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DNA Radiation Environments Program Spring 1991 2-Meter Box Experiments and Analyses

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Engineering Physics and Mathematics Division

DNA RADIATION ENVIRONMENTS PROGRAM SPRING 1991 2-METER BOX EXPERIMENTS AND ANALYSES

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ABSTRACT

This report summarizes the Spring 1991 2-m Box experiments that were performed at the Army Pulse Radiation Facility (APRF) at Aberdeen Proving Ground. These studies were sponsored by the Defense Nuclear Agency (DNA) under the Radiation Environments Program to obtain measured data for benchmarking the Adjoint Monte Carlo Code System, MASH, Version 1.0. The MASH code system was developed for the Department of Defense and NATO for calculating neutron and gamma-ray radiation fields and shielding protection factors for armored vehicles and military structures against nuclear weapon radiation. In the 2-m Box experiments, neutron and gamma-ray dose rates and reduction factors were measured in the free-field and as a function of position on an anthropomorphic phantom that was placed outside and inside a borated polyethylene lined steel-walled 2-m box. The data were acquired at a distance of 400-m from the APRF reactor. The measurements were performed by APRF, Armed Forces Radiobiology Research Institute (AFRRI), Etablissement Technique Central de l' Armement (ETCA), and Harry Diamond Laboratory (HDL). Calculations were carried out by the Oak Ridge National Laboratory (ORNL) and Science Applications International Corporation (SAIC).

The purpose of these experiments was to measure the neutron and gamma-ray dose rates as a function of detector location on the phantom for cases when the phantom was in the free-field and inside of the box. Neutron measurements were made using a BD-100R bubble detector and gamma-ray measurements were made using thermoluminescent detectors (TLD). Calculated and measured data were compared in terms of the C/M ratio. DNA mandated that C/M values of ±20% defined acceptable limits for qualifying the MASH code in replicating integral parameters.

Measurements of the neutron dose rates and reduction factors were carried out by the APRF and ETCA experimentalists. The data reported by each team were in good agreement (±12%). The agreement between the calculated and measured neutron dose rates varied with box-phantom geometry but were within the 20% acceptability limit. The differences between the measured and calculated reduction factors ranged from good to poor depending on the box-phantom geometry with the largest disparity consistently arising for the cases when the phantom was inside the box. Differences in excess of 50% occurred at specific detector locations. These disparities arise mainly from differences between the measured and calculated free-field dose rates rather than dissimilarities with the in-phantom dose rate values.

Measurements of the gamma-ray dose rates and reduction factors were made by all of the experimental teams. The agreement among the measured data was, in general, within the acceptable range. Large (>20%) differences were observed in some cases when the data were compared on a team-by-team basis. The calculated gamma-ray dose rates and reduction factors were in good agreement with the data acquired by each experimental team.

The calculated and measured neutron and gamma-ray dose rates and reduction factors agreed on the average within the ±20% limits mandated by DNA and demonstrate the capability of the MASH code system in reproducing measured data in nominally shielded assemblies.

I. INTRODUCTION

As part of the Radiation Environments Program (REP) sponsored by the Defense Nuclear Agency (DNA), a series of "benchmark" experiments were performed at the Army Pulse Radiation Facility (APRF) at Aberdeen Proving Grounds. The purpose of these experiments was to measure neutron and gamma-ray differential and integral spectra, kerma, and dose in the free-field and inside a cubical shaped steel-walled box located at a distance of 400 meters from the APRF reactor. The experiments were performed for different box configurations, i.e., unlined and lined and with and without a phantom positioned inside the box. The box configuration has been accepted as the "NATO standard test bed" and the 400 meter reactor-to-box distance is defined as the "NATO standard reference point". Measured data were obtained by experimentalists from different organizations that participate in the REP. The measured data are being used to benchmark the Monte Carlo Adjoint Shielding code system - MASH[1] that is being validated under this effort. MASH was developed to replace the Vehicle Code System (VCS)[2,3] for estimating radiation effects inside armored vehicles and other shielded configurations of interest to the military.

In previous reports (Refs 4-8), measured and calculated data were compared for experiments that were performed in the Fall of 1989 and the Spring of 1990. In the 1989 study, spectra and kerma (dose) were measured using different types of detectors placed in the free-field and inside the 2-meter box. In the 1990 study, neutron and gamma-ray dose was measured in the free-field and at several positions on an anthropomorphic phantom that was either in the free-field or inside the 2-m box. This report summarizes the last in the series of these experiments: the Spring 1991 experiments that were performed during the period 30 April - 9 May 1991.[9]

Measurements of neutron and gamma-ray dose as a function of position on an RT-200 Canadian Humanoid Phantom[10] (hereafter referred to as the phantom) positioned in the standing posture in the free-field and in the center of the 2-meter box for different box-phantom orientations were carried out at the APRF. These measurements differ from those reported in the Spring 1990 investigation in that the box was lined with 5.08-cm-thick borated polyethylene (5% boron). Neutron and gamma-ray dose data were obtained by experimentalists from the APRF, the Armed Forces Radiobiolog Research Institute (AFRRI), Harry Diamond Laboratory (HDL), and the Establissement Technique Central de l'Armement (ETCA). Calculations were performed by analysts from the Oak Ridge National Laboratory (ORNL) and Science Applications International Corporation (SAIC). The organizations and scientists that participated in this study are identified in Appendix A .

Details of the Spring 1991 experiments and comparisons among the data obtained by the experimental teams are presented in Section II. The calculated data reported by ORNL and SAIC are compared and discussed in Section III. The measured and calculated data are compared in Section IV while the conclusions, observations, and recommendations resulting from this study are presented in Section V.

II. DETAILS OF THE MEASUREMENTS

The 2-meter box assembly used in the Spring 1991 study was the same as that used in the 1989 and 1990 investigations and described in Refs. 4-8. For this study, however, the box was lined with 5.08 cm of borated polyethylene (5% boron). Measurements and calculations of neutron and gamma-ray dose were made as a function of detector position on the body of a humanoid phantom. The phantom was always in the standing position either in the free-field or inside the box. In all of the measurements, one face of the box was always perpendicular to the reactor-400m-test site axis. The phantom was positioned inside the box either facing the reactor or turned 90-degrees with the left shoulder facing the radiation source. In the free-field measurements, the phantom was facing the reactor. Details of the 2-m box and other information concerning the experiments are summarized in Table 1. The RT-200 phantom, including its dimensions, material composition,[10] and the locations on the phantom where dose rates were measured are described in Table 2.

Table 1. Details of the 2-Meter Box and Other Experiment Information.

2-Meter Box		Box Disposition	
Shape	Cubic	Reactor to Box	400 m
Interior Dimensions	2.0 m	400-m Site Elevation	10.45 m
Wall Thickness	0.1016 m	Reactor Pad Elevation	13.58 m
Wall Material	Steel	Reactor Center Elevation	26.78 m
Liner Material	Borated Polyethylene (5% Boron)		

Ground contour and terrain details, including the position of the reactor relative to the 400 meter test site, were the same as those in the Fall 1989 and Spring 1990 investigations and reported in Refs. 4-8. Atmospheric conditions (air temperature, barometric pressure, and relative humidity) and soil moisture content were monitored and recorded by the APRF staff during the measurements. Meteorological data recorded during the measurements are summarized in Ref. 11. The meteorological data are mean values obtained from observations taken at regular intervals during the course of these measurements. The soil moisture content during all experiments was relatively constant; of the order of 35% by weight of dry soil. In all cases, the reactor was operated at steady state power levels and run durations sufficient to assure acceptable statistical accuracy in the measured data.

Table 2. Details of the RT-200 Canadian Humanoid Phantom.

Composition				Physical Parameters		
Element	Lung	Tissue	Bone			
		(atoms/cm^3)				
H	1.65×10^{-2}	5.88×10^{-2}	6.14×10^{-2}	Height		175 cm
C	1.18×10^{-2}	3.36×10^{-2}	1.78×10^{-2}	Chest	(Depth)	21.4
N	1.02×10^{-3}	1.98×10^{-3}	1.84×10^{-3}	Chest	(Width)	33.8
O	3.82×10^{-3}	7.72×10^{-3}	2.52×10^{-2}	Head	(Depth)	20.8
Na	1.74×10^{-9}	2.32×10^{-7}	1.20×10^{-4}	Head	(Width)	14.8
Mg	7.13×10^{-8}		3.88×10^{-5}	Mass		74 kg
Al		2.29×10^{-9}		Locations on the Phantom where Dose rates were Measured.		
Si			6.00×10^{-7}	Free-Field (FF)		Out
P			4.54×10^{-5}	FF in Box		Box
S			4.54×10^{-5}	Mid Head		MH
Cl		2.35×10^{-8}	3.40×10^{-5}	Mid Gut		MG
K			2.30×10^{-3}	Left Chest		LC
Ca			2.14×10^{-3}	Left Wrist		LW
Fe			1.20×10^{-6}	Right Wrist		RW
				Front Belt		FB
				Back Belt		BB

Three box-phantom orientations were studied in the measurements:

A. **Free-field Measurements. Phantom standing at a distance of 10-m from the box facing the reactor.**

B. **In-Box Measurements. Phantom in standing position in the 2-m box facing the reactor.**

C. **In-Box Measurements. Phantom standing in the 2-m box with the left shoulder facing the reactor.**

Measurements were also made of the free-field dose rates and the attenuated dose rate in the box. The free-field dose rate was measured by placing dosimeters at a distance of 5.40-m to the side of the 2-m box at a height of 1.15-m above the ground and distance of 400-m from the reactor. The attenuated dose (hereafter referred to as the box dose) was measured by placing dosimeters inside the 2-m box at a height above the floor of the box of 0.68-m and at a distance of 0.70-m from the axis of symmetry of the box, i.e. alongside the phantom when the phantom was in the box.

II.A. APRF MEASUREMENTS

The APRF team measured both neutron and gamma-ray dose rates as a function of detector location on the phantom for the three box-phantom orientations described above. The neutron dose rates were obtained using BD-100R bubble detectors manufactured by Bubble Technology Industries[12]. Gamma-ray dose rates were obtained using Harshaw CaF_2:Mn thermoluminescent detectors[11] (TLD). Complete descriptions of these detectors, calibration procedures, conversion factors, and other details of the measurements may be found in Refs 10 and 11.

The neutron and gamma-ray dose rates reported by the APRF team are summarized in Tables 3 and 4, respectively. The dose rates reported in the tables, and throughout this report, are in units of mrad (Tissue) per kilowatt hour (kWh).

II.B. AFRRI MEASUREMENTS

The AFRRI team used Victoreen Model 2600-80 Aluminum Oxide TLD dosimeters to measure gamma-ray dose rates.[13] AFRRI investigators did not measure neutron dose rates. Measurements were made for the two box-phantom configurations where the phantom was inside of the 2-m box. No data were obtained for the case when the phantom was standing in the free-field. The results of the AFRRI measurements, in units of mrad (Tissue) per kilowatt hour (kWh), are summarized in Table 5.

II.C. HDL MEASUREMENTS

The HDL also only measured gamma-ray dose rates using CaF_2:Mn thermoluminescent dosimeters (Harshaw TLD-400)[14]. To achieve greater sensitivity, HDL employed TLD's having a volume eight times greater than the TLD dosimeters used by the APRF, AFRRI, and ETCA teams. For the free field measurements, the TLD's were enclosed in 1 g/cm^2-thick aluminum capsules. For the phantom measurements, the dosimeters were wrapped in four layers of 25 μm-thick aluminum foil. HDL corrected all TLD measurements to account for the effects on the dose of thermal neutrons.

The procedures used by HDL are summarized in Reference 14 and the gamma-ray dose rate measurements are summarized in Table 6. Note that the HDL investigators reported the dose rates in units of mrad(CaF_2) per kWh. The dose rates given in Table 6 must be multiplied by a factor of 1.149 to convert to units of mrad (Tissue) per kWh for direct comparison with the results reported by APRF, AFRRI, and ETCA.

II.D. ETCA MEASUREMENTS

The ETCA team, like the APRF team, also measured neutron and gamma-ray dose rates in the free-field and on the phantom for all three box-phantom configurations.[15] The neutron dose rates were measured using bubble detectors manufactured by Bubble Technology Industries and the gamma-ray dose rates were measured using Harshaw CaF_2:Mn thermoluminescent detectors.[14]

The neutron and gamma-ray dose rates measured by ETCA are summarized in Tables 7 and 8, respectively.

II.2. COMPARISONS OF MEASURED DOSE RATES

The dose rates reported by each experimental team are compared in terms of the ratios of the measured (M) data: i.e., ($M_{Team\ 1}/M_{Team\ 2}$) ratios for the various free-field and phantom TLD locations. DNA adopted the criterion that the range of acceptability for comparisons of measured and calculated neutron and gamma-ray data was ±20%.

II.2.A. Neutron Dose Rates

The neutron dose rates measured by the APRF and ETCA teams are compared in terms of the APRF/ETCA ratios in Table 9. The dose rates are compared at all detector locations for the three box-phantom configurations. Also given in the table are the averages of the ratios and the standard deviation of the average values. For most of the detector locations, the neutron dose rates measured by each team agree within ±20%. The largest differences occur at the back-belt (BB) detector position where the dose rates vary by as much as 56%. The ratios of the averages of the dose rates over detector locations on the phantom indicate consistency among the data within 12%. These results suggest congruent

application of the bubble detectors and interpretation of the measured data.

II.2.B. Gamma-Ray Dose Rates

The gamma-ray dose rates measured by APRF, HDL, and ETCA for the case when the phantom was in the free-field facing the reactor are compared in Table 10. The dose rates measured by these teams are in good agreement at most of the detector locations. Exceptions occur for the FF Box locations where the APRF and HDL results differ by 26% and the HDL and ETCA dose rates differ by 47% The averages of dose rates in the phantom are, in all cases, in good agreement and exhibit small (<10%) deviations among the ratios.

The comparisons of the measured dose rates for the cases where the phantom was in the box facing the reactor and with the left shoulder facing the reactor, are summarized in Tables 11 and 12, respectively. All of the experimental teams collected data for these box-phantom orientations. The measured gamma-ray dose rates are, again, in reasonably good agreement for all detector locations. For the case when the phantom is facing the reactor, the largest differences are among data reported by AFRRI, HDL, and ETCA. The AFRRI team reports lower (>20%) dose rates than HDL at all detector locations. While HDL reports larger dose rates than ETCA at the back-belt (BB), left-chest (LC), mid-head (MH), and mid-gut (MG) detector locations in the phantom. In the case when the phantom is in the box, left-side facing the reactor, acceptable ratios are achieved at all detector locations except at the left-wrist (LW), right-wrist (RW), and mid-gut (MG) detector locations. HDL and ETCA achieve somewhat better agreement among the data compared to the previous case where the phantom is facing the reactor except at the back-belt (BB) detector location where the dose rates differ by 33%.

III. DETAILS OF THE CALCULATIONS

Analyses of the 2-m box-phantom experiments were carried out separately by researchers from the Oak Ridge National Laboratory (ORNL) and Science Applications International Corporation (SAIC). Both teams used the MASH code to estimate the dose rates in the free-field and at detector locations on the phantom for the three experiment configurations described in the previous section. The purpose of conducting two separate analyses was to provide a cross-check of the analytic results and to assure a consistent application of the MASH code system in the benchmarking process.

All of the calculations were performed using the MASH code system, Version 1.0[1] that is maintained on the Los Alamos National Laboratory (LANL) CRAY computer. At present, this is the only authorized version of the code system. The transport calculations were carried out using the DABL69 (ENDF/B-V) cross-section library[16] that is also maintained on the LANL CRAY computer. The experimental geometry, including the 2-m box and the RT-200 Phantom were replicated in detail using the combinatorial geometry options in the MASH code system. The box and phantom geometries are described in detail in Refs. 4, 8, and 9 ORNL and SAIC used slightly different approaches to calculate the dose rates but each approach was within the existing capability of the MASH code system.

Air-over-ground calculations used to estimate the neutron and gamma-ray fluence in the free-field and on a coupling surface surrounding the box took into account the air and soil moisture content at the time of the measurements. The Monte Carlo (MORSE) calculations to determine the dose rates at the detector positions on the phantom both inside and outside the box generated and tracked a sufficiently large number of primary source particles to assure adequate sampling over all energy groups. Energy dependent relative importance factors were used to increase the frequency of sampling the adjoint source particles from energy groups having the most significant effect on the dose response function. The secondary particle production probability was set to 1.0 for all regions and energy groups and the in-group energy biasing option in MORSE was turned on for all calculations. Region dependent and energy independent splitting and Russian Roulette parameters were used to improve the statistical accuracy of the Monte Carlo calculations. These options produced an escaping particle to source particle ratio of nominally one.

Statistical uncertainties on the integral neutron and gamma-ray dose rates were consistently less than 3% for all calculations.

III.A. COMPARISONS OF CALCULATED DOSE RATES

The calculated neutron and gamma-ray dose rates are presented and compared in this section in terms of the C_{ORNL}/C_{SAIC} ratio.

III.A.1. Neutron Dose Rates

The neutron dose rates calculated by ORNL and SAIC for the three-box phantom configuration are given in Tables 13 and 14, respectively. These data are compared in terms of the ratio ORNL/SAIC in Table 15. Both analytic teams consistently calculate the neutron dose rates within the accepted ±20% tolerance at all detector locations except for the two cases, FF box location when the phantom is in the free-field and at the mid-gut (MG) detector location when the phantom is in the box with the left shoulder facing the reactor. For the FF box detector location, the calculations differ by 33% and for the MG detector location the calculated dose rates differ by 25% with ORNL reporting lower values than SAIC. Considering that most of the calculated neutron dose rates agree within ±10%, the disagreement in the dose rates calculated at these two detector locations should be treated as atypical.

III.A.2. Gamma-Ray Dose Rates

The gamma-ray dose rates calculated by ORNL and SAIC as a function of detector location in the box and on the phantom are summarized in Tables 16-19. Table 16 and 17 report the calculated dose rates in units of mrad (Tissue) per kWh for comparisons with the APRF, AFRRI, ETCA and TLD measurements. The data in Tables 18 and 19 summarize the dose rates in units of mrad (CaF_2) per kWh for comparion with the HDL measurements.

Table 20 compares the calculated gamma-ray dose rates given in Tables 16 (ORNL) and 17 (SAIC) in terms of the ratio, ORNL/SAIC. The ratios of the dose rates in Tables 18 and 19 are similarly compared in Table 21. The gamma-ray dose rates calculated by both analytic teams are in very good agreement at all detector locations.

The generally excellent agreement between the data reported by ORNL and SAIC for both neutron and gamma-ray dose rates indicate that the analysts consistently replicated the experimental configuration, reactor source term, and meteorologic conditions and applied the MASH code system and data in essentially the same way.

IV. COMPARISONS OF MEASURED AND CALCULATED DOSE RATES AND REDUCTION FACTORS

To facilitate the comparisons of the measured and calculated dose rates and reduction factors, the analytic results are compared with the measured results separately as a function of experiment team and box-phantom configuration. Given in the following tables are the measured and calculated dose rates and reduction factors and the calculated-to-measured, C/M, ratios. Also given in the tables are the averages of the measured and calculated dose rates and reduction factors and C/M ratios for the seven detector locations on the phantom.

IV.A. BD-100R BUBBLE DETECTOR NEUTRON MEASUREMENTS AND CALCULATIONS

IV.A.1. Comparisons with APRF Data

The measured neutron dose rates and reduction factors obtained by the APRF team for the three box-phantom configurations are compared with the corresponding calculated data reported by ORNL and SAIC in Tables 22-24. The dose rates are compared in units of mrad (Tissue) per kWh. In Table 22, data are compared for the case when the phantom is standing in the free-field. Note that the calculated dose rates are higher than the measured values at all detector locations. An exception occurs at the mid-head (MH) location where SAIC obtains a lower value than the measured dose rate. ORNL and SAIC calculate free-field detector dose rates that are ~17% larger than the APRF measurements. The C/M values for the dose rates as a function of detector location in the phantom indicate 5% to 36% overestimates of the calculated data. When these data are averaged over all in-phantom positions, the calculations are still higher than the measurements by ~17%. Examination of the reduction factors show more favorable agreement at all detector locations in the phantom as well as for the average values.

For the two cases when the phantom is in the box, the results in Tables 23 and 24 show a reversal in the behavior of the calculated and measured dose rates and reduction factors. For these cases, the calculations overestimate the free-field detector dose rates and underestimate, on the average, the dose rates as a function of detector location in the phantom. Correspondingly, the calculated neutron reduction factors are larger than the measured values at all detector locations.

IV.A.2. Comparisons with ETCA Data

The calculated neutron dose rates and reduction factors are compared with the ETCA measurements in Tables 25-27. For the case when the phantom is in the free-field, Table 25, the calculated and measured dose rates and reduction factors are in rather good agreement. Exceptions occur at the right-wrist (RW) position where ORNL overestimates the dose rate

measured by ETCA by 26% and SAIC calculates a value 17% higher than the measurement. These values exceed one standard deviation the average dose rates. Note also that SAIC also calculates a much higher value for the dose rate for the in box detector. The C/M values for the reduction factors are within the ±20% acceptability tolerance except for the left-wrist (LW) location where the SAIC value is only slightly higher (21%).

For the cases when the phantom is inside the box, shown in Tables 26 and 27, the agreement between the measured and calculated dose rates in the phantom are, for the most part, quite acceptable. Exceptions occur at the back-belt (BB) location when the phantom is facing the reactor and the mid-head (MH) location when the left side of the phantom is facing the reactor. In the former case, SAIC overestimates the BB dose by 31% and in the latter case ORNL underestimates the MH dose by 33%.

The differences in the calculated and free-field detector dose rates vary widely for the three box-phantom configurations - C/M values vary between 27% and 54%.

The calculated reduction factors for the cases when the phantom is in the box shown in Tables 26 and 27, are much greater than the values calculated by ETCA at all detector locations.

IV.B TLD GAMMA-RAY MEASUREMENTS AND CALCULATIONS

IV.B.1. Comparisons with APRF Data

The gamma-ray dose rates and reduction factors measured by the APRF team are compared with the calculated data reported by ORNL and SAIC for the three box-phantom configurations in Tables 28-30. The agreement between the measured and calculated results are, in all cases, very good and well within the C/M tolerance of ±20%. Exceptions occur in Table 28 where C/M values for the box reduction factors are marginal, in Table 29 where SAIC underestimates the box and back-belt (BB) reduction factors, and in Table 30 where the SAIC value for reduction factor for the left-chest (LC) detector is 27% lower than the measured value. These exceptions are noted only because they fall outside the limit of acceptability and not because they represent significant differences between the measured and calculated dose rates and reduction factors.

IV.B.2. Comparison with AFRRI Data

The calculated dose rates and reduction factors are compared with the AFRRI TLD measurements in Tables 31 and 32. AFRRI made measurements for the in-box phantom configurations only. ORNL and SAIC consistently overestimate the dose rates at all detector locations. The C/M values range from acceptable to marginal and in a few cases, i.e. the left-chest (LC), left wrist (LW), and mid-head (MH) detector locations for the phantom in the box, left shoulder facing the reactor, the analysts overestimate the doses by as much as 35%. The calculated and measured reduction factors for both configurations are generally in good

agreement ($\leq$20%) at all detector locations.

IV.B.3. Comparisons with HDL Data.

The gamma-ray dose rates and reduction factors measured by HDL are compared with the calculated data in Tables 33-35. Note that dose rate data are in units of mrad (CaF_2) per kWh. For the case when the phantom was in the free-field, both ORNL and SAIC overestimate the dose rates in all detector locations except for the detector in the box and at the left-wrist (LW) location where ORNL underestimates the dose. The calculated and measured reduction factors are in good agreement at all locations.

For the cases when the phantom was in the box, the agreement between the measured and calculated dose rates and reduction factors are generally good. The largest differences occur at the mid-head (MH) detector location, phantom facing the reactor, where the value of the C/M exceeds 30%. For the case when the phantom's left shoulder is facing the reactor, ORNL and SAIC both overestimate the dose rate at the front-belt (FB) detector location.

IV.B.4. Comparisons with ETCA Data.

The dose rates and reduction factors measured by ETCA are compared with the calculated data in Tables 36-38. The C/M values indicate very good agreement among the data at all detector locations for all three box-phantom experiment configurations.

V. CONCLUSIONS AND RECOMMENDATIONS

The authors of this document were tasked by the DNA to document the results of this study and to compare the measured and calculated data in an unbiased manner. No attempt was made to screen inconsistent data or otherwise intervene with the data by reconciling or recalculating dose rates or reduction factors. In attempting to determine the capability of the MASH code system in replicating the Spring 1991 experiments, it was determined that the optimum course was to survey the measured and calculated data on a case-by-case and teams-by-team basis and summarize the results.

The results presented in the tables display agreement between the measured and calculated neutron and gamma-ray doses and reduction factors that range from very good to marginal depending on the experiment configuration, detector location, and the experimental or analytic team reporting the results.

Measurements of the neutron dose rates and reduction factors were made by the APRF and ETCA experimentalists only. The data reported by each team were in good agreement (±12%). The agreement between the calculated and measured neutron dose rates varied with box-phantom geometry but were generally well within the 20% acceptability limit. The differences between the measured and calculated reduction factors ranged from good to poor depending on the box-phantom geometry with the largest disparity consistently arising for the cases when the phantom was inside the box. Differences in excess of 50% occurred at specific detector locations. These disparities arise mainly from differences between the measured and calculated free-field dose rates rather than very dissimilar results in the in-phantom dose rate value.[17]

Measurements of the gamma-ray dose rates and reduction factors were made by all of the experiment teams. The agreement among the measured data was, in general, within the acceptable range. Large (>20%) differences were observed in some cases when the data were compared on a team-by-team basis. The calculated gamma-ray dose rates and reduction factors were in good agreement with the data acquired by each experimental team.

The principal purpose for developing the MASH code system was to provide the U.S. Army and in particular the U.S. Army Nuclear and Chemical Agency (USANCA) with the capability to calculate reduction factors of armored vehicle shielding materials against neutron and gamma-rays produced in nuclear weapon explosions. The C/M results obtained here show that the MASH code is capable of replicating integral dose data within accepted tolerances and that MASH version 1.0 can be used to estimate neutron and gamma-ray reduction factors for armored vehicles and other shielded configurations having shield thicknesses and compositions similar to those used in these box studies.

Table 3. APRF Measurements of Neutron Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{Ti}/kWh$.

RUN NUMBER		128	113	120
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	4.26	3.88	3.88
	FF BOX		0.37	0.36
DOSE PHANTOM	BB	1.20	0.25	0.35
	LC	3.72	0.37	0.32
	LW	3.60	0.35	0.36
	RW	3.91	0.38	0.27
	MH	1.16	0.13	0.12
	MG	0.65	0.06	0.03

Table 4. APRF Measurements of Gamma-Ray Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{Ti}/kWh$.

RUN NUMBER		130/131	123	121/122
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	1.49	1.48	1.47
	FF BOX	0.35	0.34	0.34
DOSE IN PHANTOM	FB	2.02	0.38	0.35
	BB	1.45	0.30	0.34
	LC	2.05	0.41	0.38
	LW	1.82	0.34	0.36
	RW	1.82	0.35	0.30
	MH	2.03	0.41	0.41
	MG	2.04	0.37	0.36

Table 5. AFRRI Measurements of Gamma-Ray Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{Ti}/kWh$.

RUN NUMBER		123	121/122
		IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	1.23	1.24
	FF BOX	0.30	0.29
DOSE IN PHANTOM	FB	0.33	0.33
	BB	0.28	0.32
	LC	0.33	0.34
	LW	0.30	0.31
	RW	0.31	0.26
	MH	0.35	0.34
	MG	0.31	0.29

Table 6. HDL Measurements of Gamma-Ray Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{CaF}/kWh$.

RUN NUMBER		130/131	123	121/122
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	1.23	1.23	1.23
	FF BOX	0.41	0.32	0.31
DOSE IN PHANTOM	FB	1.65	0.40	0.30
	BB	1.30	0.34	0.37
	LC	1.61	0.43	0.34
	LW	1.58	0.36	0.38
	RW	1.43	0.32	0.35
	MH	1.72	0.51	0.35
	MG	1.75	0.41	0.34

Table 7. ETCA Measurements of Neutron Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{Ti}$/kWh.

RUN NUMBER		128	113	120
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	4.78	3.51	4.15
	FF BOX	0.37	0.41	0.33
DOSE IN PHANTOM	FB	4.46		
	BB	1.55	0.16	0.29
	LC	4.24	0.39	0.32
	LW	4.74	0.37	0.38
	RW	3.52	0.37	0.25
	MH	1.22	0.12	0.15
	MG	0.80	0.06	0.04

Table 8. ETCA Measurements of Gamma-Ray Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{Ti}$/kWh.

RUN NUMBER		130/131	123	121/122
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	1.39	1.38	1.30
	FF BOX	0.32	0.38	0.36
DOSE IN PHANTOM	FB	1.82		
	BB	1.43	0.35	0.32
	LC	1.77	0.40	0.35
	LW	1.52	0.38	0.36
	RW	1.50	0.34	0.37
	MH	1.86	0.44	0.41
	MG	1.81	0.34	0.36

Table 9. Ratios of Measured Neutron Dose Rates.

RUN NUMBER		128	113	120
		FF FACING	IN-BOX FACING	IN-BOX LEFT-SIDE
		APRF/ETCA	APRF/ETCA	APRF/ETCA
FF DOSE	OUTSIDE	0.89	1.11	0.93
	FF BOX		0.90	1.09
DOSE IN PHANTOM	BB	0.77	1.56	1.21
	LC	0.88	0.95	1.00
	LW	0.76	0.95	0.95
	RW	1.11	1.03	1.08
	MH	0.95	1.08	0.80
	MG	0.81	1.00	0.75
	AVG	0.88	1.10	0.97
	STD	0.12	0.21	0.16

Table 10. Ratios of Measured Gamma-Ray Dose Rates.
Free-Field, Phantom Facing the Reactor.

RUN NUMBER 131/131				
		APRF/ETCA	APRF/HDL	HDL/ETCA
FF DOSE	OUTSIDE	1.07	1.05	1.02
	FF BOX	1.09	0.74	1.47
DOSE IN PHANTOM	FB	1.11	1.07	1.04
	BB	1.01	0.97	1.04
	LC	1.16	1.11	1.05
	LW	1.20	1.00	1.19
	RW	1.21	1.11	1.10
	MH	1.09	1.03	1.06
	MG	1.13	1.01	1.11
	AVG	1.13	1.04	1.08
	STD	0.06	0.05	0.05

Table 11. Ratios of Measured Gamma-Ray Dose Rates.
In-Box, Phantom Facing the Reactor.

	Run Number 123					
	APRF/AFRRI	APRF/ETCA	APRF/HDL	AFRRI/ETCA	AFRRI/HDL	HDL/ETCA
	Free-Field Dose					
OUT	1.20	1.07	1.05	0.89	0.87	1.02
BOX	1.13	0.89	0.92	0.79	0.82	0.97
	Dose rate in Phantom					
FB	1.15		0.83		0.72	
BB	1.07	0.86	0.77	0.80	0.72	1.12
LC	1.24	1.03	0.83	0.83	0.67	1.24
LW	1.13	0.89	0.82	0.79	0.73	1.09
RW	1.13	1.03	0.95	0.91	0.84	1.08
MH	1.17	0.93	0.70	0.80	0.60	1.33
MG	1.19	1.09	0.79	0.91	0.66	1.39
AVG	1.15	0.97	0.81	0.84	0.71	1.21
STD	0.05	0.08	0.07	0.05	0.07	0.12

Table 12. Ratios of Measured Gamma-Ray Dose Rates.
In-Box, Phantom Left Side Facing the Reactor.

	Run Number 121/122					
	APRF/AFRRI	APRF/ETCA	APRF/HDL	AFRRI/ETCA	AFRRI/HDL	HDL/ETCA
	Free-Field Dose					
OUT	1.19	1.13	1.04	0.95	0.88	1.09
BOX	1.17	0.94	0.95	0.81	0.81	0.99
	Dose rates in Phantom					
FB	1.06		1.02		0.96	
BB	1.06	1.06	0.80	1.00	0.75	1.33
LC	1.12	1.09	0.97	0.97	0.87	1.12
LW	1.16	1.00	0.82	0.86	0.71	1.21
RW	1.15	0.81	0.75	0.70	0.65	1.09
MH	1.21	1.00	1.02	0.83	0.85	0.98
MG	1.24	1.00	0.92	0.81	0.74	1.09
AVG	1.14	0.99	0.90	0.86	0.79	1.14
STD	0.06	0.09	0.10	0.10	0.10	0.11

Table 13. ORNL Calculations of Neutron Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{Ti}$/kWh.

RUN NUMBER		128	113	120
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	4.97	4.69	4.92
	FF BOX	0.38	0.37	0.37
DOSE IN PHANTOM	FB	4.49	0.36	0.29
	BB	1.63	0.17	0.31
	LC	4.54	0.37	0.33
	LW	4.33	0.32	0.40
	RW	4.42	0.36	0.26
	MH	1.23	0.10	0.10
	MG	0.72	0.06	0.03

Table 14. SAIC Calculations of Neutron Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{Ti}$/kWh.

RUN NUMBER		128	113	120
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	5.02	4.81	5.04
	FF BOX	0.57	0.41	0.42
DOSE IN PHANTOM	FB	4.50	0.40	0.32
	BB	1.57	0.21	0.34
	LC	4.60	0.38	0.35
	LW	4.10	0.36	0.41
	RW	4.13	0.40	0.25
	MH	1.10	0.12	0.12
	MG	0.83	0.06	0.04

Table 15. Ratios of Calculated Neutron Dose Rates.
Dose rates in $mrad_{Ty}/kWh$.

RUN NUMBER		128	113	120
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
		ORNL/SAIC	ORNL/SAIC	ORNL/SAIC
FF DOSE	OUTSIDE	0.99	0.98	0.98
	FF BOX	0.67	0.90	0.88
DOSE IN PHANTOM	FB	1.00	0.90	0.91
	BB	1.04	0.81	0.91
	LC	0.99	0.97	0.94
	LW	1.06	0.89	0.98
	RW	1.07	0.90	1.04
	MH	1.12	0.83	0.83
	MG	0.87	1.00	0.75
	AVG	1.02	0.90	0.91
	STD	0.07	0.06	0.09

Table 16. ORNL Calculations of Gamma-Ray Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom.
Dose rates in $mrad_{Ty}/kWh$.

RUN NUMBER		130/131	123	121/122
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	1.35	1.35	1.35
	FF BOX	0.40	0.38	0.38
DOSE IN PHANTOM	FB	1.81	0.40	0.37
	BB	1.43	0.34	0.37
	LC	1.78	0.40	0.39
	LW	1.47	0.37	0.39
	RW	1.57	0.37	0.32
	MH	1.96	0.39	0.39
	MG	1.95	0.35	0.33

Table 17. SAIC Calculations of Gamma-Ray Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{Ti}/kWh$.

RUN NUMBER		130/131	123	121/122
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	1.32	1.28	1.30
	FF BOX	0.41	0.38	0.38
DOSE IN PHANTOM	FB	1.89	0.40	0.37
	BB	1.53	0.35	0.37
	LC	1.76	0.41	0.46
	LW	1.53	0.37	0.40
	RW	1.55	0.39	0.32
	MH	1.96	0.40	0.43
	MG	1.96	0.36	0.31

Table 18. ORNL Calculations of Gamma-Ray Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{CaF}/kWh$.

RUN NUMBER		130/131	123	121/122
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	1.37	1.37	1.37
	FF BOX	0.38	0.36	0.36
DOSE IN PHANTOM	FB	1.91	0.41	0.38
	BB	1.48	0.36	0.38
	LC	1.84	0.42	0.41
	LW	1.52	0.38	0.40
	RW	1.63	0.38	0.33
	MH	2.04	0.42	0.42
	MG	2.11	0.40	0.38

Table 19. SAIC Calculations of Gamma-Ray Dose Rates in the Free-Field and as a Function of Position on the RT-200 Humanoid Phantom. Dose rates in $mrad_{CaF}/kWh$.

RUN NUMBER		130/131	123	121/122
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
FF DOSE	OUTSIDE	1.46	1.43	1.44
	FF BOX	0.42	0.38	0.39
DOSE IN PHANTOM	FB	2.11	0.43	0.40
	BB	1.76	0.38	0.40
	LC	1.98	0.45	0.49
	LW	1.71	0.39	0.42
	RW	1.74	0.41	0.36
	MH	2.22	0.43	0.47
	MG	2.32	0.44	0.37

Table 20. Ratios of Calculated Gamma-Ray Dose Rates. Dose rates in $mrad_{Tr}/kWh$.

RUN NUMBER		130/131	123	121/122
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
		ORNL/SAIC	ORNL/SAIC	ORNL/SAIC
FF DOSE	OUTSIDE	1.02	1.05	1.04
	FF BOX	0.98	1.00	1.00
DOSE IN PHANTOM	FB	0.96	1.00	1.00
	BB	0.93	0.97	1.00
	LC	1.01	0.98	0.85
	LW	0.96	1.00	0.98
	RW	1.01	0.95	1.00
	MH	1.00	0.98	0.91
	MG	0.99	0.97	1.06
	AVG	0.98	0.98	0.97
	STD	0.03	0.02	0.07

Table 21. Ratios of the Calculated Gamma-Ray Dose Rates.
Dose rates in $mrad_{CaF}$/kWh.

RUN NUMBER		130/131	123	121/122
		FF FACING	IN-BOX FACING	IN-BOX LEFT SIDE
		ORNL/SAIC	ORNL/SAIC	ORNL/SAIC
FF DOSE	OUTSIDE	0.94	0.96	0.95
	FF BOX	0.90	0.96	0.92
DOSE IN PHANTOM	FB	0.91	0.95	0.95
	BB	0.84	0.95	0.95
	LC	0.93	0.93	0.84
	LW	0.89	0.97	0.95
	RW	0.94	0.93	0.92
	MH	0.92	0.98	0.89
	MG	0.91	0.91	1.03
	AVG	0.90	0.95	0.93
	STD	0.03	0.02	0.05

Table 22. Measured and Calculated Neutron Dose Rates and Reduction Factors.
Free-Field, Phantom Facing the Reactor.
Comparisons with APRF Measurements.
Dose rates in $mrad_T/kWh$.

	Run Number 128									
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
	Free-Field Dose									
OUT	4.26	4.97	1.17	5.02	1.18					
BOX		0.38		0.57			13.08		8.81	
	Dose rate in Phantom									
FB		4.49		4.50			1.11		1.12	
BB	1.20	1.63	1.36	1.57	1.31	3.55	3.05	0.86	3.20	0.90
LC	3.72	4.54	1.22	4.60	1.24	1.15	1.09	0.95	1.09	0.95
LW	3.60	4.33	1.20	4.10	1.14	1.18	1.15	0.97	1.22	1.04
RW	3.91	4.42	1.13	4.13	1.06	1.09	1.12	1.03	1.22	1.12
MH	1.16	1.23	1.06	1.10	0.95	3.67	4.04	1.10	4.56	1.24
MG	0.65	0.72	1.11	0.83	1.28	6.55	6.90	1.05	6.05	0.92
AVG	2.37	3.05	1.18	2.98	1.16	2.87	2.64	0.99	2.64	1.03
STD	1.38	1.63	0.10	1.59	0.13	1.98	2.05	0.08	1.87	0.12

Table 23. Measured and Calculated Neutron Dose Rates and Reduction Factors.
In-Box, Phantom Facing the Reactor.
Comparisons with APRF Measurements.
Dose rates in $mrad_{TT}/kWh$.

Run Number 113										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	3.88	4.69	1.21	4.81	1.24					
BOX	0.37	0.37	1.00	0.41	1.11	10.49	12.68	1.21	11.73	1.12
Dose rate in Phantom										
FB		0.36		0.40			13.03		12.03	
BB	0.25	0.17	0.68	0.21	0.84	15.52	27.59	1.78	22.90	1.48
LC	0.37	0.37	1.00	0.38	1.03	10.49	12.68	1.21	12.66	1.21
LW	0.35	0.32	0.91	0.36	1.03	11.09	14.66	1.32	13.36	1.20
RW	0.38	0.36	0.95	0.40	1.05	10.21	13.03	1.28	12.03	1.18
MH	0.13	0.10	0.77	0.12	0.92	29.85	46.90	1.57	40.08	1.34
MG	0.06	0.06	1.00	0.06	1.00	64.67	78.17	1.21	80.17	1.24
AVG	0.26	0.25	0.89	0.28	0.98	23.64	29.44	1.39	27.60	1.27
STD	0.12	0.12	0.12	0.13	0.07	19.57	23.06	0.21	23.46	0.10

Table 24. Measured and Calculated Neutron Dose Rates and Reduction Factors.
In-Box, Phantom Left Side Facing the Reactor.
Comparisons with APRF Measurements.
Dose rates in $mrad_{Tr}$/kWh.

Run Number 120										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	3.88	4.92	1.27	5.04	1.30					
BOX	0.36	0.37	0.86	0.42	1.17	10.78	13.30	1.23	12.00	1.11
Dose rate in Phantom										
FB		0.29		0.32			16.97			
BB	0.35	0.31	0.89	0.34	0.97	11.09	15.87	1.43	14.82	1.34
LC	0.32	0.33	1.03	0.35	1.09	12.13	14.91	1.23	14.40	1.19
LW	0.36	0.40	1.11	0.41	1.14	10.78	12.30	1.14	12.29	1.14
RW	0.27	0.26	0.96	0.25	0.93	14.37	18.92	1.32	20.16	1.40
MH	0.12	0.10	0.83	0.12	1.00	32.33	49.20	1.52	42.00	1.30
MG	0.03	0.03	1.00	0.04	1.33	129.33	164.00	1.27	126.00	0.97
AVG	0.24	0.25	0.97	0.26	1.08	35.01	41.74	1.32	38.28	1.22
STD	0.12	0.12	0.09	0.12	0.14	42.84	51.26	0.13	40.48	0.14

Table 25. Measured and Calculated Neutron Dose Rates and Reduction Factors.
Free-Field, Phantom Facing the Reactor.
Comprarisons with ETCA Measurements.
Dose rates in $mrad_{Tr}/kWh$.

Run Number 128										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	4.78	4.97	1.04	5.02	1.05					
BOX	0.37	0.38	1.03	0.57	1.54	12.92	13.08	1.01	8.81	0.68
Dose rate in Phantom										
FB	4.46	4.49	1.01	4.50	1.01	1.07	1.11	1.04	1.12	1.04
BB	1.55	1.63	1.05	1.57	1.01	3.08	3.05	0.99	3.20	1.04
LC	4.24	4.54	1.07	4.60	1.08	1.13	1.09	0.96	1.09	0.97
LW	4.74	4.33	0.91	4.10	0.86	1.01	1.15	1.14	1.22	1.21
RW	3.52	4.42	1.26	4.13	1.17	1.36	1.12	0.82	1.22	0.89
MH	1.22	1.23	1.01	1.10	0.90	3.92	4.04	1.03	4.56	1.16
MG	0.80	0.72	0.90	0.83	1.04	5.98	6.90	1.15	6.05	1.01
AVG	2.93	3.05	1.03	2.98	1.01	2.51	2.64	1.02	2.64	1.05
STD	1.56	1.63	0.11	1.59	0.10	1.77	2.05	0.10	1.87	0.10

Table 26. Measured and Calculated Neutron Dose Rates and Reduction Factors.
In-Box, Phantom Facing the Reactor.
Comparisons with ETCA Measurements.
Dose rates in $mrad_T/kWh$.

Run Number 123										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	3.51	4.69	1.34	4.81	1.37					
BOX	0.41	0.37	0.73	0.41	1.00	8.56	12.68	1.48	11.73	1.37
Dose rate in Phantom										
FB		0.36		0.40			13.03		12.03	
BB	0.16	0.17	1.06	0.21	1.31	21.94	27.59	1.26	22.90	1.04
LC	0.39	0.37	0.95	0.38	0.97	9.00	12.68	1.41	12.66	1.41
LW	0.37	0.32	0.86	0.36	0.97	9.49	14.66	1.54	13.36	1.41
RW	0.37	0.36	0.97	0.40	1.08	9.49	13.03	1.37	12.03	1.27
MH	0.12	0.10	0.83	0.12	1.00	29.25	46.90	1.60	40.08	1.37
MG	0.06	0.06	1.00	0.06	1.00	58.80	78.17	1.33	80.17	1.36
AVG	0.25	0.25	0.95	0.28	1.06	23.00	29.44	1.42	27.60	1.31
STD	0.14	0.12	0.08	0.13	0.12	17.71	23.06	0.12	23.46	0.13

Table 27. Measured and Calculated Neutron Dose Rates and Reduction Factors.
In-Box, Phantom Left Side Facing the Reactor.
Comparisons with ETCA Measurements.
Dose rates in $mrad_{n}/kWh$.

Run Number 120										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	4.15	4.92	1.19	5.04	1.21					
BOX	0.33	0.37	1.12	0.42	1.27	12.58	13.30	1.06	12.00	0.95
Dose rate in Phantom										
FB		0.29		0.32			16.97			
BB	0.29	0.31	1.07	0.34	1.17	14.31	15.87	1.11	14.82	1.04
LC	0.32	0.33	1.03	0.35	1.09	12.97	14.91	1.15	14.40	1.11
LW	0.38	0.40	1.05	0.41	1.08	10.92	12.30	1.13	12.29	1.13
RW	0.25	0.26	1.04	0.25	1.00	16.60	18.92	1.14	20.16	1.21
MH	0.15	0.10	0.67	0.12	0.80	27.67	49.20	1.78	42.00	1.52
MG	0.04	0.03	0.75	0.04	1.00	103.75	164.00	1.58	126.00	1.21
AVG	0.24	0.25	0.94	0.26	1.02	31.04	41.74	1.31	38.28	1.20
STD	0.11	0.12	0.16	0.12	0.12	32.96	51.26	0.26	40.48	0.15

Table 28. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
Free-Field, Phantom Facing the Reactor.
Comparisons with APRF Measurements.
Dose rates in $mrad_{Ti}/kWh$.

Run Number 130/131										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	1.49	1.35	0.91	1.32	0.89					
BOX	0.35	0.40	1.06	0.41	1.17	4.26	3.38	0.79	3.22	0.76
Dose in Phantom										
FB	2.02	1.81	0.90	1.89	0.94	0.74	0.75	1.01	0.70	0.94
BB	1.45	1.43	0.99	1.53	1.06	1.03	0.94	0.91	0.86	0.84
LC	2.05	1.78	0.87	1.76	0.86	0.73	0.76	1.04	0.75	1.03
LW	1.82	1.47	0.81	1.53	0.84	0.82	0.92	1.12	0.86	1.05
RW	1.82	1.57	0.86	1.55	0.85	0.82	0.86	1.05	0.85	1.04
MH	2.03	1.96	0.97	1.96	0.97	0.73	0.69	0.95	0.67	0.92
MG	2.04	1.95	0.96	1.96	0.96	0.73	0.69	0.95	0.67	0.92
AVG	1.89	1.71	0.91	1.74	0.92	0.80	0.80	1.00	0.77	0.96
STD	0.20	0.20	0.06	0.19	0.07	0.10	0.10	0.07	0.08	0.07

Table 29. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
In-Box, Phantom Facing the Reactor.
Comparisons with APRF Measurements.
Dose rates in $mrad_{Ti}$/kWh.

	Run Number 123									
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
	Free-Field Dose									
OUT	1.48	1.35	0.91	1.28	0.86					
BOX	0.34	0.38	1.12	0.38	1.12	4.35	3.55	0.82	3.37	0.77
	Dose in Phantom									
FB	0.38	0.40	1.05	0.40	1.05	3.89	3.38	0.87	3.20	0.82
BB	0.30	0.34	1.13	0.35	1.17	4.93	3.97	0.81	3.66	0.74
LC	0.41	0.40	0.98	0.41	1.00	3.61	3.38	0.94	3.12	0.86
LW	0.34	0.37	1.09	0.37	1.09	4.35	3.65	0.84	3.46	0.80
RW	0.35	0.37	1.06	0.39	1.11	4.23	3.65	0.86	3.28	0.78
MH	0.41	0.39	0.95	0.40	0.98	3.61	3.46	0.96	3.20	0.89
MG	0.37	0.35	0.95	0.36	0.97	4.00	3.86	0.97	3.56	0.89
AVG	0.37	0.37	1.03	0.38	1.05	4.09	3.62	0.89	3.35	0.83
STD	0.04	0.02	0.07	0.02	0.07	0.43	0.21	0.06	0.19	0.05

Table 30. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
In-Box, Phantom Left Side Facing the Reactor.
Comparisons with APRF Measurements.
Dose rates in $mrad_{Ti}/kWh$.

	Run Number 121/122									
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
	Free-Field Dose									
OUT	1.47	1.35	0.92	1.30	0.88					
BOX	0.34	0.38	1.12	0.38	1.12	4.32	3.55	0.82	3.42	0.79
	Dose in Phantom									
FB	0.35	0.37	1.06	0.37	1.06	4.20	3.65	0.87	3.51	0.84
BB	0.34	0.37	1.09	0.37	1.09	4.32	3.65	0.84	3.51	0.81
LC	0.38	0.39	1.03	0.46	1.21	3.87	3.46	0.89	2.83	0.73
LW	0.36	0.39	1.08	0.40	1.11	4.08	3.46	0.85	3.25	0.80
RW	0.30	0.32	1.07	0.32	1.07	4.90	4.22	0.86	4.06	0.83
MH	0.41	0.39	0.95	0.43	1.05	3.59	3.46	0.96	3.02	0.84
MG	0.36	0.33	0.92	0.31	0.86	4.08	4.09	1.00	4.19	1.03
AVG	0.36	0.37	1.03	0.38	1.06	4.15	3.71	0.90	3.48	0.84
STD	0.03	0.03	0.06	0.05	0.10	0.38	0.29	0.06	0.47	0.08

Table 31. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
In-Box, Phantom Facing the Reactor.
Comparisons with AFRRI Measurements.
Dose rates in $mrad_{Ti}/kWh$.

Run Number 123										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	1.23	1.35	1.10	1.28	1.04					
BOX	0.30	0.38	1.27	0.38	1.27	4.10	3.55	0.87	3.37	0.82
Dose in Phantom										
FB	0.33	0.40	1.21	0.40	1.21	3.73	3.38	0.91	3.20	0.86
BB	0.28	0.34	1.21	0.35	1.25	4.39	3.97	0.90	3.66	0.83
LC	0.33	0.40	1.21	0.41	1.24	3.73	3.38	0.91	3.12	0.84
LW	0.30	0.37	1.23	0.37	1.23	4.10	3.65	0.89	3.46	0.84
RW	0.31	0.37	1.19	0.39	1.26	3.97	3.65	0.92	3.28	0.83
MH	0.35	0.39	1.11	0.40	1.14	3.51	3.46	0.99	3.20	0.91
MG	0.31	0.35	1.13	0.36	1.16	3.97	3.86	0.97	3.56	0.90
AVG	0.32	0.37	1.19	0.38	1.21	3.91	3.62	0.93	3.35	0.86
STD	0.02	0.02	0.04	0.02	0.04	0.27	0.21	0.03	0.19	0.03

Table 32. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
In-Box, Phantom Left Side Facing the Reactor.
Comparisons with AFRRI Measurements.
Dose rates in $mrad_{T\gamma}/kWh$.

	Run Number 121/122									
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
	Free-Field Dose									
OUT	1.24	1.35	1.09	1.30	1.05					
BOX	0.29	0.38	1.31	0.38	1.31	4.28	3.55	0.83	3.42	0.80
	Dose in Phantom									
FB	0.33	0.37	1.12	0.37	1.12	3.76	3.65	0.97	3.51	0.93
BB	0.32	0.37	1.16	0.37	1.16	3.88	3.65	0.94	3.51	0.91
LC	0.34	0.39	1.15	0.46	1.35	3.64	3.46	0.95	2.83	0.78
LW	0.31	0.39	1.26	0.40	1.29	4.00	3.46	0.87	3.25	0.81
RW	0.26	0.32	1.23	0.32	1.23	4.77	4.22	0.88	4.06	0.85
MH	0.34	0.39	1.15	0.43	1.26	3.65	3.46	0.95	3.02	0.83
MG	0.29	0.33	1.14	0.31	1.07	4.28	4.09	0.96	4.19	0.98
AVG	0.31	0.37	1.17	0.38	1.21	4.00	3.71	0.93	3.48	0.87
STD	0.03	0.03	0.05	0.05	0.09	0.38	0.29	0.04	0.47	0.07

Table 33. Measured and Calculated Gamma-Ray Doses Rates and Reduction Factors.
Free-Field, Phantom Facing the Reactor.
Comparisons with HDL Measurements.
Dose rates in $mrad_{CaF}/kWh$.

Run Number 130/131										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	1.23	1.37	1.11	1.46	1.19					
BOX	0.41	0.38	0.93	0.42	1.02	3.00	3.61	1.20	3.45	1.15
Dose in Phantom										
FB	1.65	1.91	1.16	2.11	1.28	0.75	0.72	0.96	0.69	0.92
BB	1.30	1.48	1.14	1.76	1.35	0.95	0.93	0.98	0.83	0.87
LC	1.61	1.84	1.14	1.98	1.23	0.76	0.74	0.97	0.74	0.97
LW	1.58	1.52	0.96	1.71	1.08	0.78	0.90	1.15	0.85	1.09
RW	1.43	1.63	1.14	1.74	1.22	0.86	0.84	0.98	0.84	0.98
MH	1.72	2.04	1.19	2.22	1.29	0.72	0.67	0.93	0.66	0.92
MG	1.75	2.11	1.21	2.32	1.33	0.70	0.65	0.93	0.63	0.90
AVG	1.58	1.79	1.13	1.98	1.25	0.79	0.78	0.99	0.75	0.95
STD	0.15	0.23	0.07	0.23	0.08	0.08	0.10	0.07	0.09	0.07

Table 34. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
In-Box, Phantom Facing the Reactor.
Comparisons with HDL Measurements.
Dose rates in $mrad_{CaF}/kWh$.

Run Number 123										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	1.23	1.37	1.11	1.43	1.16					
BOX	0.32	0.36	1.13	0.38	1.19	3.84	3.81	0.99	3.76	0.98
Dose in Phantom										
FB	0.40	0.41	1.03	0.43	1.08	3.08	3.34	1.08	3.33	1.08
BB	0.34	0.36	1.06	0.38	1.12	3.62	3.81	1.05	3.76	1.04
LC	0.43	0.42	0.98	0.45	1.05	2.86	3.26	1.14	3.18	1.11
LW	0.36	0.38	1.06	0.39	1.08	3.42	3.61	1.06	3.67	1.07
RW	0.32	0.38	1.19	0.41	1.28	3.84	3.61	0.94	3.49	0.91
MH	0.51	0.42	0.82	0.43	0.84	2.41	3.26	1.35	3.33	1.38
MG	0.41	0.40	0.98	0.44	1.07	3.00	3.43	1.14	3.25	1.08
AVG	0.40	0.40	1.01	0.42	1.07	3.18	3.47	1.11	3.43	1.10
STD	0.06	0.02	0.10	0.02	0.12	0.45	0.19	0.12	0.20	0.13

Table 35. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
In-Box, Phantom Left Side Facing the Reactor.
Comparisons with HDL Measurements.
Dose rates in $mrad_{CaF}$/kWh.

Run Number 121/122										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	1.23	1.37	1.11	1.44	1.17					
BOX	0.31	0.36	1.16	0.39	1.26	3.97	3.81	0.96	3.69	0.93
Dose in Phantom										
FB	0.30	0.38	1.27	0.40	1.33	4.10	3.61	0.88	3.60	0.88
BB	0.37	0.38	1.03	0.40	1.08	3.32	3.61	1.09	3.60	1.08
LC	0.34	0.41	1.21	0.49	1.44	3.62	3.34	0.92	2.94	0.81
LW	0.38	0.40	1.05	0.42	1.11	3.24	3.43	1.06	3.43	1.06
RW	0.35	0.33	0.94	0.36	1.03	3.51	4.15	1.18	4.00	1.14
MH	0.35	0.42	1.20	0.47	1.34	3.51	3.26	0.93	3.06	0.87
MG	0.34	0.38	1.12	0.37	1.09	3.62	3.61	1.00	3.89	1.08
AVG	0.35	0.39	1.12	0.42	1.20	3.56	3.57	1.01	3.50	0.99
STD	0.02	0.03	0.11	0.04	0.15	0.26	0.27	0.10	0.37	0.12

Table 36. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
Free-Field, Phantom Facing the Reactor.
Comparisons with ETCA Measurements.
Dose rates in $mrad_{Tr}/kWh$.

	Run Number 130/131									
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
	Free-Field Dose									
OUT	1.39	1.35	0.99	1.32	0.95					
BOX	0.32	0.40	1.25	0.41	1.28	4.34	3.38	0.78	3.42	0.79
	Dose in Phantom									
FB	1.82	1.81	0.99	1.89	1.04	0.76	0.75	0.99	0.70	0.92
BB	1.43	1.43	1.00	1.53	1.07	0.97	0.94	0.97	0.86	0.89
LC	1.77	1.78	1.01	1.76	0.99	0.79	0.76	0.96	0.75	0.95
LW	1.52	1.47	0.97	1.53	1.01	0.91	0.92	1.01	0.86	0.95
RW	1.50	1.57	1.05	1.55	1.03	0.93	0.86	0.92	0.85	0.91
MH	1.86	1.96	1.05	1.96	1.05	0.75	0.69	0.92	0.68	0.91
MG	1.81	1.95	1.08	1.96	1.08	0.77	0.69	0.90	0.67	0.87
AVG	1.67	1.71	1.02	1.74	1.04	0.84	0.80	0.95	0.77	0.91
STD	0.17	0.20	0.04	0.19	0.03	0.09	0.10	0.04	0.08	0.03

Table 37. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
In-Box, Phantom Facing the Reactor.
Comparisons with ETCA Measurements.
Dose rates in $mrad_T/kWh$.

Run Number 123										
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
Free-Field Dose										
OUT	1.38	1.35	0.98	1.28	0.93					
BOX	0.38	0.38	1.00	0.38	1.00	3.63	3.55	0.98	3.37	0.93
Dose in Phantom										
FB		0.40		0.40			3.38			
BB	0.35	0.34	0.97	0.35	1.00	3.94	3.97	1.01	3.66	0.93
LC	0.40	0.40	1.00	0.41	1.03	3.45	3.38	0.98	3.12	0.90
LW	0.38	0.37	0.97	0.37	0.97	3.63	3.65	1.01	3.46	0.95
RW	0.34	0.37	1.09	0.39	1.15	4.06	3.65	0.90	3.28	0.81
MH	0.44	0.39	0.89	0.40	0.91	3.14	3.46	1.10	3.20	1.02
MG	0.34	0.35	1.03	0.36	1.06	4.06	3.86	0.95	3.56	0.88
AVG	0.37	0.37	0.99	0.38	1.02	3.71	3.62	0.99	3.38	0.91
STD	0.03	0.02	0.06	0.02	0.07	0.34	0.21	0.06	0.19	0.07

Table 38. Measured and Calculated Gamma-Ray Dose Rates and Reduction Factors.
In-Box, Phantom Left Side Facing the Reactor.
Comparisons with ETCA Measurements.
Dose rates in $mrad_{Ty}/kWh$.

	Run Number 121/122									
	DOSE	OR	C/M	SAI	C/M	RF	OR	C/M	SAI	C/M
	Free-Field Dose									
OUT	1.30	1.35	1.04	1.30	1.00					
BOX	0.36	0.38	1.06	0.38	1.06	3.61	3.55	0.98	3.42	0.95
	Dose in Phantom									
FB		0.37		0.37			3.65			
BB	0.32	0.37	1.16	0.37	1.16	4.06	3.65	0.90	3.51	0.87
LC	0.35	0.39	1.11	0.46	1.31	3.71	3.46	0.93	2.83	0.76
LW	0.36	0.39	1.08	0.40	1.11	3.61	3.46	0.96	3.25	0.90
RW	0.37	0.32	0.86	0.32	0.86	3.51	4.22	1.20	4.06	1.16
MH	0.41	0.39	0.95	0.43	1.05	3.17	3.46	1.09	3.02	0.95
MG	0.36	0.33	0.92	0.31	0.86	3.61	4.09	1.13	4.19	1.16
AVG	0.36	0.37	1.01	0.38	1.06	3.61	3.71	1.04	3.48	0.97
STD	0.03	0.03	0.11	0.05	0.16	0.26	0.29	0.11	0.51	0.15

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