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DNA Radiation Environments Program Fall 1989 2-Meter Box Experiments and Analysis

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DNA RADIATION ENVIRONMENTS PROGRAM FALL 1989 2-METER BOX EXPERIMENTS AND ANALYSIS

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EXECUTIVE SUMMARY

This report summarizes the results of measurements and calculations to determine neutron and gamma-ray spectra and integral data (kerma) inside a steel, cube shaped box (2-m inside dimensions, 0.1016-m-thick wall thickness) from radiation emitted from the U. S. Army Pulse Reactor Facility (APRF) at Aberdeen Proving Ground, Maryland. Measurements were made during the period 23 October 1989 through 2 November 1989. This study was carried out as part of the Radiation Environments Program sponsored by the Defense Nuclear Agency. The purpose of this effort was to obtain measured data for benchmarking the Adjoint Monte Carlo Code, MASH, that is being evaluated to replace the Vehicle Code System (VCS) as the "code-of-choice" for ascertaining radiation protection and reduction factors of armored vehicles and other military configurations exposed to nuclear weapon radiation.

The measured data were obtained by researchers from the APRF, the Defence Research Establishment Ottawa (DREO), Canada, Bubble Technology Industries (BTI), Canada, and the Establissement Technique de l'Armement (ETCA), France. Calculated results, using the MASH code, were obtained by analysts from the Oak Ridge National Laboratory (ORNL) and Science Applications International Corporation (SAIC).

Details of the Measurements

Differential and integral measurements were made at distances of 170- and 400-m from the APR core. Free-in air data were obtained at both distances while the in-box measurements were made only at the 400-m distance which had been previously adopted as the NATO Standard Reference point. The reactor was operated at steady state for all measurements. Details of the terrain between the reactor and the test locations along with daily meteorological conditions (temperature, humidity, and barometric pressure) were accounted for in all of the measurements. (These data were also given to the analysts for inclusion in the MASH calculations). Soil moisture content was determined to be relatively constant (35% by weight of dry soil) during the measurement sequence.

The series of measurements were carefully coordinated by the APRF staff to ensure minimum interference between experimentalists and to optimize the use of the various detector systems. Neutron and gamma-ray data were obtained using various combinations of NE-213 Liquid Scintillators, a ROSPEC Detector System (a system comprised of four hydrogen based proportional counters), Tissue Equivalent Counters, Geiger-Mueller Counters, Neptunium Ionization Chamber, Bubble Detectors, Thermoluminescent Dosimeters, and a BGO Spectrometer.

The measured integral neutron kerma data obtained by the different experimental teams generally agreed within ± 20%, which was accepted as the standard for acceptable agreement. A few of the comparisons fell outside this range depending on the detectors used to acquire the neutron data and whether the comparison was made for free-field or in-box measurements. Where the disagreement was outside this bound, it was found that the detector used by one or the other of the teams was not functioning properly at the time the measurement was made. The NE-213 measurements made by the APRF team were suspect, so comparisons of neutron kerma obtained by the other experimental teams with these results are generally poor. Comparisons of neutron kerma data obtained by DREO and ETCA fall consistently within ± 20%. In all cases, the gamma-ray kerma obtained by the experimental teams are within acceptable limits of ± 20%.

Details of the Analysis

All of the calculations were carried out using the Adjoint Monte Carlo Code System, MASH. Neutron and gamma-ray transport calculations were performed using the DABL69 (ENDF/B-V) transport cross-section library using a P_5 Legendre expansion to account for the angular distributions of scattered neutrons and gamma rays. Neutron and gamma-ray fluence-to-kerma conversion factors were also taken from DABL69. The analytic approach adopted by the ORNL and SAIC analysts were similar with principal differences arising in the representation of the two-dimensional geometry used to obtain the air-over-ground radiation source environment. The calculated neutron and gamma-ray free-in-air and in-box kerma values and reduction factors obtained for the steel box obtained by ORNL and SAIC were within 10%. The excellent replication of the experiment between the analytic teams indicates that the experiment, reactor source term, cross-sections, and the modeling of the experiment was consistently represented.

Comparisons of Measured and Calculated Data

Extensive comparisons were made between calculated (C) and experimentally (E) determined neutron and gamma-ray kerma and reduction factors. Except for comparisons with APRF results where the experimentalists reported difficulties with their spectrometer, the C/E values for the free-in-air neutron kerma at the 170- and 400-meter locations are generally within the ± 20% acceptance bound. Some of the data range as high as ± 30% except in the cases where comparisons of C/E are made with the APRF data where the C/E differs by as much as 60%. The C/E for the in-box measurements are in excellent agreement with the DREO and the ETCA NE-213 results but are outside of the acceptance bound for the ETCA tissue equivalent and neptunium detector measurements. The C/E values for the free-in-air gamma-ray data at 170- and 400-m are generally poor ranging from 0.6 to 0.92. Poor agreement among these data can be attributed to the failure on the part of the analysts to include in the calculational model the tree line adjacent to the 170m and 400m sites. The in-box gamma-ray kerma C/E values are well within the 20% bound since gamma radiation produced by neutron reactions with the trees is absorbed by the steel walls of the box.

The C/E values for the neutron and gamma ray reduction factors by the steel walled box range from excellent to slightly marginal depending on the detector used in the measurement.

Conclusions

The results obtained here show differences among the E/E, C/C, and C/E ratios that range from very good to poor. Based on the information provided by the participants, it remains difficult to fully resolve and identify the sources of the discrepancies among the data.

Widely different results are reported for the same kind of detector system used by the different experimental teams. The APRF experimental staff has expressed some concerns over the state of their NE-213 detector at the time of the measurements and have recently made extensive measurements of detector response functions using neutrons of known energies. Other discrepancies between measured data may also arise from the methods of calibration, detector linearity, spectral unfolding techniques, or, in the worse case, unresolved difficulties with the detector or its associated electronic systems.

The calculated results obtained by ORNL and SAIC appear to be generally consistent among themselves which suggests that both teams are similarly replicating the experimental configuration and incorporating consistent cross-section data and response functions.

In summary, such differences as exist between calculation and measurement appear to be very consistent. However, it should be noted that a single laboratory, acting alone, may obtain results which differ significantly from a "true" or consensus value. Further, consistency does not imply agreement. The calculated values of both neutrons and gamma rays rise by approximately 20% relative to the measurements between 170-m and 400-m. Fortunately, there appears to be a correlation in the relationship between calculated and measured neutron kerma within and outside the steel box, such that the agreement between calculated and measured neutron reduction factors is better than that for the associated kerma. This is not the case for gamma rays, where differences between calculation/measurement agreement within the box and in the free field lead to 10% to 20% differences between calculated and measured reduction factors.

R. T. Santoro
April 1991

ABSTRACT

This report summarizes the Fall 1989 2-m Box Experiment performed at the Army Pulse Reactor Facility (APRF) at Aberdeen Proving Ground. This effort, sponsored by the Defense Nuclear Agency under the Radiation Environments Program, was carried out to obtain measured data for benchmarking MASH, the Monte Carlo Adjoint Code System. MASH was developed to replace the Vehicle Code System, VCS, that has been used by the Department of Defense and NATO for calculating neutron and gamma-ray radiation fields and shielding protection factors inside armored vehicles and structures from nuclear weapon radiation. Measurements of the free-field differential spectra and kerma were performed by experimentalists from the APRF, the Defense Research Establishment Ottawa, Canada and the Establissement Technique Central de l' Armement, France. Free-field data were obtained at distances of 170- and 400-meters from the APR while in-box measurements were made at 400 meters only. The box, included to obtain neutron and gamma-ray reduction factors, was a 2-meter cube configuration having 0.1016-m-thick steel walls. Calculated data were obtained using MASH by analysts from the Oak Ridge National Laboratory and Science Applications International Corporation. Calculated (C) results were compared with experimental (E) data in terms of C/E ratios. The Defense Nuclear Agency, with concurrence of the program participants, established ± 20% as the acceptable C/E for this study and for qualifying MASH.

Free-field and in-box neutron kerma generally agreed within ± 20%, although some C/E comparisons fell outside this range depending upon the detector against which the calculated data were compared. For those cases where the C/E ratio is marginal or unacceptable, problems in the detector systems were acknowledge to be principal cause of the discrepancy. Generally poor agreement (~25-35%) was achieved among the C/E ratios for the free-field gamma-ray Kerma at the 170- and 400-m locations while excellent (10%, or better) C/E values were obtained for the in-box conditions. The discrepancy for the free-field comparison was attributed to the failure by the analysts to include a tree line adjacent to the measurement site in the calculational geometry. C/E values for the neutron and gamma-ray reduction factors ranged from 1% to 23% depending on the detector.Comparisons of calculated with the measured neutron and gamma-ray differential spectra ranged from excellent to marginal depending on choice of detector and energy interval.

I. INTRODUCTION

For over a decade, the Department of Defense (DoD) and NATO have relied almost exclusively on the Vehicle Code System (VCS)[1,2] for calculating neutron and gamma-ray radiation fields and shielding protection factors for tactical armored vehicles, buildings, and other shielded configurations from nuclear weapon radiation. Several problems were encountered in the VCS system and the evolution of improvements and modifications to VCS led to the development of the MASH code system.[3]

MASH, A Monte Carlo Adjoint Shielding Code System, was produced in a joint effort by the Oak Ridge National Laboratory (ORNL), Science Applications International Corporation (SAIC), and the Ballistic Research Laboratory (BRL).

MASH is being appraised as the "code-of-choice" to replace the VCS system. However, before it can be fully adopted, the code system must first be verified and validated through comparisons with experimental data and with previously calculated results obtained using VCS. Such an effort is being sponsored by the Defense Nuclear Agency (DNA) as part of the Radiation Environments Program (REP). The REP takes advantage of multinational expertise and resources to orchestrate a comprehensive set of measurements and calculations to determine the capability of the MASH code system to reproduce measured neutron and gamma-ray data for a variety of experimental and other benchmarking configurations.

The first in a series of experiments was performed in the Fall 1989 (23 October to 2 November 1989) at the Army Pulse Radiation Facility (APRF) at Aberdeen Proving Ground to determine the neutron and gamma-ray radiation fluence and kerma in the free field and inside a steel walled box having lateral dimensions of 2-m and a wall thickness of 0.1016-m at the NATO Standard Reference point 400-m from the APRF reactor core. Measured at the NATO Standard Reference point 400-m from the APRF reactor core. Measured neutron and gamma-ray data were obtained using widely different detector systems by experimentalists from APRF, the Defence Research Establishment Ottawa, Canada, (DREO), Bubble Technology Industries, Canada, (BTI), and the Establissement Technique Central de l'Armement, France (ETCA). Calculated results were obtained by analysts at ORNL and SAIC and comparisons have been made between the measured and calculated data to corroborate the capabilities of MASH, as well as the relative merits of the different measurement techniques, for determining the free-field and in-assembly radiation environments for complex shielding configurations.

This document summarizes the results of the measurements and the supporting calculations for the Fall 1989 2-m box experiments. Details of the measurements are delineated in Section II and the methods of analysis are discussed in Section III. The measured and calculated results are compared and discussed in Section IV. Specific conclusions, observations, and recommendations by the participants in this study are stated in Section V.

II. DETAILS OF THE MEASUREMENTS

The terrain profile from the reactor core to the 400-m reference location is shown schematically in Figure 1. Free-field measurements were made at both the 170- and 400-m locations while the in-box measurements were made at the 400-m location only. The box was always present at the 400-m location. Free-field data were obtained by placing the detectors at a distance of 400-m from the reactor and separated from the box by approximately 10 m, or less. In all of the measurements, the reactor was located outside of the APRF building and was fixed at a height of 12.7-m above the concrete experimental pad. This corresponds to a height above ground at the 400-m test location of nominally 16-m .

Detailed ground contour data from the reactor position to the 170- and 400-m test sites were provided by APRF staff for inclusion in the MASH calculations. These data make it possible to accurately account for the effects of ground scattering of the source radiation. In addition, measurements were made by the APRF staff to determine the water content in the soil, the air temperature, barometric pressure, and relative humidity. Estimation of the neutron and, to a lesser extent, gamma-ray environments between the reactor and the detector locations depends primarily on knowledge of the hydrogen content in both the soil and air, as well as other meteorological information.

A schematic drawing of the steel box assembly is shown in Figure 2. The box is a cube having inside dimensions of 2-m on each side, with 0.1016-m-thick walls. The assembly was positioned so that one face was always normal to the axis from the reactor to the test location. The in-box spectra were obtained by placing the detectors inside this assembly with the signal and high voltage cables passing through a port on the side of the box away from the reactor. The signal and high-voltage cables extended from the box to data acquisition

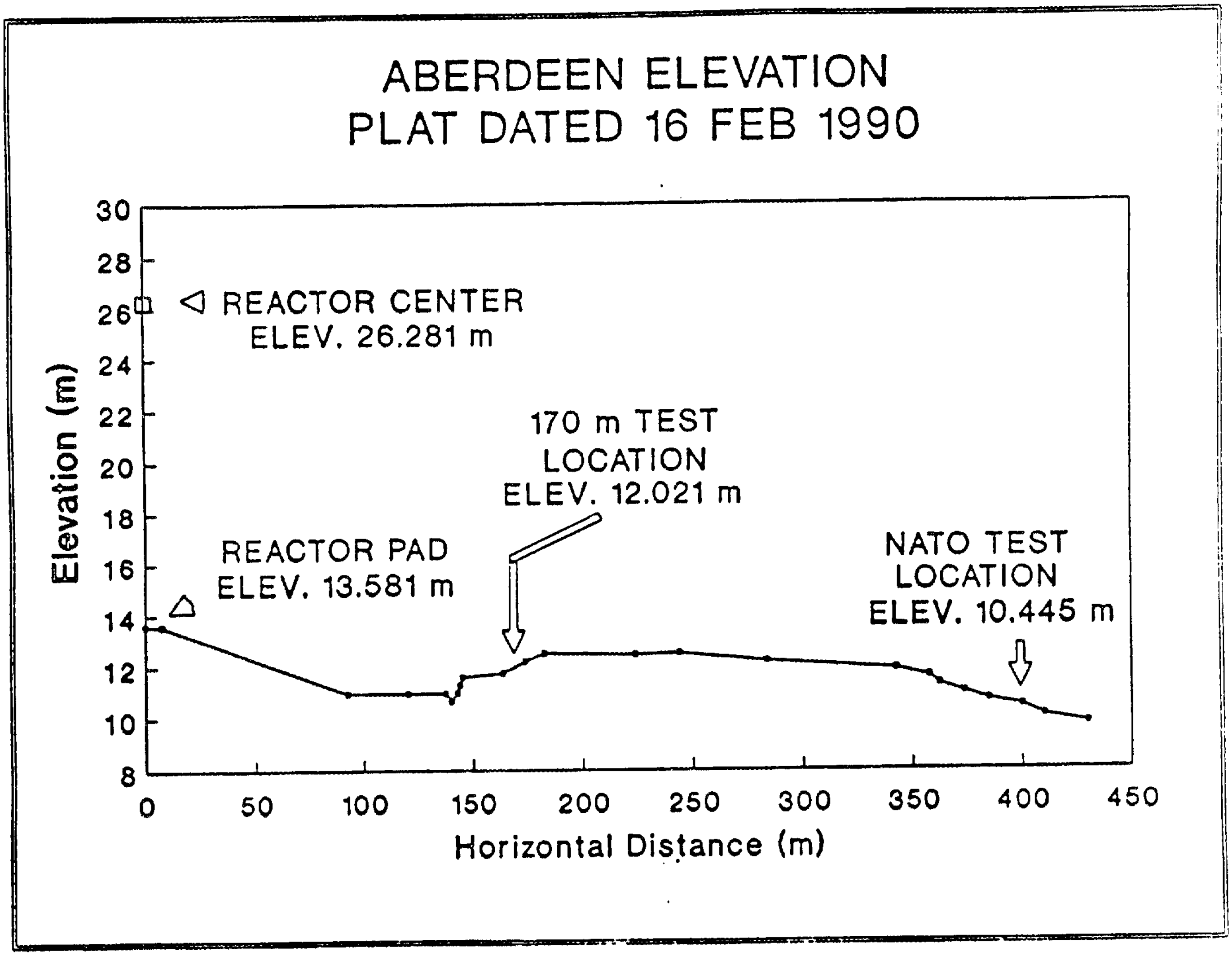

Figure 1. DIAGRAM OF THE APRF EXPERIMENTAL SITE

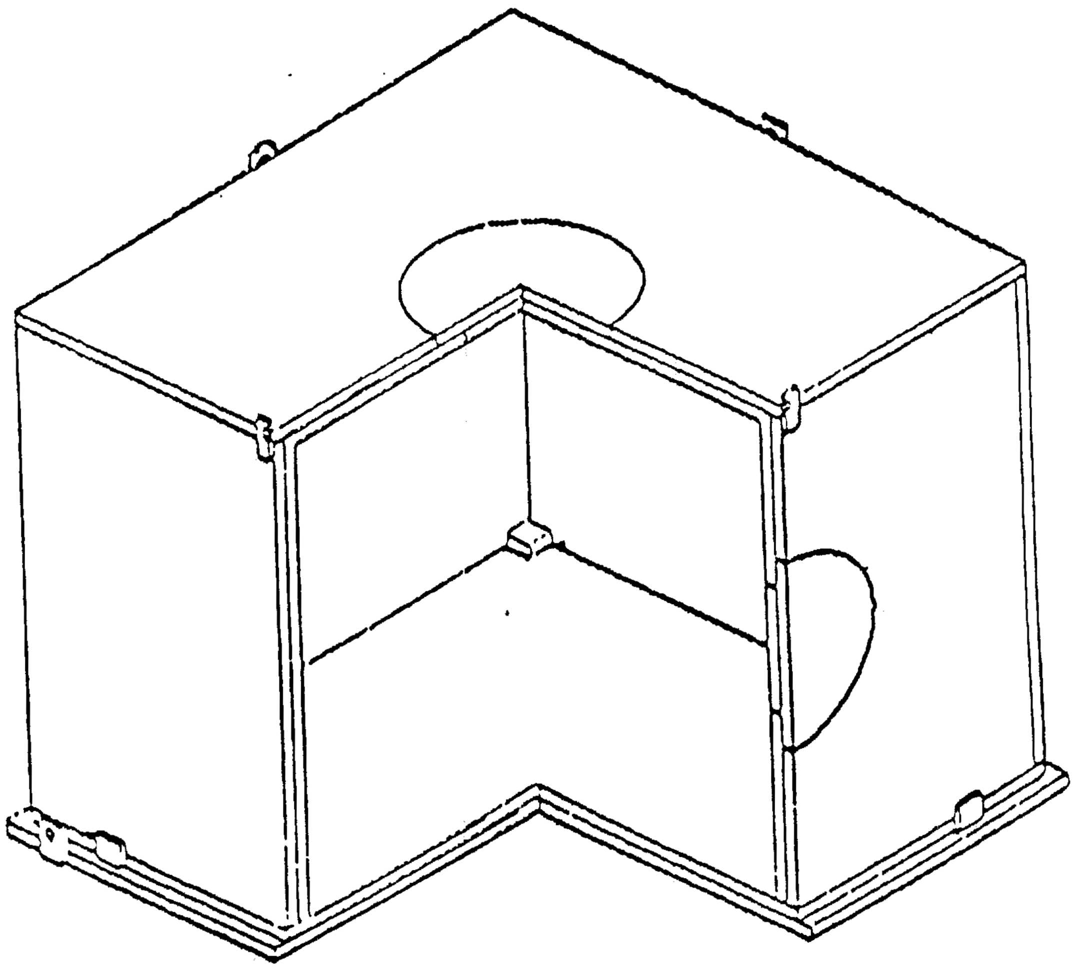

Figure 2. DETAILS OF THE IRON BOX

instrumentation inside the APRF experimental building or in mobile counting laboratories located near the 400-m site.

The reactor was operated at steady-state for all of the measurements reported here. Power levels and run durations were determined for each experiment and by the requirements of the detector system being used to assure sufficient statistical accuracy in the measured results as well as to minimize dead-times, losses, etc. The reactor operation data and the meteorological data are summarized in Table 1 as a function of the date of the measurement. The meteorological data given in the table are mean values obtained from observations taken every half hour and, in some cases, every quarter hour. Soil moisture content over the measurement period was relatively constant; of the order of 35% by weight of dry soil.

II.a DETECTOR SYSTEMS AND RESULTS

The sequence of free-field and in-box neutron and gamma-ray measurements was carefully coordinated by the APRF staff to ensure minimum interference between the different experimental teams and for achieving optimum reactor-detector-box dispositions. Measurements often involved simultaneous use of several spectrometers/dosimeters and associated electronics including as many as three NE-213 scintillators, two BGO spectrometers, and a ROSPEC detector system that were operated concurrently or sequentially by the different experimental teams. Also incorporated in the measurements were tissue equivalent ionization chambers (TE), Geiger-Mueller detectors (GM), and thermoluminescent dosimeters (TLD). The detector systems used by each experimental team are listed in Table 2.

Table 1. REACTOR OPERATION AND METEOROLOGICAL DATA

Run Number	Date	Reactor Data: Operating Time (min)	Reactor Data: Power Level (kw)	Reactor Data: Integrated Power (kw·min)	Meteorological Data: Air Temperature (K)	Meteorological Data: Air Pressure (mm Hg)	Meteorological Data: Relative Humidity (%)
218	10/23/89	60.00	6.0	360.00	290.4	772.3	47
219	10/24/89	120.00	2.0	240.00	289.2	773.8	67
220	10/24/89	80.50	0.4	32.20	290.7	771.8	37
221	10/24/89	30.50	0.4	12.20	282.3	772.3	78
222	10/25/89	125.00	3.0-6.0[a]	740.00	291.3	771.4	54
223	10/25/89	80.25	0.6	48.15	295.3	770.0	45
224	10/25/89	44.50	0.6-2.0[b]	77.10	289.0	769.9	72
225	10/26/89	125.00	2.0-0.4[c]	170.00	292.2	771.4	75
226	10/26/89	131.00	4.0	524.00	297.5	770.0	41
228	10/27/89	10.00	2.0	20.00	288.5	771.4	93
229	10/27/89	10.00	3.0	30.00	294.3	771.2	67
230	10/27/89	30.00	4.0	120.00	296.0	770.8	55
233	10/30/89	101.00	0.1	10.10	294.0	766.8	77
234	10/30/89	100.00	0.04-0.3[d]	11.80	293.0	766.0	79
235	10/31/89	10.00	0.1	1.00	291.0	761.5	96
236	10/31/89	10.00	0.2	2.00	293.5	758.1	91
237	10/31/89	10.00	0.4	4.00	292.2	756.0	91
238	11/01/89	10.00	5.0	50.00	285.6	766.1	60
239	11/01/89	30.00	3.0	90.00	286.5	766.3	53
240	11/01/89	10.00	5.0	50.00	286.7	765.9	53
241	11/01/89	32.00	6.0	192.00	288.2	765.6	49
242	11/01/89	10.00	5.0	50.00	288.5	765.4	44
243	11/01/89	30.00	6.0	180.00	288.2	765.7	42
244	11/01/89	10.00	0.1	1.00	287.3	766.1	43
245	11/01/89	10.00	6.0	60.00	285.5	766.5	45
246	11/01/89	30.00	6.0	180.00	283.6	766.8	54
247	11/02/89	30.00	6.0	180.00	284.7	767.5	62
248	11/02/89	30.00	6.0	180.00	285.4	767.2	59
249	11/02/89	10.00	2.0	20.00	286.0	766.4	55
250	11/02/89	180.00	6.0	1080.00	285.5	764.9	54

[a] 2 min at 3 kw, 1 min at 4 kw, 2 min at 5 kw, and 120 min at 6 kw
[b] 8.5 min at 600 w and 32 min at 2 kw
[c] 75 min at 2 kw and 50 min at 400 w
[d] 70 min at 40 w and 30 min at 300 w

Table 2.
DETECTORS USED IN THE FALL 1989 2-M BOX EXPERIMENTS

APRF TEAM

NE-213 Liquid Scintillator

600 keV < E_n < 10 MeV, 300 keV < E_γ < 9 MeV[(a)]

Tissue Equivalent Ionization Chamber + Geiger-Mueller Counter

1 keV < E_n < 20 MeV, 10 kev < E_γ < 20 MeV

Bonner Spheres

1 keV < E_n < 20 MeV

DREO/BTI Team

ROSPEC System (rotating system of four hydrogen based proportional counters)

60 keV < E_n < 4.5 MeV

NE-213/BF_3 System

NE 213: 600 keV < E_n < 7.6 MeV, System: Thermal < E_n < 20 MeV

Bubble Spectrometer (BD-100R)

10 keV < E_n < 20 MeV

BGO Spectrometer

100 keV < E_γ < 10 MeV

ETCA Team

NE-213 Spectrometer

600 keV < E_n < 12 MeV

BGO (1"x1") Spectrometer

100 keV < E_γ < 10 MeV

Neptunium Ionization Chamber

Thermal 700 keV < E_n < 20 MeV

Tissue Equivalent Ionization Chamber + Geiger-Mueller Counter

1 keV < E_n < 20 MeV, 80 keV < E_γ < 20 MeV

Bubble Spectrometer (BD-100R) (From BTI)

10 keV < E_n < 20 MeV

CR39 Detector

200 keV < E_n < 20 MeV

Thermoluminescent Dosimeter

10 keV < E_γ < 20 MeV

(a) Energy ranges correspond to those over which the measured data are reported.

Each experimental team collected differential (spectra) and integral (kerma) data at the 170- and 400-m test sites. Kerma values were reported for free-field measurements at 170- and 400-m and inside the 2-m box at 400-m. The data summarized in this report were taken primarily from presentation charts and other documents that were distributed at the DNA Radiation Environments Program Review Meeting held on 20-22 Feb 1990.

II.a.1 APRF MEASUREMENTS

The results reported by the APRF team are summarized in Tables 3. Neutron spectra were measured using a 2" x 2" NE-213 spectrometer (incorporating pulse-shape discrimination, PSD) and Bonner Spheres. Gamma-ray spectra were also measured using the NE-213 detector. The TE ionization chamber results obtained in the Fall experiments were found to be in error due to the presence of faulty gas in the chamber. This problem was corrected and the measurements were repeated. These values for the neutron kerma are reflected in Table 3. Also, Bonner Sphere data that were obtained after the fall experiments are included here for completeness.

II.a.2 DREO/BTI MEASUREMENTS

The integral data reported by the DREO/BTI teams are presented in Tables 4 and 5. The neutron data were measured using the ROSPEC system and an NE-213/BF_3 detector with the NE-213 neutron and gamma-ray signals being separated using a cross-over pickoff PSD circuit. The BF_3 system employed both cadmium-covered and bare detectors. As indicated

TABLE 3.
APRF TEAM INTEGRAL MEASUREMENTS[a]

	KERMA VALUES (mrad/kwh)		
DETECTOR/LOCATION	TOTAL	GAMMA-RAY	NEUTRON
NE-213[b]			
400 m FF (Run #220)		1.54	2.28
400 m Box (Run #225)		0.38	0.69
170 m FF (Run #234)		20.5	45.3
TE/GM DETECTORS			
400 m FF (Run #228)	4.8[c]	1.36	3.4
400 m Box (Run #230)	1.9	0.38	1.5
170 m FF (Run #234)		18.5	
BONNER SPHERES[d]			
400 m FF			3.8[e]
400 m Box			2.2[e]

(a) From Craig R. Heimbach, "APRF Measurement Results", Unpublished
(b) 600 keV $< E_n <$ 10 MeV, 300 keV $< E_\gamma <$ 10 MeV
(c) The TE ionization chamber results were obtained after the Fall 1989 Experimental Series.
The original data were suspect due to the presence of a faulty gas mixture in the chamber.
(d) These data were obtained 31 Jan - Feb 1990 and are included for completeness.
(e) Bonner Sphere Response Functions, Craig Heimbach, APRF (Undated).

Table 4.
DREO/BTI INTEGRAL MEASUREMENTS[a]

Location	Run Number	Detector	Total Fluence	NEUTRON KERMA: KERMA (<600 Kev)	NEUTRON KERMA: KERMA (>600 KeV)	TOTAL KERMA
			(n/cm^2 - kWh)	(mrad/kWh)	(mrad/kWh)	(mrad/kWh)
170m FF	233/234	ROSPEC[b]	4.58×10^7	25.9	54.9	80.8
	224	NE-213[c]	1.99×10^7	23.4	55.5	78.9
	234	NE-213[d]	4.50×10^7	33.9	60.0	93.9
400m FF	218-220	ROSPEC	2.34×10^6	1.41	2.55	3.96
	220	NE-213[c]	1.06×10^6	1.29	2.57	3.86
	220	NE-213[d]	2.27×10^6	1.55	2.63	4.18
400m BOX	222	ROSPEC	1.88×10^6	1.44	1.23	2.67
	230	NE-213[c]	8.11×10^5	0.77	0.93	1.70
	230	NE-213[d]	1.26×10^6	1.44	1.43	2.87
					GAMMA-RAY KERMA: KERMA (mrad/kWh)	TOTAL KERMA (mrad/kWh)
170m FF	234	BGO			22.6	22.6
400m FF	220	BGO			1.56	1.56
400m BOX	230	BGO			0.38	0.38
400m WOODS[e]	226	BGO			1.35	1.35

(a) These results taken from T. Cousins and B. E. Hoffarth, Defence Research Establishment Ottawa and H. Ing and K. Tremblay, Bubble Technology Industries, "Recent Remeasurements of the Neutron and Gamma-Ray Fields at Large Distances from a Prompt Critical Facility," Defence Research Establishment, Ottowa Report No. 1031, April 1990.

(b) ROSPEC covers the energy range $0.06 \leq E_n \leq 4.5$ MeV.

(c,d) NE-213/BF_3 detector system. Thermal $\leq E_n \leq 12$ MeV; c = uncorrected, d= corrected.

(e) This measurement was made with the detector in the woods adjacent to the 400 m test site to determine the effects of the trees on the measured data.

Table 5.
DREO/BTI INTEGRAL MEASUREMENTS

COMPARISON OF BUBBLE DETECTOR (BD-100R) WITH ROSPEC NEUTRON MEASUREMENTS

Location	Run Number	Dose Equivalent[a]	(KERMA) Q = 12.44	ROSPEC MEASURED Q-VALUE	BD100R[b] / ROSPEC	ROSPEC MEASURED KERMA[c]
		(mrem/kWh)	(mrad/kWh)	(rem/rad)	(mrad/kWh)	(mrad/kWh)
170m FF	244	976.8	78.5	11.59	84.28	80.8
400m FF	238/242	44.35	3.57	11.44	3.88	3.96
400m BOX	238/242	31.51	2.53	11.26	2.80	2.67
400m WOODS[d]	240	14.89	1.20	-	-	-

(a) Measured using the BD-100R.
(b) Kerma (mrad/kWh) = BD-100R measured dose equivalent in mrem/kwh divided by the ROSPEC Q-value (rem/rad).
(c) These data taken from Table 4.
(d) This measurement was made with the detector in the woods adjacent to the 400 m test site to determine the effects of the trees on the measured data.

in Table 2, the ROSPEC detectors cover the neutron energy range from nominally 60-keV to 4.5-MeV. The NE-213 ideally measures neutrons above 600-keV while the BF_3 detectors measure thermal and epithermal neutrons. A 1/E extrapolation is used to infer the neutron spectrum from thermal energy to 600-keV. Gamma-ray spectra were measured using a BGO scintillator as indicated in Table 4. Neutron kerma measured using the BTI Bubble Detector (BD-100R) are reported in Table 5. For comparison, kerma data obtained using the ROSPEC system (see Table 4) are also given in Table 5. ROSPEC was also used to establish a Q (rem/rad) value for the experimental scenarios since the detectors are calibrated in rem (PuBe).

The DREO/BTI team report both "uncorrected" and "corrected" Kerma values obtained using the NE-213/BF_3 system. Note that in all cases the uncorrected data are lower than the corrected results. The reason for the lower (uncorrected) values was that the effective neutron energy threshold of the NE-213 detector had increased from 0.6 to 1.0 MeV due to detector and discrimination problems. This resulted in too few counts in the bottom two neutron energy bins centered at 0.7 MeV and 0.9 MeV. The DREO procedure for estimating the fluence between thermal energy and 0.6 MeV relies on a power fit (of the form $\upsilon (E) = AE^{-p}$) between the BF_3 - measured thermal fluence and the NE-213 - measured fluence in these two bins. (Note that for a perfect 1/E spectrum, p = 1.0. In practice p is usually found to be 0.95 ± 0.05). The correction procedure applied here was to overwrite the contents of the bottom two bins based upon extrapolation of a second power fit to the data in the 1.0 - 2.0 MeV range, and then proceed as normal. The corrected data are in good agreement with the data obtained by ROSPEC.

II.a.3 ETCA MEASUREMENTS

The integral data reported by the ETCA Team are summarized in Table 6. Neutron kerma were obtained from spectra measured using NE-213 and convoluted with the DABL69 soft tissue kerma[4]. Neutron kerma were also obtained using a neptunium ionization chamber. Gamma-ray kerma data were measured with NE-213 and BGO spectrometers. ETCA, like DREO, did not report NE-213 gamma-ray results. ETCA did, however, report neutron and gamma-ray kerma obtained using paired TE ionization chambers and GM detector combinations.

II.a.4 MEASUREMENT INTERCOMPARISON

The kerma results obtained by the experimental teams are compared in Tables 7 and 8. In Table 7, selected neutron kerma values are compared as the ratios of the free-field and in-box kerma results obtained by the experimental teams using different detectors. Except for a few cases, the data agree within nominally 20%. Similar agreement is obtained for the gamma-ray kerma data compared in Table 8. Note that no NE-213 gamma data were acquired by the DREO/BTI team.

All of the experimental teams reported differential spectra. While it is recognized that some of the differences among the results reported in Tables 3-8 could be identified by comparing spectra, the volume of these data precludes their inclusion in their entirety in this document. A few comparisons are presented in Appendix A. It is expected that more

Table 6.
ETCA TEAM INTEGRAL MEASUREMENTS

Detector/ Location	Run Number	Total	Gamma Ray	Neutron
NE-213/BGO				
170m	233	89.4	23.5[a]	65.9[b]
400m	225	4.9	1.7[a]	3.2[b]
400m BOX	224	1.64	0.39[a]	1.25[b]
TE/GM				
170m	c	102.5	20.5	82
400m	d	5.58	1.58	4.0
400m BOX	226	2.85	0.44	2.41
Np				
170m	e			87
400m	218			4.0
400m BOX	226			2.3

a. BGO, 200 keV $< E <$ 10 MeV
b. NE-213, 600 keV $< E <$ 12 MeV
c. Multiple Runs, 233, 234, 239, 246, 247, 248, 250
d. Multiple Runs, 218, 219, 220, 221, 222, 223, 224, 225
e. Multiple Runs, 233, 234, 239, 243, 246 (two detectors)

Table 7.
COMPARISON OF SELECTED MEASURED NEUTRON KERMA VALUES.

Location:	Detector Combination	APRF / DREO-BTI	APRF / ETCA	DREO-BTI / ETCA
170m FF		0.82	0.69	0.84
400m FF	(NE-213/NE-213)[a]	0.89	0.71	0.80
400m BOX		0.74	0.55	0.74
		APRF / ROSPEC	DREO-BTI / ROSPEC	ETCA / ROSPEC
170m FF		0.83	0.98	1.20
400m FF	(NE-213/ROSPEC)[b]	0.89	0.97	1.25
400m BOX		0.56	0.64	1.02
170m FF		-	1.16	-
400m FF	(NE-213/ROSPEC)[c]	-	1.06	-
400m BOX		-	1.07	-
			DREO-BTI	
170m FF			1.04	
400m FF	(BD-100R/ROSPEC)[d]		0.98	
400m BOX			1.04	

(a) Neutron energy threshold, E_n > 600 keV. Uncorrected NE-213 data.
(b) Neutron energy threshold, E_n > 600 keV. Uncorrected NE-213 data.
(c) Neutron energy threshold, E_n > 600 keV. Corrected NE-213 data.
(d) Neutron energy threshold, E_n > 600 keV.

Table 8.
COMPARISON OF SELECTED MEASURED GAMMA-RAY KERMA VALUES.

Location:	Detector Combination	APRF	DREO-BTI	ETCA
170m FF		0.91	(b)	(b)
400m FF	NE-213[a]/BGO (DREO/BTI)	0.99	-	-
400m BOX		1.00	-	-
170m FF		0.87	-	-
400m FF	NE-213/BGO (ETCA)	0.91	-	-
400m BOX		0.97	-	-
170mFF		0.82	-	1.04
400m FF	GM/BGO (DREO-BTI)	0.87	-	1.01
400m BOX		1.00	-	1.16
	Total KERMA Values			
170m FF		0.85[c]	-	1.10[d]
400m FF		0.92	-	1.19
400m BOX		0.66	-	1.02

(a) NE-213 Energy Threshold, $E_n > 600$ keV.
(b) Gamma-Ray data not reported for NE-213 spectrometer.
(c) APRF NE-213 Total KERMA/DREO-BTI [ROSPEC(>600 keV) + BGO] Total KERMA
(d) ETCA NE-213 Total KERMA/DREO-BTI [ROSPEC(>600 keV) + BGO] Total KERMA

extensive details on differential and integral spectra will be included in reports to be published separately by the experimentalists and analysts.

III. DETAILS OF THE ANALYSIS

Analyses of the 2-m Box experiments were carried out separately by researchers from the Oak Ridge National Laboratory and Science Applications International Corporation. Each organization used the MASH code to acquire spectra and kerma data to compare against measured data. This was done to benchmark MASH against measured data and establish criteria for assessing its merits as the "code-of-choice" to replace VCS.

The calculations were carried out using the version of MASH code currently installed and maintained on the Los Alamos National Laboratory (LANL) CRAY computer. The transport calculations were carried out using the DABL69 (ENDF/B-V) cross-section library[4] that is also currently maintained on the LANL CRAY. Neutron and gamma-ray fluence-to-kerma conversion factors also were taken from DABL69. The experimental geometry and the 2-m Box, shown in Figures 1 and 2, respectively, were reproduced for the calculations using the GIFT5 geometry subroutines in the MASH code.

IIIa PRELIMINARY ANALYSIS

One-dimensional transport and more detailed MASH code calculations were performed by ORNL and SAIC, respectively, to compare the effects on the free-field and in-box neutron and gamma-ray spectra and kerma of the experimental site topography and water concentration in the ground and atmosphere. Differences between the results obtained using detailed topographical geometry and those obtained using a flat terrain representation between the source and the experimental locations were found to be relatively small. SAIC reported ratios of calculated doses (flat to detailed terrain) as a function of distance from the reactor (170-and 400-m) ranging from ~0.95 to ~1.01 for neutrons and ~0.93 to ~0.99 for gamma-rays.

Similar results were obtained for the energy and spatial dependencies of the neutron and gamma-ray spectra. ORNL studied the effects of air and ground moisture and showed that for a factor of approximately three change in the hydrogen density in the air between the reactor and the 400-m test site, the neutron dose varied by about ~9%, the gamma-ray dose varied by ~6%, while the total dose fluctuated by approximately 8%. Calculations of the effects of ground moisture concentration ranging between 20% to 48% indicated changes in neutron, gamma-ray, and total doses of ~11%, ~7%, and ~6%, respectively, depending on the concentration of water vapor in the air.

III.b ORNL CALCULATIONAL METHODOLOGY

The APRF radiation environment was modeled in the GRTUNCL and DORT codes to determine the air-over ground environment from which the flux on the coupling surface could be obtained. GRTUNCL calculates the uncollided component of the flux and DORT calculates the scalar and directional fluxes of the collided component. All three components of the flux are processed through VISTA to obtain the flux on the coupling surface to be folded in DRC. The ORNL air-over-ground model for APRF incorporated 66 radial intervals and 98 axial intervals in a flat topographical r-z model. This mesh modeled a 800-m by 800-m air environment. Approximately one meter of ground was included in the calculations to account for ground scattering. The reactor source height was set at 16.1 meters above the air/ground interface and at the center of the radial mesh (r=0.0). The air-over-ground model utilized a 240 direction forward biased quadrature, P_5 Legendre expansion of the cross sections, the DABL69 (46n/23γ) cross-section library, and three different materials - air, ground, and borated concrete (the reactor pad). Three ground moisture and three air moisture contents were utilized to encompass the full spectrum of ground moisture and meteorological data recorded by APRF. Five air-over-ground flux files were calculated at the coupling surface using the GRTUNCL-DORT-VISTA code stream. These five environments modeled dry air-dry ground, dry air-wet ground, mean air-mean ground, wet air-dry ground, and wet air-wet ground; where, dry, mean, and wet correspond to the amount of moisture in the material. For ground moisture, dry, mean and wet correspond to 20%, 34%, and 48% water (by weight) respectively. For air moisture, dry, mean, and wet correspond to 0.63%, 1.18%, and 1.85% hydrogen content as a percent of dry weight. These five flux files enabled the ORNL analysts to choose an air-over-ground environment which closely approximated the environmental conditions for a given experimental measurement.

The MASH calculations also utilized the DABL69 cross-section library, The Monte Carlo (MORSE) calculation for the detector position generated and tracked 1,500,000 primary source particles (1500 batches of 1000 particles) sampled over all energy groups. An energy dependent relative importance factor was utilized to increase the frequency of sampling the adjoint source particle from energy groups which have 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 switched on. Region dependent and energy independent splitting and Russian Roulette parameters were utilized in the steel to improve the efficiency of the Monte Carlo calculations. This was accomplished by subdividing the 10.16-cm thickness of steel into two equally thick concentric regions and assigning each of the steel regions different splitting and Russian Roulette parameters to allow a sufficient number of source particles (and secondary particles) to escape. This allowed nominally one escaping particle for each source particle generated.

The mean air and mean ground moisture conditions were chosen for the adjoint MORSE calculations. Analysis of the MORSE escape history tapes in DRC for the detector position yielded statistical uncertainties on the order of ±1% for integral neutron fluence (dose), gamma-ray fluence (dose), and total fluence (dose). Differential fluence (dose) results typically exhibited statistical uncertainties less than 10% for all 69 energy groups.

As presently configured, DRC, assumes the DORT flux on the "coupling surface" is dependent on energy and elevation only, and not on azimuth. Consequently, DRC only uses the flux at the 170 and 400 meter radii in the DORT mesh and does not use the radii encompassing the box. This assumption is valid for small objects at a great distance from the source. Since the size of the box is small relative to the distance from the source, it was felt that this assumption is valid for this analysis. A modification to DRC and re-analysis of the experiments using a true "coupling surface" would help determine the validity of this assumption. Examining the variation in flux as a function of distance from the source is the only true way to evaluate this constant flux approximation.

III.c. SAIC CALCULATIONAL METHODOLOGY

The APRF radiation environment was calculated by SAIC using GRTUNCL to calculate the uncollided components of the fluence propagating from the neutron and gamma-ray sources and the associated first-collision sources. The DORT code was used to calculate the scattered and secondary fluence components, using the spatially-distributed neutron and gamma-ray first-collision sources. The use of the first-collision sources is necessary to avoid streaming along quadrature angles, a calculational artifact referred to as a "ray effect."

SAIC performed calculations using two sets of geometry models, each incorporating air, ground and a borated concrete pad directly below the reactor. The first model was a simple depiction of the APRF site, with reactor represented by a point source over flat ground. The height of the point source was 14 meters (r=0.0), which is approximately the mean for the three locations at which measurements have been made, 170, 300 and 400 meters. The flat-ground model extended to a radius of 1900-m, using 89 mesh intervals, and to a height of 1000-m, using 81 mesh intervals, of which 59 were in the air. The second model was more complex, including the terrain of the APRF shown in Figure 1. The detailed terrain model depicted the reactor at 12.7 meters above the concrete pad, 14.26 meters above the 170-m station and 15.84 meters above the 400-m station. The detailed terrain model extended to a radius of 1100-m, using 45 mesh intervals, and to a height of 1100-m, using 123 intervals, 70 of which included ground.

The calculation used a point source, differential in energy and angle. The source and cross section energy format was that of the DABL69 cross section set (46n/23γ). The angle quadrature was a 240 angle set, derived from an S_8 quadrature by subdividing each direction five for one in the polar direction. The cross sections were implemented using a P_5 Legendre scattering order.

As noted previously, the results of the detailed terrain calculation did not seem to differ sufficiently from those obtained using flat ground to justify continuing with the former approach, which had the potential for convergence problems and did not lend itself to air density scaling. Therefore, the flat terrain calculation was run for three different ground moisture contents, 10%, 25% and 50% of dry weight, using a nominal air density of 1.233 mg/cc (total), of which water vapor accounted for 0.60%. ANISN, one-dimensional, discrete ordinate code calculations were then performed for air of identical total density, with moisture contents of 0.10%, 0.25%, 0.60%, 1.50% and 4.00%. A code called APRFLUX was written to perform density scaling and interpolation among the two-dimensional data sets to obtain the energy- and angle-differential fluence values applicable to the desired air density and soil moisture content. The ANISN results were incorporated to correct the fluence data to reflect the desired air moisture content, an energy-dependent (scalar) correction only. APRFLUX also prepared a VISTA tape for use with MASH.

SAIC determined the radiation environments applicable to the FAll 1989 series by performing calculations for each time at which meteorological data were reported within the temporal bounds of each experiment interval and taking the mean. Meteorological values selected for use were those corresponding to sea level. The ground moisture content was assumed to be constant throughout the experiment series at 35% of dry weight.

The MORSE, Monte Carlo calculation used in MASH was also performed using the DABL69 cross section set (P_5) The calculation was performed starting 100,000 particles, biased toward energies between 100 keV and 2 MeV, which were expected to produce the majority of the kerma within the box. The in-group biasing option was used, which also causes MORSE to interpret the secondary particle production probability to be the fraction of the natural production probability, as specified by the cross section. SAIC set that probability to 1.0.

The MORSE calculation was run with a square patch of ground, 10 meters on a side, centered under the box, which was a cube, 2 meters on a side, with a thickness of 10.16 cm all around. The iron cross sections were those for infinitely dilute material (no resonance self-shielding). The ground in the MORSE calculation had a water content of 15% by dry weight soil. This was a hold-over from a previous application, but was considered to be appropriate, even in the face of the more moist ambient conditions, given that the 400 meter station had been back-filled with gravel. DRC was used to couple the box with the free field in four separate orientations, which are assumed to result in four independent estimates of the dose, since the incident field is so directional. The precision of the mean value of the kerma thus obtained was determined to be 1% FSD for neutrons and vehicle gamma rays and 4% for gamma rays. The precision of the "other" gamma rays, a minor contributor to the total, including those from the MORSE ground was poor, being of the order of 15% FSD after taking credit for the multiple coupling. Differential fluence values between 100 keV and 2 MeV had a precision generally ranging between 5% and 10% FSD, though some groups in this range exhibited even more precise values.

III.d CALCULATION INTERCOMPARISON

Table 9 summarizes the results of calculation of the 170-m free-field and 400-m free-field and in-box kerma. Included in the tables are the ratios of the calculated data obtained by each team. As in the case of similar comparisons for the measured data, these results are intended to show the relative figure-of-merit of the independent analyses by each team. The SAIC kerma values given in the table are averages for all runs calculated at each distance. The ORNL kerma data are averages of DORT or MASH calculations that were carried out to account for differences in the environmental conditions. The ORNL results are normalized to a reactor neutron source strength of 1.26×10^{17} n/kWh. The calculated free-field and in-box neutron and gamma-ray kerma are in good agreement; well within the 20% limit adopted and accepted by the experimentalists and analysts at the February 1990 REP program review. Table 10 compares calculated neutron and gamma-ray reduction factors. Again, the agreement among the calculated results is good.

The agreement among the data presented in Tables 9 and 10 indicates reliable reproduction of the experimental configuration, replication of the reactor source term, and consistent use of the MASH code and cross-sections by both ORNL and SAIC analysis. Some of the differences among the data suggest that differences may exist in the MASH calculations, in particular the methods used to account for the meteorological variations between experiments. The reduction factors are, however, within the 20% tolerance accepted by the REP.

Table 9.
COMPARISON OF CALCULATED KERMA

Location	ORNL	SAIC	C_{ORNL}/D_{SAIC}
	Neutron KERMA (mrad/kWh)		
170m FF	84.4	86.0	0.98
400m FF	4.94	5.06	0.99
400m BOX	2.95	3.26	0.90
	Gamma KERMA (mrad/kWh)		
170m FF	13.7	13.6	1.01
400m FF	1.21	1.24	0.98
400m BOX	0.34	0.37	0.92

Table 10
COMPARISON OF CALCULATED REDUCTION FACTORS

Location	ORNL	SAIC	C_{ORNL}/C_{SAIC}
	Neutron Reduction Factor (0.0 to 20 MeV)		
400m FF	1.67	1.55	1.08
	Gamma Reduction Factor (0.1 to 10 MeV)		
400m FF	3.56	3.35	1.06

IV. COMPARISONS OF MEASURED AND CALCULATED DATA

The calculated and measured neutron and gamma-ray kerma are compared in Tables 11 and 12, respectively. As discussed above, the calculated kerma were obtained by convoluting the calculated energy spectra with the fluence-to-kerma conversion factors contained in the DABL69 cross-section library and integrating within the minimum and maximum energy ranges specified by the experimentalists for the detector against which the calculation is compared. The measured kerma are those reported by the experimentalists. The fluence-to-kerma conversions factors used to obtain the measured kerma results are those adopted by the different experimental teams and are not the same as the data used in obtaining the calculated data. It was agreed at the February 1990 REP Review Meeting that measured kerma would, in the future, be obtained using the fluence-to-kerma conversion tables in the DABL69 data. Consequently, some of the observed differences among the data may reflect the choice of fluence-to-kerma response functions used by the experimentalists. SAIC has made comparisons of calculated and measured kerma obtained using the DABL69 kerma function. These results are included in Tables 11 and 12 for comparison purposes only and should not be treated as data reported by the experimental teams.

The comparison between calculation and measurement can be summarized as follows: In the case of the neutrons (Table 11) the measurement results of APRF are inconsistent with those of DREO and ETCA, as well as with the calculated values of ORNL and SAIC.

Table 11.
Comparisons of Measured and Calculated Neutron KERMA.

Team	Detector	Measured	ORNL	$C_o/E^{(a)}$	SAIC	$C_s/E^{(b)}$	Measured[c]	$C_s/E^{(d)}$
				170m FF				
APRF	NE 213	45.3	63.5	1.40	57.5	1.27	47.3	1.21
	TE/GM	54.1	85.5	1.58	84	1.55	54.1	1.55
DREO/BTI	ROSPEC	80.8	78.7	0.97	75.7	0.94	83.4	0.91
	NE-213	93.9	85.5	0.91	84.2	0.90	99.4	0.85
	BD-100R	84.3	80.7	0.96	86.9	1.03	84.3	1.03
ETCA	NE-213	65.9	63.5[e]	0.96	57.5	0.87	64.0	0.90
	TE/GM	82	85.5	1.04	85.3	1.04	82.0	1.04
	Np	87	85.5	0.98	85.6	0.98	87.0	0.98
				400m FF				
APRF	NE-213	2.28	3.72	1.63	3.44	1.51	2.38	1.45
	TE/GM	3.4	5.18	1.52	4.71	1.39	3.4	1.39
DREO/BTI	ROSPEC	3.96	4.51	1.14	4.48	1.14	4.11	1.09
	NE-213	4.18	5.18	1.24	4.90	1.17	4.42	1.11
	BD-100R	3.88	4.66	1.20	5.23	1.35	3.88	1.35
ETCA	NE-213	3.2	3.53[e]	1.10	3.27	1.02	3.09	1.06
	TE/GM	4.0	4.85	1.21	5.0	1.25	4.0	1.25
	Np	4.0	4.85	1.21	5.12	1.28	4.0	1.28
				400m BOX				
APRF	NE-213	0.69	1.42	2.06	1.23	1.78	0.72	1.71
	TE/GM	1.5	2.97	1.98	3.25	2.17	1.5	2.17
DREO/BTI	ROSPEC	2.67	2.83	1.06	3.02	1.13	2.78	1.09
	NE-213	2.87	2.99	1.04	3.25	1.13	3.23	1.01
	BD-100R	2.80	2.76	0.99	3.25	1.16	2.80	1.16
ETCA	NE-213	1.25	1.42[e]	1.14	1.23	0.98	1.18	1.04
	TE/GM	2.41	2.99	1.24	3.38	1.40	2.41	1.40
	Np	2.3	2.99	1.30	3.38	1.47	2.3	1.47

(a) C/E; ORNL calculation
(b) C/E; SAIC calculation
(c) Measured Kerma corrected by SAIC using DABL69 Fluence-to-Kerma conversion
(d) C/E; SAIC calculation/SAIC corrected measured data
(e) ORNL data integrated over the neutron energy range 600 keV < E_n < 12 MeV for ETCA NE-213 comparison

Table 12.
COMPARISONS OF MEASURED AND CALCULATED GAMMA-RAY KERMA

Team	Detector	Measured (mrad/kWh)	ORNL	C_o/E^a	SAIC	C_s/E^b	Measured[c] (mrad/kWh)	C_s/E^d
				170m FF				
APRF	NE 213	20.5	12.6	0.61	12.43	0.61	18.54	0.67
	TE/GM	18.5	13.7	0.74	14.11	0.76	18.5	0.76
DREO/BTI	BGO	22.6	13.8	0.61	13.60	0.60	22.5	0.60
ETCA	TE/GM	20.5	13.7	0.67	13.67	0.67	20.5	0.67
	BGO	23.5	13.8	0.59	13.70	0.59	23.5	0.58
				400m FF				
APRF	NE-213	1.54	1.10	0.77	1.06	0.69	1.43	0.74
	TE/GM	1.36	1.19	0.88	1.25	0.92	1.36	0.92
DREO/BTI	BGO	1.56	1.22	0.78	1.17	0.75	1.54	0.76
ETCA	TE/GM	1.58	1.17	0.74	1.24	0.78	1.58	0.78
	BGO	1.70	1.19	0.70	1.21	0.71	1.70	0.71
				400m BOX				
APRF	NE-213	0.38	0.33	0.87	0.32	0.84	0.33	0.97
	TE/GM	0.38	0.34	0.89	0.37	0.97	0.38	0.97
DREO/BTI	BGO	0.38	0.34	0.89	0.37	0.97	0.40	0.93
ETCA	TE/GM	0.44	0.35	0.80	0.38	0.86	0.44	0.86
	BGO	0.39	0.35	0.90	0.36	0.97	0.38	0.95

(a) C/E; ORNL calculation
(b) C/E; SAIC calculation
(c) Measured Kerma corrected by SAIC using DABL69 Fluence-to-Kerma conversion
(d) C/E; SAIC calculation/SAIC corrected measured data

Excepting the APRF data, the relationship between the calculated and measured free field values are very consistent at each of the two distances studied, with the calculations agreeing with the measurements within a few percent at 170-m and being 20% higher than the measurements at 400-m. The fractional standard deviations associated with the mean agreement between calculation and measurement at each distance are very low, being of the order of 10% or less. However, there does appear to be a consistent difference between the spread of comparisons achieved by ORNL and those achieved by SAIC. Since both laboratories are using similar methods, this difference probably grows out of the selection of meteorological data or some other aspect of the basis of comparison for each individual measurement and should be investigated further.

Within the box, the calculations are also higher than the measurements by a factor similar to that for the 400-m free field. The spread of comparison values is approximately double that for the free field. This is not consistent with the mere addition of Monte Carlo precision, which is reported by both SAIC and ORNL to be on the order of 1%.

In the case of gamma rays (Table 12) the comparison between the free field results for both calculators and the data from the experimentators is very consistent at each distance. The calculated values are 65% of those measured at 170-m and 77% of those measured at 400-m, with a very high degree of precision at both distances. Inside the box, the calculated values are approximately 90% of those measured, again with a very high degree of precision.

Table 13 and 14 provide a comparison between calculated and measured reduction factors for neutrons and gamma rays, respectively. The agreement between calculated and measured neutron reduction factors is generally within ±10%, except in the case of APRF data, in which case a larger discrepancy is observed. The calculated gamma ray reduction factors are all less than those measured by 10% to 30%.

Table 13.
COMPARISONS OF MEASUED AND CALCULATED NEUTRON REDUCTION FACTORS.

Team	Detector	Measured	ORNL	$C_o/E^{(a)}$	SAIC	$C_s/E^{(b)}$	Measured$^{(c)}$	$C_s/E^{(d)}$
APRF	NE 213	3.30	2.62	0.79	2.80	0.85	3.36	0.83
	TE/GM	2.27	1.74	0.77	1.45	0.64	2.64	0.55
DREO/BTI	ROSPEC	1.48	1.59	1.07	1.50	1.01	1.50	1.01
	NE-213	1.46	1.73	1.18	1.51	1.03	1.37	1.10
	BD-100R	1.39	1.69	1.22	1.61	1.16	1.39	1.16
ETCA	NE-213	2.56	2.49	0.97	2.66	1.04	2.62	1.02
	TE/GM	1.66	1.62	0.98	1.48	0.89	1.66	0.89
	Np	1.74	1.62	0.93	1.51	0.87	1.74	0.87

(a) C/E; ORNL calculation
(b) C/E; SAIC calculation
(c) Measured Kerma corrected by SAIC using DABL69 Fluence-to-Kerma conversion
(d) C/E; SAIC calculation/SAIC corrected measured data

Table 14.
COMPARISONS OF MEASURED AND CALCULATED GAMMA RAY REDUCTION FACTORS.

Team	Detector	Measured	ORNL	$C_o/E^{(a)}$	SAIC	$C_s/E^{(b)}$	Measured$^{(c)}$	$C_s/E^{(d)}$
APRF	NE 213	4.05	3.33	0.82	3.31	0.82	4.33	0.76
	TE/GM	3.58	3.50	0.98	3.38	0.94	3.58	0.94
DREO	BGO	4.11	3.59	0.87	3.36	0.82	3.85	0.87
ETCA	TE/GM	3.59	3.34	0.93	3.26	0.91	3.59	0.91
	BGO	4.36	3.40	0.78	3.36	0.77	4.47	0.75

(a) C/E; ORNL calculation
(b) C/E; SAIC calculation
(c) Measured Kerma corrected by SAIC using DABL69 Fluence-to-Kerma conversion
(d) C/E; SAIC calculation/SAIC corrected measured data

V. DISCUSSION OF RESULTS

The results obtained here show differences among the E/E, C/C, and C/E ratios that range from very good to poor. Based on the information provided by the participants, it remains difficult to fully resolve and identify the sources of the discrepancies among the data. Widely different results are reported for the same kind of detector system used by the different experimental teams. The APRF experimental staff has expressed some concerns over the state of their NE-213 detector at the time of the measurements and have recently made extensive measurements of detector response functions using neutrons of known energies. Other discrepancies between measured data may also arise from the methods of calibration, detector linearity, spectral unfolding techniques, or, in the worse case, unresolved difficulties with the detector or its associated electronic systems.

The calculated results obtained by ORNL and SAIC appear to be generally consistent among themselves which suggests that both teams are similarly replicating the experimental configuration and incorporating consistent cross-section data and response functions.

In summary, such differences as exist between calculation and measurement appear to be very consistent. However, it should be noted that a single laboratory, acting alone, may obtain results which differ significantly from a "true" or consensus value. Further, consistency does not imply agreement. The calculated values of both neutrons and gamma rays rise by approximately 20% relative to the measurements between 170-m and 400-m. Fortunately, there appears to be a correlation in the relationship between calculated and measured neutron kerma within and outside the steel box, such that the agreement between calculated and measured neutron reduction factors is better than that for the associated kerma. This is not the case for gamma rays, where differences between calculation/measurement agreement within the box and in the free field lead to 10% to 20% differences between calculated and measured reduction factors.

V.a. COMMENTS BY APRF

Overall, it is concluded that with adequate care and control, measurements can be made in the box at the 400-m ground range, and provide an adequate basis to validate the analytical models. This experiment has therefore, been successful in laying the foundation for the Spring 1990 experiment which will include not only free field box measurements but also a phantom both free field and in the box. This experiment in turn will lay the groundwork for experiments with phantoms in actual armored vehicles.

V.b. COMMENTS BY DREO

As a result of APG work, a great deal of controversy and ambiguity concerning experimental data at the 400-m NATO standard test point has been overcome. Using this work as basis, future plans to better characterize the radiation environment - both its measurement and calculation - have emerged. The following list of recommendations is intended as a guideline as to focal points for the future work.

(1). A ROSPEC-based system should be accepted as the current standard for all NATO neutron spectroscopy in fission/degraded fission environments. In such spectra, the system may act as a stand-alone unit. For spectra with a significant higher energy (fusion) component, an NE-213 or He-4 system must augment ROSPEC. The ROSPEC-based system must be used by APG staff to perform a complete analysis of the influence of ground/air moisture (or any other effect) on the neutron spectrum at the NATO standard reference point. The BGO spectrometer should be the standard for all NATO gamma-ray spectroscopy.

(2). The BD-100R should be the NATO standard neutron dosimeter. Its efficacy as an absolute dosimeter in the fields examined here has been verified.

(3). For now, TLD 400s should be recognized as the NATO standard gamma-ray dosimeter (again in the absolute sense). However, the TLD 400 is incompatible (too insensitive for simultaneous work) with the BD-100R for many shielding experiments. Thus, a new, more sensitive device should be sought. Either physically larger TLDs or a gamma-ray sensitive bubble detector appear to be the main options.

(4). The bubble spectrometer set is the fastest way of achieving crude (6 group) neutron spectral data. It is also the only way of getting any spectral information in small, confined areas such as in-vehicle or in-phantom.

(5). A version of the RT-200 phantom with articulating limbs should be designed, built and standardized for NATO work. New work at Radiology Support Devices on (more tissue equivalent) polyester fabrics may be helpful here.

(6). More work on arboreal shielding, both theoretical and experimental, needs to be done, as these scenarios are more realistic.

(7). Future work on the test-bed should include:

- non-uniform shielding,
- various liner materials,

- internal structure, and
- more than one phantom inside the box.

V.c. COMMENTS BY ETCA

Comparisons of NE-213 neutron spectrometer and calculated results look very satisfactory. The NE-213 neutron spectrometer appears to be suited to the neutron spectrometry for neutron energies above 1-MeV. With some precautions in the calibration process, it is possible to extend this threshold down 600 keV. On the other hand, the discrepancies observed with the other NE-213 experimenters can be explained by differences in calibration method.

Comparisons with the Np chamber results look less consistent. The discrepancy is negligible at 170 meters but goes up 21% or 28% at 400 meters and 30% or 47% in the box, according to calculation. This sets the problem of the neutron fluence evaluation in the 1 keV-600 keV energy range, which has a non negligible contribution to the dose in the box. To accurately determine the neutron dose using Np chamber, the average kerma factor to average Np cross-section ratio has to be known over the neutron spectrum. Such a ratio is obtained using calculated spectra, and possibly using a NE-213 neutron spectrum. Here, this evaluation was made using ETCA's calculated spectra. Quite obviously such a determination was wrong and it would be interesting to use ORNL and SAIC calculated spectra to see whether an improvement is observed or not.

The TE/GM-method is less reliable because it is always difficult to determine the gamma ray dose with the GM (energy response and thermal neutron sensitivity). Nevertheless, it is interesting to notice that, in spite of these inadequacies, these detectors give consistent results. In conclusion, this experiment was very fruitful. All the experimenters have obtained consistent results and the agreement with calculations is satisfactory. With respect to the NE-213 measurements, common work in laboratory conditions should allow for reduction in the differences observed.

V.d. COMMENTS BY SAIC

Based on the available measured and calculated data, it is difficult to determine an explicit figure-of-merit which can be used to justify the selection of a specific data acquisition system as "detector-of-choice" for measuring fluence, kerma, and reduction factors, particularly for neutrons. The standard deviation of the distribution of calculation/measurement ratios for neutrons, as a percentage about ideal agreement for each measurement location, ranges in value from 20% at 170-m to over 60% inside the iron box. This improves to 10% or better for the gamma ray component.

ROSPEC neutron fluence/kerma values compare well with calculated values over the energy range for which the detector is valid. However, according to the calculations, ROSPEC is missing approximately 14% of the total kerma because of the limitations of that energy range, primarily at high energies. The BD-100R bubble spectrometer agrees well with ROSPEC. However, given its supposed energy range advantages over ROSPEC, it should register a consistent 10 to 20% higher, which it does not. This critique also applies to the Np detector. However, the bubble spectrometer depends on the proper choice of a Q value to obtain the dose value. Dependence of Q on ROSPEC spectra, which extend to only

4.5 MeV, may result in an overestimate of its value and, hence, an underestimate of the bubble dose. There is a large discrepancy between TE/GM neutron dose measurements and between the measurements and calculations. The fact that the discrepancies of both kinds become worse inside the box indicate that the problem with this detector depends on how well it can be used to measure dose below 1 MeV. NE-213 results vary significantly between laboratories for ostensibly the same measurement. As in the case of the TE/GM system the discrepancy increases when the detectors are moved inside the box, again indicating a problem with low energy neutron measurement. Based on the above observations it may be concluded that the detector of choice for neutron kerma is ROSPEC, with the bubble spectometer as a backup. However, it should be pointed out that only one laboratory reported ROSPEC and bubble results, while at least one other laboratory obtained good agreement with the these detectors using either the TE/GM or NE-213. This raises the question of how well the ROSPEC and bubble detectors would perform in independent hands.

While the three laboratories making measurements had difficulty agreeing on neutron dose, they had no trouble agreeing on gamma-ray dose, with the standard deviation of the distribution as a percentage about the mean for each measurement location being of the order of 10% or less. Thus, there appears to be little to choose between the GM, NE-213 or BGO for measuring gamma-rays. On the other hand only the measurements inside the iron box agreed well with the calculations. This does not indicate that there is necessarily anything wrong with the measurements. However, agreement in the box, where the field is dominated by secondary gamma radiation, indicates that some source of gamma rays is missing from the calculations.

V.e. COMMENTS BY ORNL

In general, the ORNL calculational results are in good agreement with the experimental results measured by the different experimental teams and the calculational results generated by SAIC. The multiple air-over-ground environments generated by ORNL yielded an accurate representation of the ground moisture and meteorological data supplied by APRF. Plotting the dose response as a function of hydrogen content in the air, ground moisture, and detector energy range, and correlating the different experimental measurements with the ground moisture and meteorological data, allowed the ORNL analysts to extrapolate between the five base air-over-ground environments to obtain results consistent with the environmental conditions at the time of a given measurement. This appears to be the most viable option for representing the environment over the course of a series of experimental measurements. Calculating the flux on the coupling surface for each air-over-ground environment during the series of measurements would be otherwise prohibitive. Analyzing 1,500,000 adjoint source particle may appear to be a bit excessive, but it is felt by ORNL analysts that differential data statistics (by energy group) should be within 10% for all groups since this comparison is to serve as a benchmark for the MASH code system. By following this logic, the energy groups contributing 95% of the dose exhibited fractional standard deviations typically less than 5%. Furthermore, comparisons of the differential spectral data would not be subject to criticisms due to poor statistical convergence of the calculated data.

Analyzing the calculated dose responses over the energy range for which the detector generating the measured results is valid yielded excellent comparisons between the calculated and measured responses in almost all cases. The principal exceptions are the APRF data and the majority of the free-field gamma data. The APRF experimental team has since concluded that there were problems with their detector systems during the Fall 1989 and, therefore, most of their measured (neutron) results are low. The consistency of the measured gamma free field data, and the consistency of the ORNL and SAIC calculated gamma free field data lead the ORNL analysts to believe there is some source of gammas not adequately accounted for in the calculational model. The two potential sources to investigate are the flash X-ray machine located next to the reactor silo and in the line-of-sight to the 400 meter test site and the trees surrounding the corridor to the 400 meter test site. Both of these potential sources contain considerable amounts of hydrogen which upon absorbing a neutron would generate a secondary gamma.

Overall, the ORNL calculations agreed quite well with most of the measured data. Generally, the agreement was within the ± 20% limit deemed as acceptable by the DNA. This was the first concerted effort aimed at benchmarking the MASH code against experimental measurements and some problems were encountered. With better communication among the analysts and experimentalist, improved agreement may be achievable; possibly within a tighter acceptance limit (i.e. 10% - 15%).

VI REFERENCES

1. W. A. Rhoades and M. B. Emmett, et. al., "Vehicle Code System (VCS) User's Manual", ORNL/TM-4648, Oak Ridge National Laboratory, (August 1974)

2. W. A. Rhoades, et. al., "Development of a Code System for Determining Radiation Protection for Armored Vehicles (The VCS Code)" ORNL/TM-4664, Oak Ridge National Laboratory (October 1974)

3. J. O. Johnson et al., "A User's Manual for MASH 1.0 - A Monte Carlo Adjoint Shielding Code System," ORNL/11778, Oak Ridge National Laboratory, (to be published 1991).

4. D. T. Ingersoll, R. W. Roussin, C. Y. Fu, and J. E. White, "DABL69: A Broad Group Neutron/Photon Cross-section Library for Defense Nuclear Applications" ORNL/TM-10568, Oak Ridge National Laboratory, Martin Marietta Energy Systems, Inc., (June 1989)

APPENDIX A

Measured and Calculated Neutron and Gamma-Ray Spectra

Extensive measurements and calculations were made to determine neutron and gamma-ray spectra in the free-field at 170-m and in the free-field and inside the 2-m box at 400-m from the APR. Considerable data were obtained at both locations and experimental conditions for the variety of detectors used in this study. Some of these data are presented in this appendix to illustrate these results and show agreement that has been achieved among both measured and calculated spectra. The experimental and analytic teams each generated large quantities of spectral data that would by themselves contribute to a voluminous document. Detailed spectral data will be summarized by the experimental and analytic teams in final reports issued by the participants.

Shown in Figures A1 to A3 are measured neutron spectra obtained by DREO comparing the data obtained using ROSPEC and the Bubble Spectrometer. The spectra are given in units of $E \bullet \phi(E)$ versus E, where E is the neutron energy in MeV and $\phi(E)$ is the neutron flux ($n \bullet cm^{-2} \bullet MeV^{-1}$). The data are compared over the energy range from approximately 0.1 to 4.5 MeV.

Figures A4 to A9 show comparisons of measured and calculated neutron and gamma-ray spectra ($E \bullet \phi(E)$ versus E) at the 170-m location (free-field) and at 400-m (free-field and in-box). Figures A4 and A5 compare the calculated neutron and gamma-ray spectra obtained by ORNL using the MASH code with measured spectra using an NE-213 spectrometer obtained by the APRF team. Figures A6 and A7 compare calculated neutron and gamma-ray spectra with measured NE-213 spectra obtained by ETCA. Finally, comparisons of ORNL calculated neutron and gamma-ray spectra are compared with NE-213 data obtained by DREO.

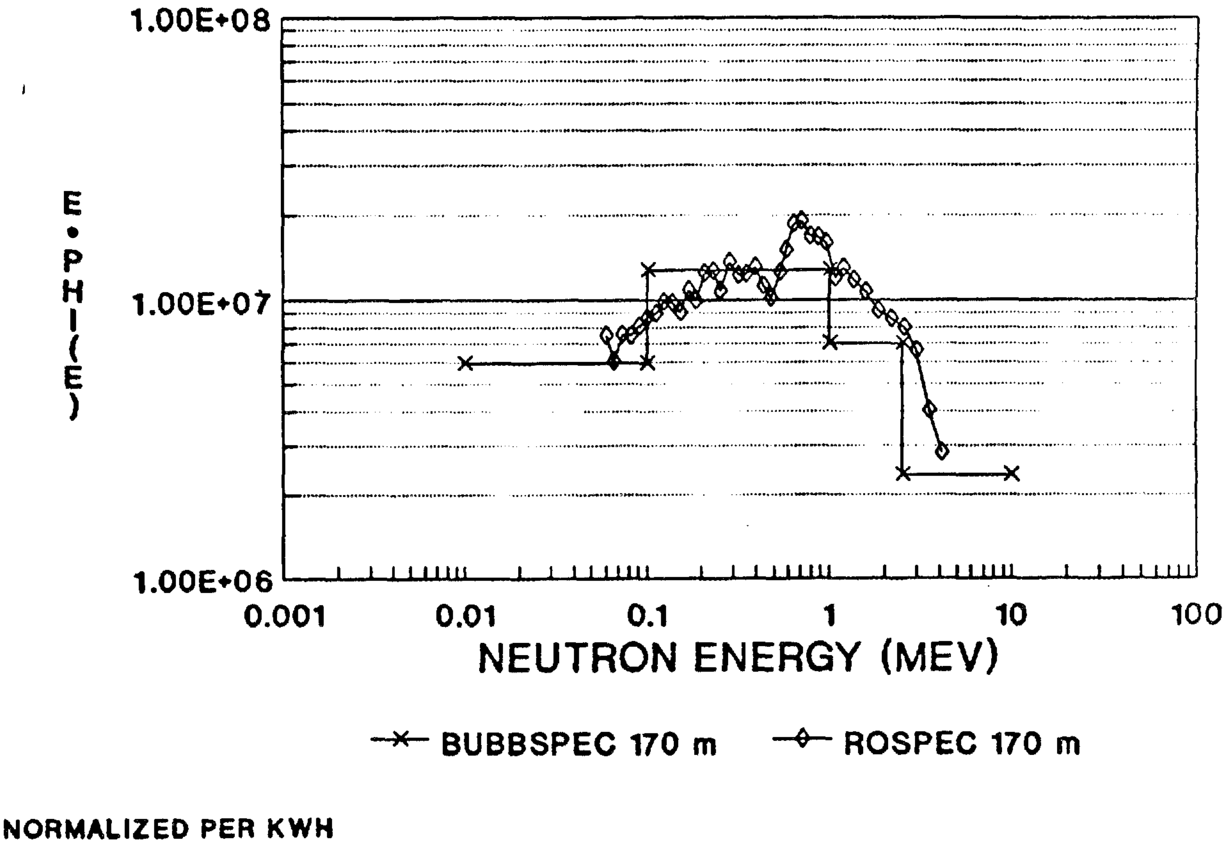

Figure A1. Measured Neutron 170-m Free Field Spectra using in the ROSPEC and Bubble Spectrometers. Results Reported by DREO.

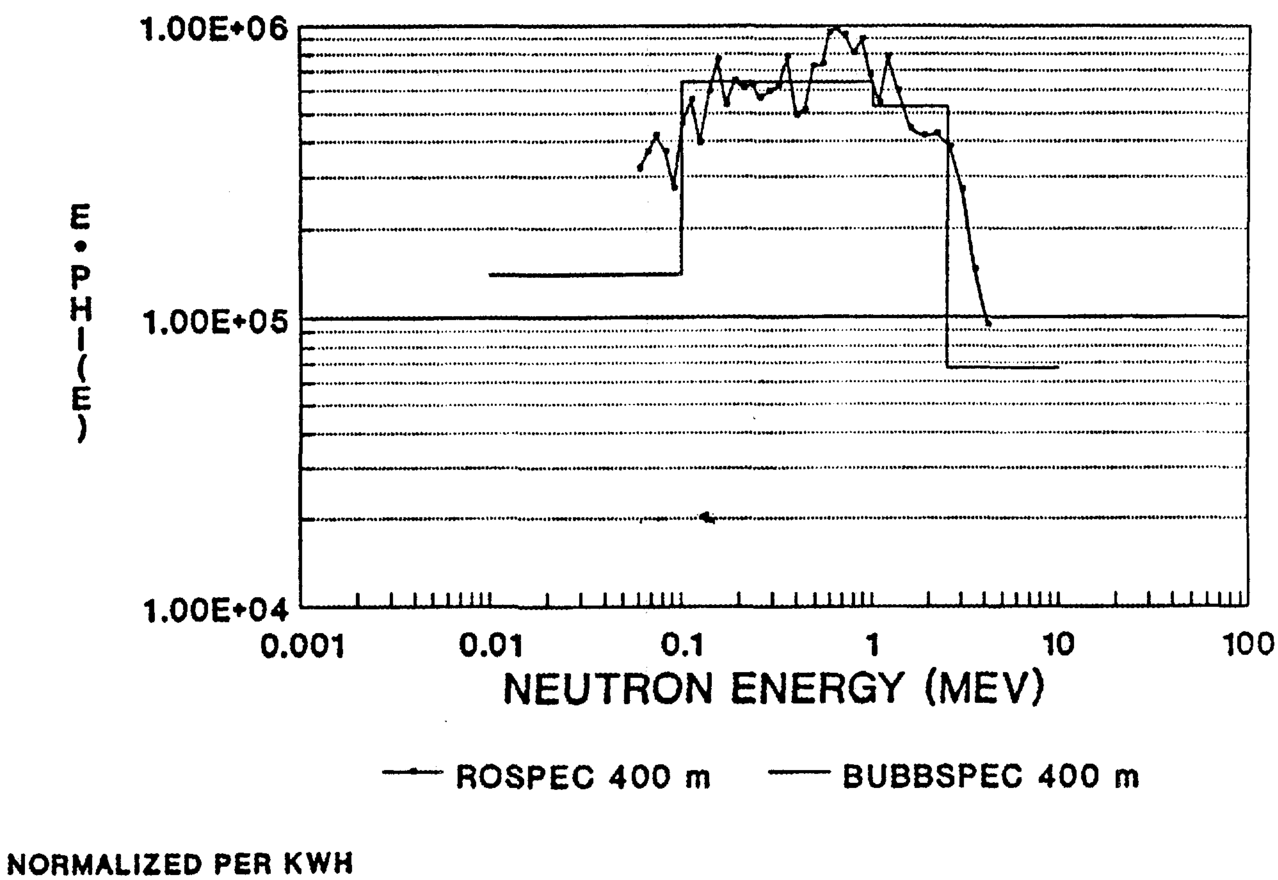

Figure A2. Measured Neutron 400-m Free Field Spectra using the ROSPEC and Bubble Spectrometers. Results Reported by DREO.

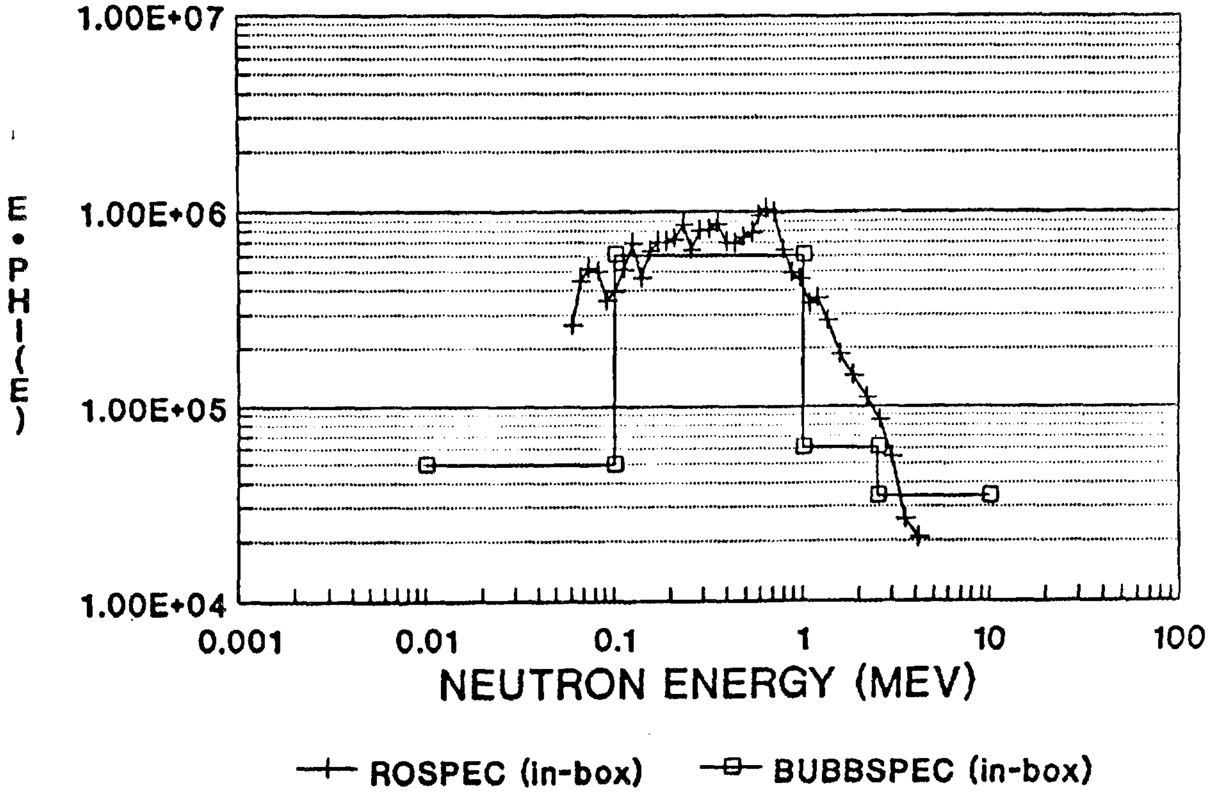

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Figure A3. Measured Neutron 400-m In-Box Spectra using the ROSPEC and Bubble Spectrometers. Results Reported by DREO.

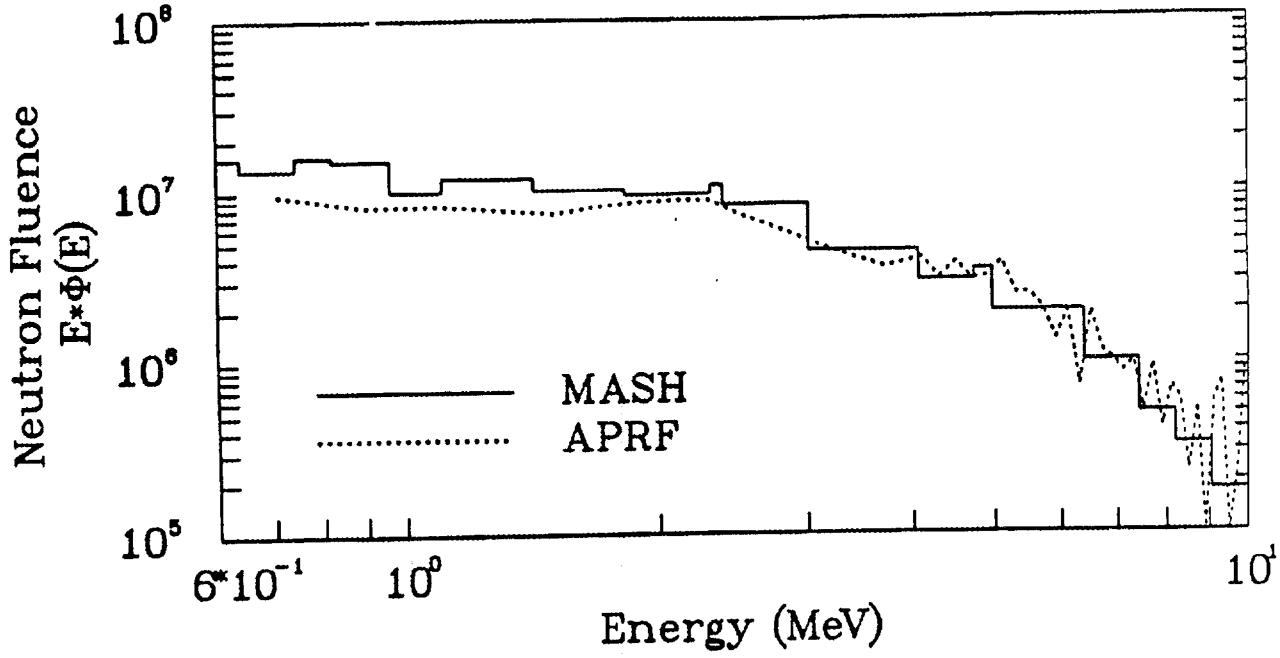

Figure A4. Measured and Calculated Neutron 170-m Free Field Spectra. Measured Data Reported by APRF. Calculated Results Obtained by ORNL using the MASH Code.

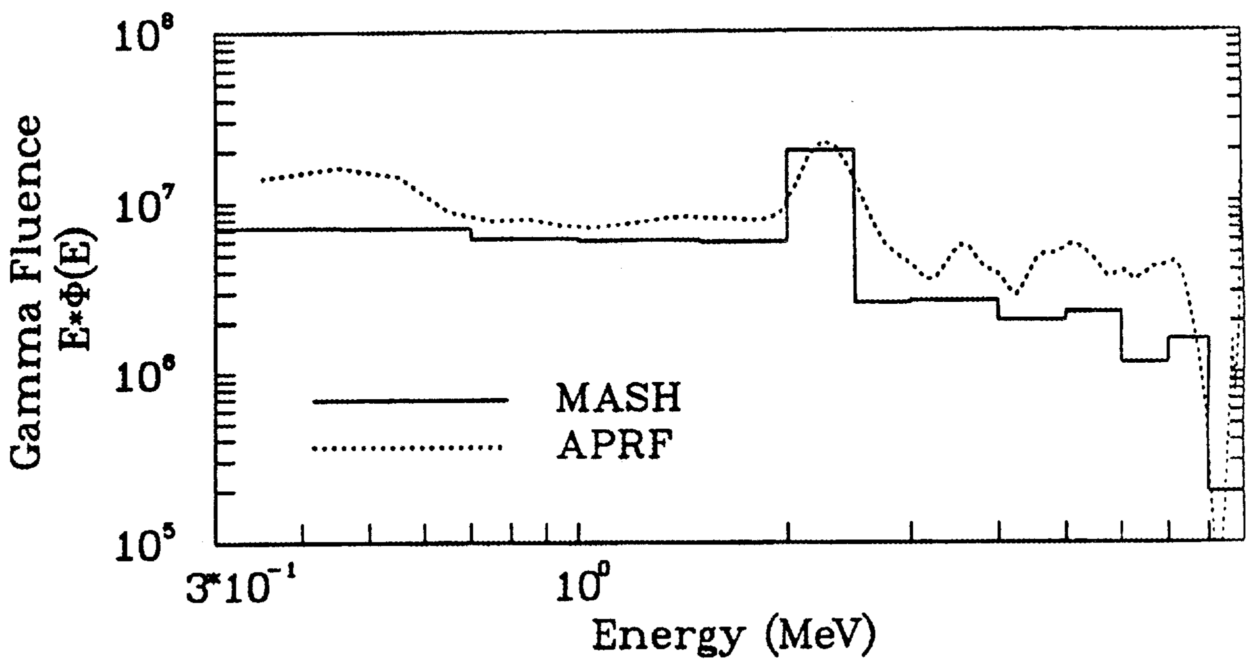

Figure A5. Measured and Calculated Gamma-Ray 170-m Free-Field Specrea. Measured Data Reported by APRF. Calculated Results Obtained by ORNL using the MASH Code.

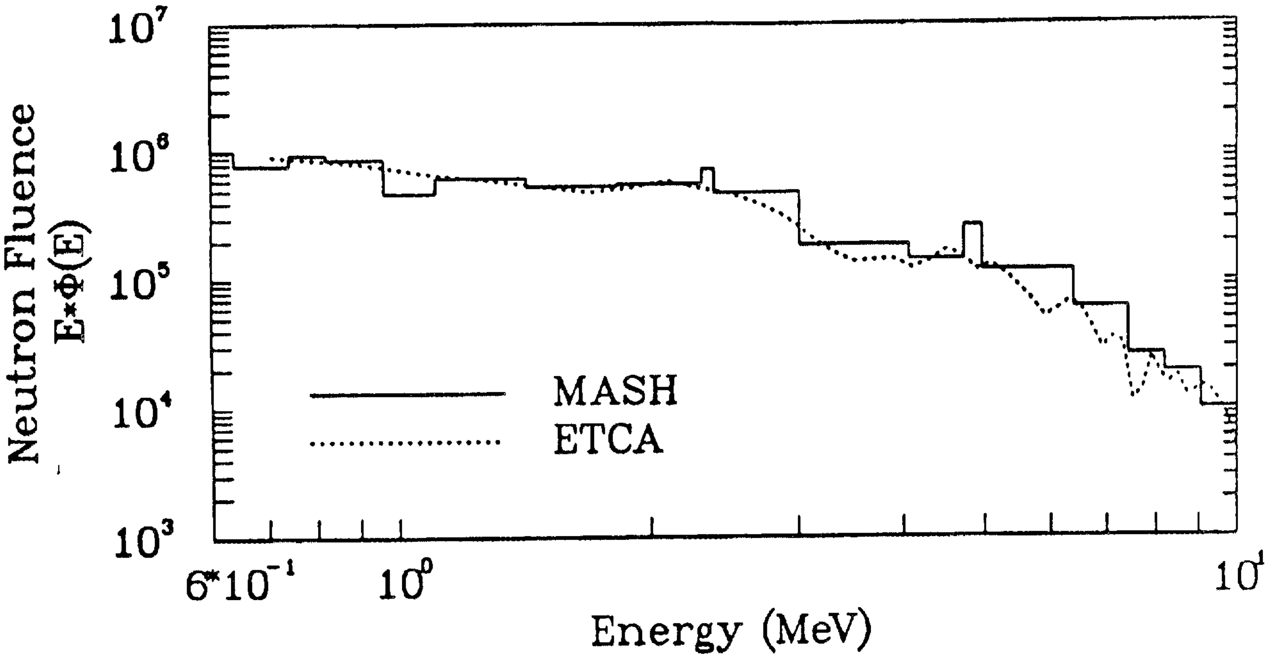

Figure A6. Measured and Calculated Neutron 400-m Free-Field Spectra. Measured Data Reported by ETCA. Calculated Results Obtained by ORNL using the MASH Code.

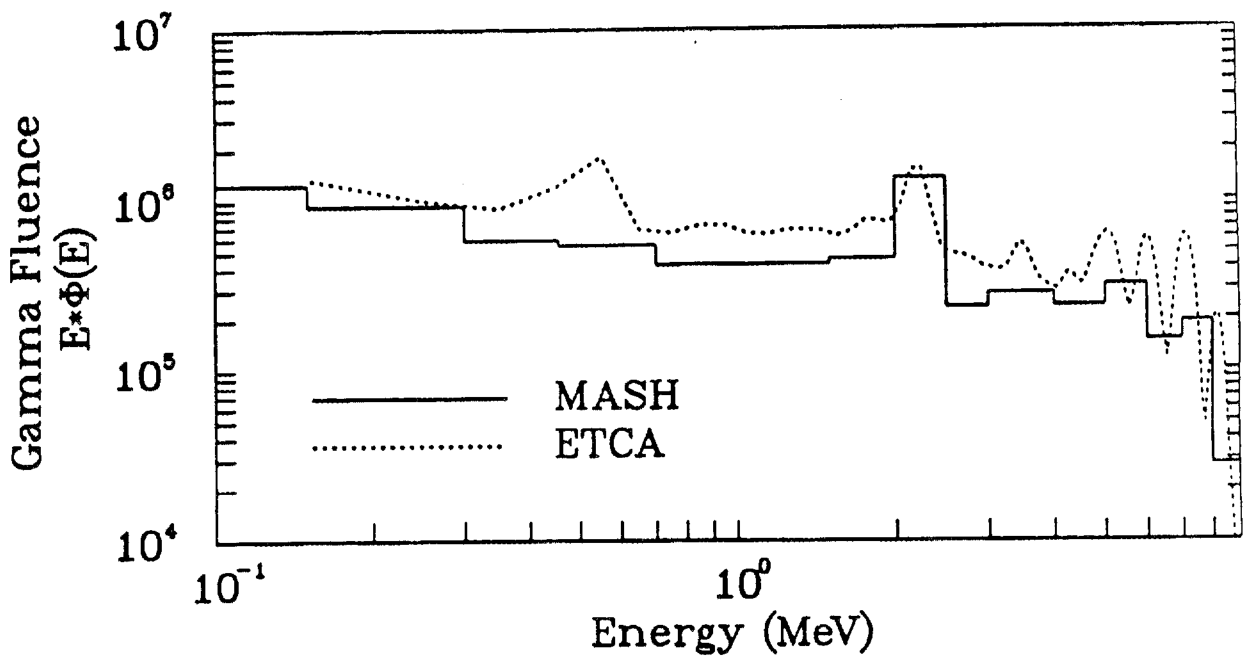

Figure A7. Measured and Calculated Gamma-Ray 400-m Free-Field Spectra. Measured Data Reported by ETCA. Calculated Results Obtained by ORNL using the MASH Code.

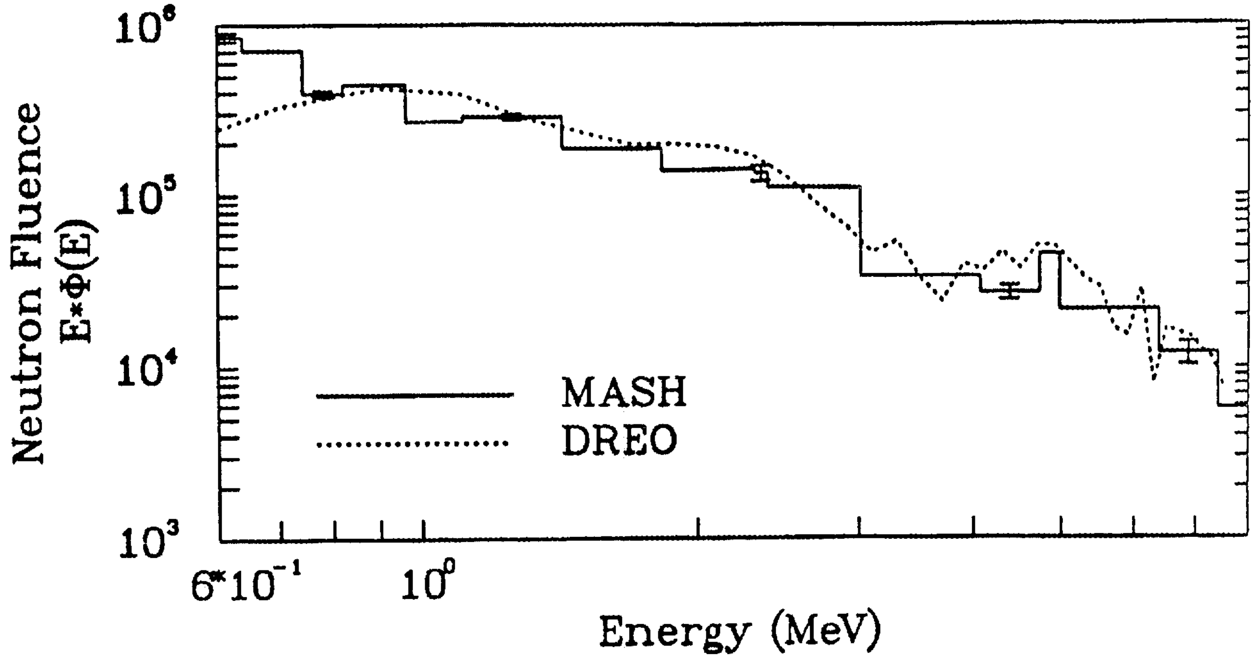

Figure A8. Measured and Calculated Neutron In-Box Spectra at 400 Meters. Measured Data Reported by DREO. Calculated Results Obtained by ORNL using the MASH Code.

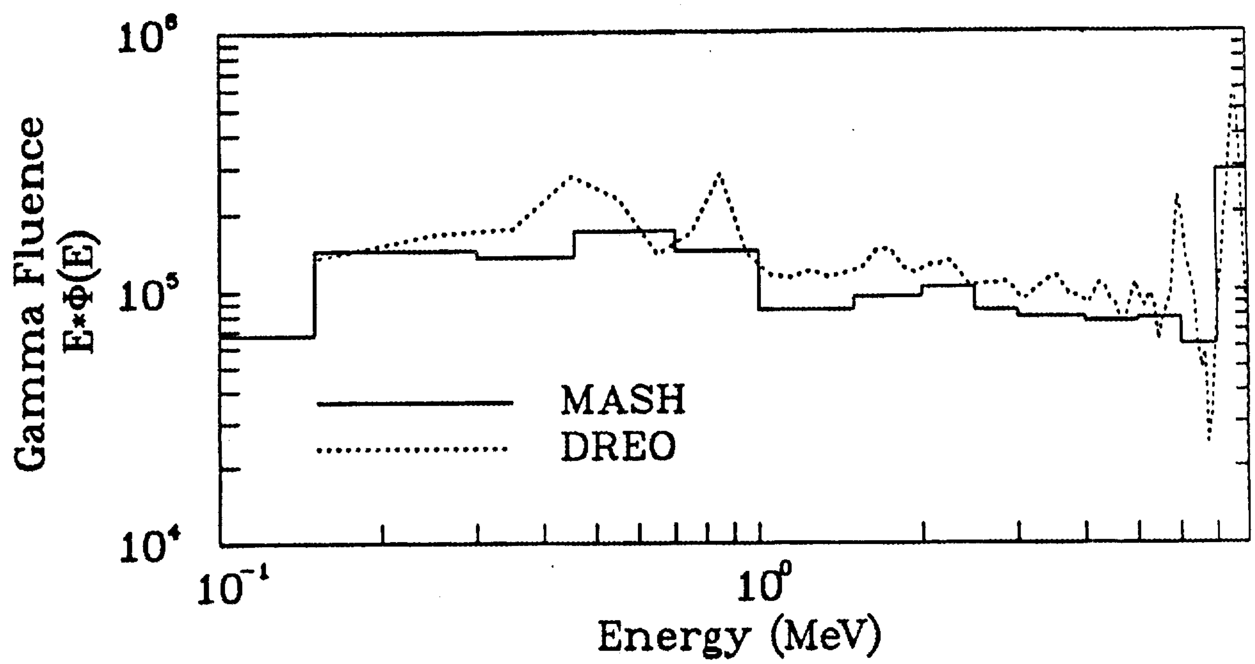

Figure A9. Measured and Calculated Gamma-Ray In-Box Spectra at 400 Meters. Measured Data Reported by DREO. Calculated Results Obtained by ORNL using the MASH Code.

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