a] Kerma	Element 57	Neutron-to-gamma dose ratio[b]	Gamma dose, 10^{-2} Gy[c]
1	None	9.05	362	415	6.1	59
2	20-cm concrete	6.12	53	61	2.6	20
3	13-cm steel	8.38	146	150	7.8	19

[a]Calculated dose at 3 m from the reactor centerline based on HPRR reference dosimetry document ORNL/TM-7748. Units are 10^{-2} Gy (1 rad).

[b]Dose ratio at 3 m from the reactor based on measured results from the first nineteen nuclear accident dosimetry intercomparison studies.

[c]Neutron kerma divided by neutron-to-gamma dose ratio.

Table 3. Reference neutron and gamma doses on phantoms

Pulse No.	Neutron air-to-phantom conversion[a]	Neutron dose, 10^{-2} Gy: Kerma[b]	Neutron dose, 10^{-2} Gy: Element 57	Gamma air-to-phantom conversion[a]	Gamma dose, 10^{-2} Gy[b]
1	1.0[illegible]	380	436	1.70	101
2	1.20	64	73	1.62	33
3	1.19	174	179	2.33	44

[a]Ratio of phantom-to-air dose based on measured results from the first nineteen nuclear accident dosimetry intercomparison studies.

[b]Product of conversion factor times the dose in air given in Table 2.

Table 4. Measurements at air stations for pulse no. 1
Yield: 9.05 (10^{16}) fissions
Shield: none

Group	Neutron dose, 10^{-2} Gy[a]	Gamma dose, 10^{-2} Gy	Dn/Dγ	Detector system	
				neutron	gamma
Reference	362	59	6.1	-	-
Reference	415[b]	-	-	-	-
DOSAR	357	59	6.1	Act	TLD-700
GAT	280	68	4.1	TLD	TLD-700
GAT	290	68	4.3	Act	TLD-700
SRP	237	57	4.2	Act	TLD-700
SRP	-	57	4.2	-	TLD-$CaSO_4$

[a]Neutron doses represent wet tissue kerma unless otherwise indicated and are given in units of 10^{-2} Gy (1 rad).

[b]Neutron dose represents element 57 dose with the $^{1}H(n,\gamma)^{2}H$ component excluded.

Table 5. Measurements at air stations for pulse no. 2
Yield: 6.12 (10^{16}) fissions
Shield: 20-cm concrete

Study group	Neutron dose, 10^{-2} Gy[a]	Gamma dose, 10^{-2} Gy	Dn/Dγ	Detector system neutron	Detector system gamma
Reference	53	20	2.7	-	-
Reference	61[b]	-	-	-	-
DOSAR	48	17	2.8	Act	TLD-700
GAT	57	24	2.4	TLD	TLD-700
GAT	60	24	2.5	Act	TLD-700
SRP	51	21	2.4	Act	TLD-700
SRP	-	22	2.3	-	TLD-$CaSO_4$

[a]Neutron doses represent wet tissue kerma unless otherwise indicated and are given in units of 10^{-2} Gy (1 rad).

[b]Neutron dose represents element 57 dose with the $^1H(n,\gamma)^2H$ component excluded.

Table 6. Measurements at air stations for pulse no. 3
Yield: 8.38 (10^{16}) fissions
Shield: 13-cm steel

Study group	Neutron dose, 10^{-2} Gy[a]	Gamma dose, 10^{-2} Gy	Dn/Dγ	Detector system	
				neutron	gamma
Reference	146	19	7.7	-	-
Reference	150[b]	-	-	-	-
DOSAR	128	17	7.5	Act	TLD-700
GAT	110	16	6.9	TLD	TLD-700
SRP	132	16	8.3	Act	TLD-700

[a]Neutron doses represent wet tissue kerma unless otherwise indicated and are given in units of 10^{-2} Gy (1 rad).

[b]Neutron dose represents element 57 dose with the $^{1}H(n,\gamma)^{2}H$ component excluded.

Table 7. Measurements on phantoms for pulse no. 1
Yield: 9.05 (10^{16}) fissions
Shield: none

Study group	Neutron dose, 10^{-2} Gy[a]	Gamma dose, 10^{-2} Gy	Basis for estimating neutron dose	Basis for estimating gamma dose
Reference	415	101	–	–
Reference	380[b]	–	–	–
DOSAR	439	104	NaAct[c]	TLD–700
DOSAR	438	–	HAct[d]	–
GAT	285[b]	128	Act	TLD–700
GAT	390	–	TLD	–
LLNL	390	117	ACT	TLD–700
LLNL	390	–	TLD–albedo	–
LLNL	390	–	Na+HAct[e]	–
SRP	260[b]	84	Act	TLD–700
SRP	390[b]	95	NaAct	TLD–$CaSO_4$

[a]Neutron doses represent element 57 values unless otherwise indicated and are given in units of 10^{-2} Gy (1 rad).

[b]Neutron dose represents wet tissue kerma.

[c]Blood sodium activation.

[d]Hair activation.

[e]Combination of hair and sodium activation.

Table 8. Measurements on phantoms for pulse no. 2
Yield: 6.12 (10^{16}) fissions
Shield: 20-cm concrete

Study group	Neutron dose, 10^{-2} Gy[a]	Gamma dose, 10^{-2} Gy	Basis for estimating	
			neutron dose	gamma dose
Reference	61	33	–	–
Reference	64[b]	–	–	–
DOSAR	52	32	NaAct[c]	TLD-700
DOSAR	50	–	HAct[d]	–
GAT	57[b]	41	Act	TLD-700
GAT	63	–	TLD	–
LLNL	69	46	ACT	TLD-700
LLNL	80	–	TLD-albedo	–
LLNL	61	–	Na+HAct[e]	–
SRP	54[b]	32	Act	TLD-700
SRP	68[b]	29	NaAct	TLD-$CaSO_4$

[a]Neutron doses represent element 57 values unless otherwise indicated and are given in units of 10^{-2} Gy (1 rad).

[b]Neutron dose represents wet tissue kerma.

[c]Blood sodium activation.

[d]Hair activation.

[e]Combination of hair and sodium activation.

Table 9. Measurements on phantoms for pulse no. 3
Yield: 8.38 (10^{16}) fissions
Shield: 13-cm steel

Study group	Neutron dose, 10^{-2} Gy[a]	Gamma dose, 10^{-2} Gy	Basis for estimating neutron dose	Basis for estimating gamma dose
Reference	150	44	–	–
Reference	174[b]	–	–	–
DOSAR	141	33	NaAct[c]	TLD-700
DOSAR	125	–	HAct[d]	–
GAT	130[b]	41	Act	TLD-700
GAT	130	37	TLD	TLD-700
LLNL	140	51	ACT	TLD-700
LLNL	210	–	TLD-albedo	–
LLNL	170	–	Na+HAct[e]	–
SRP	165[b]	46	Act	TLD-700
SRP	188[b]	38	NaAct	TLD-$CaSO_4$

[a]Neutron doses represent element 57 values unless otherwise indicated and are given in units of 10^{-2} Gy (1 rad).

[b]Neutron dose represents wet tissue kerma.

[c]Blood sodium activation.

[d]Hair activation.

[e]Combination of hair and sodium activation.

Table 10. Summary of results of neutron measurements at air stations and on phantoms

Pulse No.	Dosemeter location (spectrum)	Neutron dose, 10^{-2} Gy[a]				
		Activation[b]	Sodium/Hair[c]	TLD and albedo	All[d]	Reference[e]
1	Air (bare)	294 ± 60 (3)[f]	-	280(1)	291 ± 50 (4)	362
2	Air (concrete)	53 ± 6 (3)	-	57 (1)	54 ± 5 (4)	53
3	Air (steel)	130 ± 3 (2)	-	110 (1)	123 ± 12 (3)	146
1	Phantom (bare)	312 ± 69 (3)	414 ± 28 (4)	390 ± 0 (2)	375 ± 62 (9)	436
2	Phantom (concrete)	60 ± 8 (3)	58 ± 8 (4)	72 ± 12 (2)	62 ± 10 (9)	73
3	Phantom (steel)	145 ± 18 (3)	156 ± 28 (4)	170 ± 57(2)	155 ± 30 (9)	179

[a]Values are average doses based on data shown in Tables 4-6 (air) and Tables 7-9 (phantom) and are given in units of 10^{-2} Gy (1 rad).

[b]Includes only foil activation and threshold detector unit data.

[c]Blood sodium and hair activation data.

[d]Includes data from all detector types.

[e]Reference values given in terms of wet tissue kerma for air station measurements and in terms of element 57 dose for phantom measurements.

[f]Mean of reported results ± one standard deviation (number of reported measurements).

Table 11. Normalized average measured neutron doses and associated percent standard deviations[a]

Pulse No.	Dosemeter location (spectrum)	Normalized neutron dose (percent standard deviation)[b]			
		Activation[b]	Sodium/Hair[c]	TLD and albedo	All[c]
1	Air (bare)	0.81 (20)	-	0.97[d]	0.80 (17)
2	Air (concrete)	1.00 (11)	-	1.08[d]	1.02 (9)
3	Air (steel)	0.89 (2)	-	0.75[d]	0.84 (9)
1	Phantom (bare)	0.71 (22)	0.95 (7)	0.89 (0)	0.86 (16)
2	Phantom (concrete)	0.82 (13)	0.79 (14)	0.98 (17)	0.84 (16)
3	Phantom (steel)	0.81 (12)	0.87 (18)	0.95 (33)	0.87 (19)

[a]Based on data shown in Table 10.

[b]Average reported measured dose divided by the reference value (percent of standard deviation about the mean).

[c]Includes results for all measurement methods.

[d]One measurement reported.

Table 12. Summary of results of gamma dose measurements at air stations and on phantoms

Pulse No.	Dosemeter location (spectrum)	Gamma dose, 10^{-2} Gy[a]		$D_n/D\gamma$	
		TLD[b]	Reference	Measured[c]	Reference[d]
1	Air (bare)	62 ± 6[e]	59	4.7 ± 1.5	6.1
2	Air (concrete	22 ± 3	20	2.4 ± 0.4	2.6
3	Air (steel)	16 ± 1	19	7.7 ± 0.8	7.8
1	Phantom (bare)	106 ± 17	101		
2	Phantom (concrete)	36 ± 7	33		
3	Phantom (steel)	41 ± 7	44		

[a]Values are average doses based on data shown in Tables 4-6 (air) and Tables 7-9 (phantoms) and are given in units of 10^{-2} Gy (1 rad).

[b]All reported gamma measurements were made with TLD-700 or $CaSO_4$ dosemeters.

[c]Average of all reported neutron kerma measurements divided by the average of all reported gamma dose measurements.

[d]Data from Table 2.

[e]Mean ± one standard deviation.

Table 13. Normalized average measured gamma doses and associated percent standard deviations[a]

Pulse No.	Shield	Dosemeter Location	Normalized dose (percent standard deviation)[b]
1	None	air	1.05 (9)
2	Concrete	air	1.08 (13)
3	Steel	air	0.86 (4)
1	None	phantom	1.05 (16)
2	Concrete	phantom	1.09 (19)
3	Steel	phantom	0.93 (17)

[a]Based on data given in Table 12.

[b]Average reported measured dose divided by the reference value (percent of standard deviation about the mean).

Table 14. Comparison of doses measured on phantoms with those measured at air stations

Pulse No.	Shield	Ratio of phantom dose to air station dose: Neutron, Measured[a]	Neutron, Reference[b]	Gamma, Measured[c]	Gamma, Reference[b]
1	None	1.29 ± 0.28[d]	1.05	1.71 ± 0.36	1.70
2	Concrete	1.14 ± 0.43	1.20	1.63 ± 0.44	1.62
3	Steel	1.26 ± 0.41	1.19	2.56 ± 0.35	2.33

[a]Based on data given in Table 10 for all reported dose measurements.

[b]Based on experimental data obtained during the previous 19 intercomparison studies.

[c]Based on data given in Table 12 for all reported dose measurements.

[d]Phantom dose divided by air dose ± one standard deviation about the mean.

Table 15. Summary of final measured results relative to regulatory criteria[a]

Pulse number	Dosemeter location (shield)	Neutron measurements: Number of measurements	Neutron measurements: Number meeting criterion[b]	Gamma measurements: Number of measurements	Gamma measurements: Number meeting criterion[b]
1	Air (none)	4	3 (75)	5	5 (100)
2	Air (concrete)	4	4 (100)	5	5 (100)
3	Air (steel)	3	3 (100)	3	3 (100)
1	Phantom (none)	9	7 (78)	5	4 (80)
2	Phantom (concrete)	9	6 (67)	5	3 (60)
3	Phantom (steel)	9	6 (67)	6	5 (83)
Total		38	29 (75)	29	25 (86)

[a]Criteria presented in ANSI N13.3 which suggest accuracies of ± 25% for neutron doses and ±20% for gamma doses.

[b]Number of measurements meeting the above mentioned criteria (percent meeting criteria).

APPENDIX A

PROGRAM

TWENTY-FIRST NUCLEAR ACCIDENT DOSIMETRY INTERCOMPARISON STUDY

August 6-10, 1984

Date	Time	Activity
August 6 (Monday)	9:00 AM	Welcome and Orientation, C. S. Sims (ORNL)
	9:30	Review of the study program, R. E. Swaja (ORNL)
	10:00	Tour of DOSAR Facility and HPRR
		LUNCH
	1:00 PM	Lecture: Introduction to Criticality Accident Dosimetry, R. E. Swaja (ORNL)
	2:00	Lecture: Neutron Activation Principles, R. T. Greene, (ORNL)
	3:00	Preparation for Pulse No. 1
August 7 (Tuesday)	8:30 AM	Final setup of dosimetry for Pulse No. 1
	9:00	Lecture: Reporting Accident Doses, C. S. Sims (ORNL)
	10:00	Observation of Pulse operation of HPRR
	10:30	Pulse No. 2 (unshielded)
	11:00	Group photograph
	11:30	Collect dosimeters
		LUNCH
	1:00 PM	Analysis of data and preparation for Pulse No. 2 - Demonstration of foil activation analysis
August 8 (Wednesday)	8:30 AM	Final setup of dosimeters for Pulse No. 2
	9:00	Lecture: Biological Perspective of Occupational Exposures, T. D. Jones, (ORNL)
	10:00	Lecture: Medical Aspects of Radiation Accidents, S. A. Fry (ORAU)

	10:30	Pulse No. 2 (20-cm concrete shield)
	11:00	Collect dosimeters
		LUNCH
	1:00 PM	Analysis of data and preparation for Pulse No. 3 Demonstration of hair and blood sodium activation analysis
August 9 (Thursday)	8:00 AM	Final setup of dosimeters for Pulse No. 3
	9:00	Lecture: <u>Progress in the Analysis of the Japanese Bomb Survivor Data</u>, G. D. Kerr, (ORNL)
	10:00	Pulse No. 3 (13-cm steel shield)
		Discussion: Requirements and problems associated with nuclear accident monitoring at participating facilities
	11:00	Collect dosimeters
		LUNCH
	1:00	Analysis of data
August 10 (Friday)	9:0C AM	Presentation of preliminary dose estimates and discussion of results
	10:00	Discussion: The future of accident monitoring and dosimetry
	11:00	Final critique

APPENDIX B

List of Participants and Observers

Name	Affiliation
E. G. Bailiff T. L. Chou R. T. Greene G. R. Patterson P. A. Scofield C. S. Sims R. E. Swaja J. E. Wofford	Oak Ridge National Laboratory Dosimetry Applications Research Building 7710 P. O. Box X Oak Ridge, Tennessee 37831 *DOSAR
S. J. James T. H. Maggard	Goodyear Atomic Corporation P.O. Box 628 Piketon, Ohio 45661 *GAT
D. E. Hankins	Lawrence Livermore National Laboratory P. O. Box 5505 Livermore, California 94550 *LLNL
B. H. Lane J. H. Miller	Oak Ridge National Laboratory Environmental and Occupational Safety P. O. Box X Oak Ridge, Tennessee 37831 *ORNL
R. M. Hall P. C. Padezanin	Savannah River Plant Aiken, South Carolina 29801 *SRP

---

*Abbreviation used to identify this organization in this report.

INTERNAL DISTRIBUTION

1-2. Central Research Library
3. Document Reference Section
4-5. Laboratory Records Department
6. Laboratory Records, ORNL R.C.
7. ORNL Patent Office
8. E. G. Bailiff
9. C. D. Berger
10. B. A. Berven
11. J. S. Bogard
12. R. O. Chester
13. H. R. Dyer
14. K. F. Eckerman
15. L. B. Holland
16. D. A. Jones
17. S. V. Kaye
18. B. H. Lane
19. J. M. Mahathy
20. C. W. Miller
21. W. T. Mullins
22. D. C. Parzyck
23. G. R. Patterson
24. C. R. Richmond
25. P. S. Rohwer
26-30. C. S. Sims
31-35. R. E. Swaja

EXTERNAL DISTRIBUTION

36. J. M. Aldrich, Rockwell International-Rocky Flats Plant, P.O. Box 464, Golden, CO 80401
37. V. E. Aleinikov, International Atomic Energy Agency, P.O. Box 100, Wagramerstrasse 5, A-1400 Vienna, AUSTRIA
38. R. E. Alexander, USNRC, 1130 Silver Spring, Washington, DC 20555
39. C. R. Beverly, Martin Marietta Energy Systems, Inc., P.O.Box 1410, Paducah, KY 42001
40. J. E.Bonville, Knolls Atomic Power Laboratory, P.O. Box 1072, Schenectady, New York 12301
41. R. P. Bradley, Radiation Protection Bureau, Dosimetry Section, Brookfield Road, Ottawa, Ontario, KIA ICI CANADA
42. G. Burger, Gesellschaft fur Strahlen-und Umweltforschung, Ingolstadter Landstrassel, 8042 Neuherberg, FEDERAL REPUBLIC OF GERMANY
43. A. Cavallini, ENEA - PAS/FIBI/DOSI, via Mazzini n. 2, 40138 Bologna, ITALY
44. T. L. Chou, Taiwan Power Company, Radiation Laboratory, P.O. Box 7, Shinmen, Taiwan 253, REPUBLIC OF CHINA
45. P. Christensen, RISO National Laboratory, Health Physics Department, Dk-4000 Roskilde, DENMARK
46. L. E. Coldren, Rockwell International-Rocky Flats Plant, P.O. Box 464, Golden, CO 80401
47. P. G. daCunha, Instituto de Radioprotecao e Dosimetria, Av das Americas, Km 11.5, Barra da Tijuca, Cx.P. 37025, Rio de Janeiro, BRAZIL
48. J. P. Cusimano, U.S. Dept. of Energy, Dosimetry Branch, 550 Second Street, Idaho Falls, ID 83401
49. H. Delafield, AERE, Environmental and Medical Sciences Division, Harwell, Oxfordshire, OX 11 ORA, UNITED KINGDOM
50. E. H. Dolecek, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, Illinois 60439
51. K. Duftschmid, Austrian Research Center-Seibersdorf, Lenaugasse 20, A-1082 Wien, AUSTRIA

52. I. Dvornik, Ruder Boskovic Institute, Bijenicka 54, P.O. Box 1016, 41001 Zagreb, Croatia, YUGOSLAVIA
53. J. J. Fix, Battelle Pacific Northwest Laboratories, P.O. Box 999, Richland, WA 99352
54. F. N. Flakus, International Atomic Energy Agency, Wagramerstrasse 5, P.O. Box 100, A-1400 Vienna, AUSTRIA
55. R. L. Gladhill, National Bureau of Standards, TECH-B141, Washington, DC 20234
56. R. T. Greene, General Electric Company, Neutron Devices Dept., P.O. Box 2908, Largo, FL 34294
57. R.V. Griffith, Lawrence Livermore Nationl Laboratory, P. O. Box 5505, Livermore, CA 94550
58. R. M. Hall, Savannah River Plant, Aiken, SC 29801
59. D.E. Hankins, Lawrence Livermore National Laboratory, P.O. Box 5505, Livermore, CA 94550
60. M. Hofert, CERN TIS/RP, CH 1211 Geneva 23, SWITZERLAND
61. P. Y. Hwang, Taiwan Power Company, Radiation Laboratory, P.O. Box 7, Shinmen, Taiwan 253, REPUBLIC OF CHINA
62. H. Ing, Chalk River Nuclear Laboratories, Chalk River, Ontario, CANADA KOH IJO
63. J. S. Jun, Chungnam National University, Department of Physics, Chungnam 300-31, KOREA
64. E. E. Kearsley, Nationl Naval Medical Center, BU,ED Dosimetry Center, MS C45, Bethesda, Maryland 20814
65. J. M. Langsted, Rockwell International-Rocky Flats Plant, P.O. Box 464, Golden, CO 80401
66. H. Lesiecki, Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-3300 Braunshweig, FEDERAL REPUBLIC OF GERMANY
67. R. K. Kher, Bhabha Atomic Research Centre, Radiation Protection Division, Trombay, Bombay 400 085, INDIA
68. W. M. Lowder, Environmental Monitoring Laboratory, Department of Energy, 376 Hudson Street, New York, New York 10014
69. R. W. Martin, Los Alamos National Laboratory, Health Physics Group, P.O. Box 1663, Los Alamos, NM 87545
70. T. H. Maggard, Goodyear Atomic Corporation, P.O. Box 628, Piketon, Ohio 45661
71. T. Mahautt, Armed Forces Radiobiological Institute, RSDP, Bethesda, MD 20814
72. J. C.Manaranche, Institute de Protection et de Surete Nucleaire, Centre d'Etudes de Valduc, B. P. 64, 21120 IS-SUR-TILLE, FRANCE
73. T. O. Marshall, NRPB, Chilton-Didcot, Oxfordshire, OX11 ORQ, UNITED KINGDOM
74. R. Medioni, Centre d'Etudes Nucleres, F.P. No. 6, F-92260 Fontenay aux Roses, FRANCE
75. A. A. O'Dell, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, CA 94550
76. J. R. Ortman, Goodyear Atomic Corporation, P. O. Box 628, Piketon, OH 45661
77. J. Palfalvi, Hungarian Academy of Sciences, H-1525, P.O. Box 49, Budapest 114, HUNGARY
78. E. Piesch, KFZ Karlsruhe, Postfach 3640, D-7500 Karlsruhe, FEDERAL REPUBLIC OF GERMANY
79. G. Portal, CEA-Department of Protection, F-92260 Fontenay aux Roses, FRANCE

80. T. E. Reed, Bettis Atomic Power Laboratory, P.O. Box 79, West Mifflin, PA 15122
81. G. A. Riekstz, Battelle Pacific Northwest Laboratories, P.O. Box 999, Richland, WA 99352
82. S. Romagnoli, Segreteria Technic del Lab. di Fisica, Instituto Superiore di Sanita, Viale, Regina Elena 299, 00161 Roma, ITALY
83. D. J. Ruggles, Goodyear Atomic Corporation, P.O. Box 628, Piketon, OH 45661
84. H. Schraube, Gesellschaft fur Strahlen-und Umweltforschung, Ingolstadter-Landstrasse 1, 8042 Neuherberg, FEDERAL REPUBLIC OF GERMANY
85. R. B. Schwartz, National Bureau of Standards, Building 235, Gaithersburg, MD 20899
86. R. I. Smith, Bechtel National, Inc., Fifty Beale Street, P.O. Box 3965, San Francisco, CA 94119
87. C. Stenquist, Studsvik Energiteteknik AB, S-611 82 Nykoping, SWEDEN
88. D. J. Thompson, Sandia National Laboratories, Division 313, P.O. Box 5800, Albuquerque, NM 87185
89. D. G. Vasilik, Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, New Mexico 87545
90. I. J. Wells, REECO, Environmental Sciences Department, P.O. Box 14400, Las Vegas, Nevada 89114
91. R. V. Wheeler, R. S. Landauer, Jr. and Co., Glenwood Science Park, Glenwood, Illinois 60425
92. R. W. Wood, USDOE, Division of Physical and Technological Research, Washington, DC 20545
93. C. N. Wright, Savannah River Laboratories, Aiken, SC 29808
94. A. Yamadera, Tokyo University, Aramaka AOBA Seudai, JAPAN
95. Office of Assistant Manager for Energy Research and Development, Department of Energy, Oak Ridge Operations Office, Oak Ridge, TN 37831

96-122. Technical Information Center, Department of Energy, Oak Ridge, TN 37831