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NEUTRON AND GAMMA RADIATION MEASUREMENTS AND CALCULATIONS UP TO--ETC(U)
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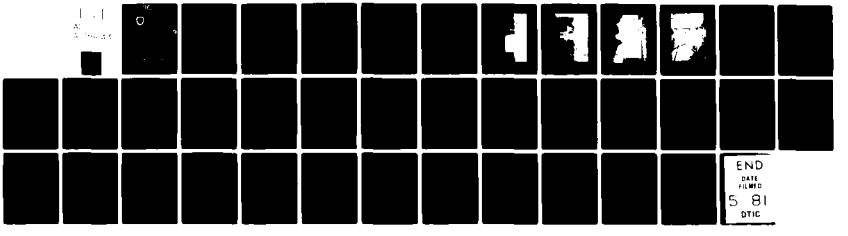

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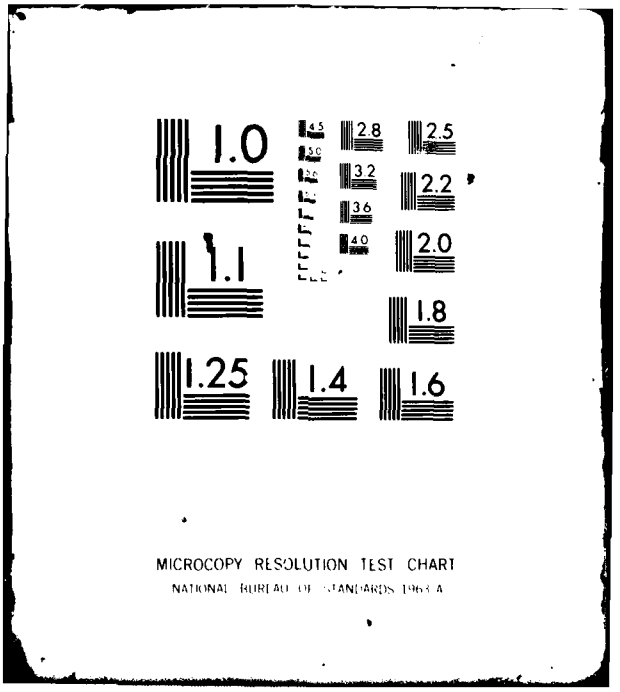
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TECOM PROJECT NO. 7-CO-1LO-API-001
TEST AGENCY REPORT NO. APG-MT-5490
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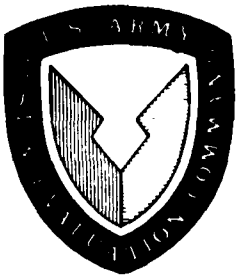
PROGRAM ELEMENT 61101A
PROJECT NO. 1T061101A91A
AGENCY ACCESSION NO. DA 0M1505



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RESEARCH REPORT

NEUTRON AND GAMMA RADIATION MEASUREMENTS AND CALCULATIONS UP TO 1.1 KILOMETERS FROM A FISSION SOURCE

BY

A. H. KAZI
C. R. HEIMBACH
R. C. HARRISON

JANUARY 1981

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US ARMY ABERDEEN PROVING GROUND
ABERDEEN PROVING GROUND, MARYLAND
21005

CONTENTS

SUMMARY

The primary objective of this study was to attempt to verify by experimental data whether state-of-the-art radiation transport codes and models, such as DOT III used by Oak Ridge National Laboratory (ORNL) and the Defence Research Establishment Ottawa (DREO) are suitable for predicting radioactive dose and spectra versus distance for fission nuclear weapons. To accomplish this, neutron and gamma spectra, tissue kerma, and dose were measured and calculated at ranges of 100 to 1100 meters from the Army Pulse Radiation Division's (APRD) reactor at Aberdeen Proving Ground, Maryland. This fast, unshielded reactor simulates a tactical nuclear burst, and was operated outdoors at 14 meters above ground.

It was found that APRD measurements were quite close to those predicted by calculations for total (gamma plus neutrons) kerma. For example, at 170 meter range, the measured kerma was 6.78×10^{-19} rads per source neutron while the calculated value was 6.85×10^{-19}. At 1.1 KM range, the measured value was 1.84×10^{-22} and the calculated value 2.04×10^{-22} rads per source neutron.

In terms of fluence and spectra, however, there were significant differences between calculations and measurements. For example, there was a 30 to 40% greater measured dose for fast ($\geq$ 3 MeV) neutrons than was predicted by calculations at 100 to 400 m. However, improvement was shown at 1.1 KM where measured exceeded calculated by only 9%.

This effort was accomplished in collaboration with scientists from the DREO, Canada. Agreement between the US and Canadian measurements was excellent. APRD uses primarily integral radiation detectors such as ion chambers while DREO used differential spectrometers. These techniques and the calibrations involved are quite different. Agreement in the results is therefore noteworthy.

The present data are also compared to earlier measurements made to a range of 300 meters by scientists from the Wehrwissenschaftliche Dienststelle, Munster, Germany. Agreement with these data is also very good.

It is concluded that, within the state of the art, calculated kerma or dose are close enough to experimental results to consider using existing transport theory codes for typical applications such as dose versus range for fission nuclear weapons. Caution must be exercised when these codes are used to determine differential quantities such as neutron or gamma spectra and fluences.

It is premature to suggest that changes be made to current codes or cross sections. Further data are required at the larger ranges with better accuracy and energy resolution, particularly in the energy range below 0.8 MeV. This requirement is currently being investigated.

It is also concluded that agreement between current US, Canadian and German radiation measurement techniques is excellent. These techniques can be used with good confidence for experimental tests and other applications in a simulated tactical nuclear environment.

1.0 INTRODUCTION

1.1 Technical Objective and Approach

This report summarizes work performed under the Materiel Testing Directorate's In-House Laboratory Independent Research (ILIR) Program, Task 9: "Basic Studies in Dosimetry and Spectroscopy at Large Distances from a Fission Source".

The technical objective of this task is to provide accurate experimental benchmark quality neutron and gamma radiation data which can be used to evaluate theoretical radiation transport models as well as to characterize a simulated tactical nuclear radiation test environment. The calculation of the neutron and gamma radiation environment from a nuclear weapon requires the ability to solve the problem of radiation transport over an air-ground interface. Such data are basic to all determinations of radiation shielding and nuclear vulnerability and survivability. Validation of these models is necessary before the calculations can be relied upon to provide results upon which military decisions can be based. There are also many instances in which calculations by themselves are inadequate and where an accurately characterized test environment is required. An example of current concern is the design and evaluation of various liners or shields which can improve the radiation protection provided by armored vehicles to their crews.

To attain this objective, use is made of the Army Pulse Radiation Divisions's (APRD) reactor which is a unique facility to provide such benchmark tests. The APRD reactor is a small bare all-metal critical assembly which can be readily operated outdoors 14m above ground to simulate an in-air nuclear weapon burst. The terrain surrounding the facility, and often times the weather, is typical of central Europe. Neutron and gamma spectra, kerma and dose are measured at ranges of 100m to 1.1 Km from the reactor, and compared with radiation transport calculations.

1.2 Canadian Participation

The present measurements and calculations were made in collaboration with Dr. H. Alan Robitaille and his collegues from the Defence Research Establishment Ottawa (DREO), Canada. In addition, a series of measurements was also made by Dr. Ross C. Hirning and his collegues, also from DREO, to determine the LET (Linear Energy Transfer) neutron and gamma spectra inside an anthropomorphic phantom. The phantom was positioned at various orientations at 15m from the reactor, and at one orientation at a range of 170m from the reactor. It is expected that LET measurements inside a phantom, and in the corresponding free field position, might result in a technique to determine radiation protection factors which can be better correlated with radiobiological data.

The above joint measurements were made as a preliminary implementation of a US/CA Memorandum of Understanding for a Collaborative Research Project on Radiation Shielding Capabilities of Armored Combat Vehicles, which is currently in the final stages of ratification. In addition to the present report, the results of both sets of Canadian experiments will be reported separately by DREO. Figures 1-4 show the US and Canadian equipment in place at APRD.

1.3 Measurement Techniques

The APRD measurements made use of tissue equivalent ionization chambers and Geiger Müller counters to determine total and gamma tissue kerma (kinetic energy released in matter) respectively. These detectors have been previously described and validated.[1] The neutron kerma is given by the difference between the total and gamma kerma. Differential spectra as well as particle fluences are obtained with an NE 213 neutron and gamma spectrometer. APRD also uses gold foils to determine thermal neutron flux and sulfur pellets to determine the $\geq$ 3 MeV neutron fluence.

DREO also uses an NE 213 spectrometer, however data reduction and spectrum unfolding are different from that used by APRD. DREO also uses a bare and cadmium covered boron trifluoride counter. These data can be used to obtain a good approximation to the total neutron spectrum from thermal energies to $\sim$ 10 MeV. A bare boron trifluoride detector is senstive to thermal and near-thermal (epithermal) neutrons. The cadmium covered detector is sensitive only to the epithermal neutrons. The epithermal flux is obtained by assuming that the spectrum below 0.8 MeV has the shape

$$\phi(E) = AE^{\alpha}$$

The constants A and α are obtained from the measured NE 213 flux at 0.8 MeV and the total epithermal flux given by the boron trifluoride detector. α is usually close to minus one. That is, as is to be expected in the present case, the spectra vary approximately as 1/E.

The DREO calculation is a standard DOT 3 two dimensional discrete ordinate transport calculation using P3-S6 and analytical first collison approximations. The calculation models the reactor ground-over-air interface using an air density of 1.22 g/litre and a hydrogen concentration in the soil of 4.2×10^{-2} atoms per barn-cm. The air hydrogen density was taken as zero. Both the DREO measurements and calculations are described in detail in reference 7.

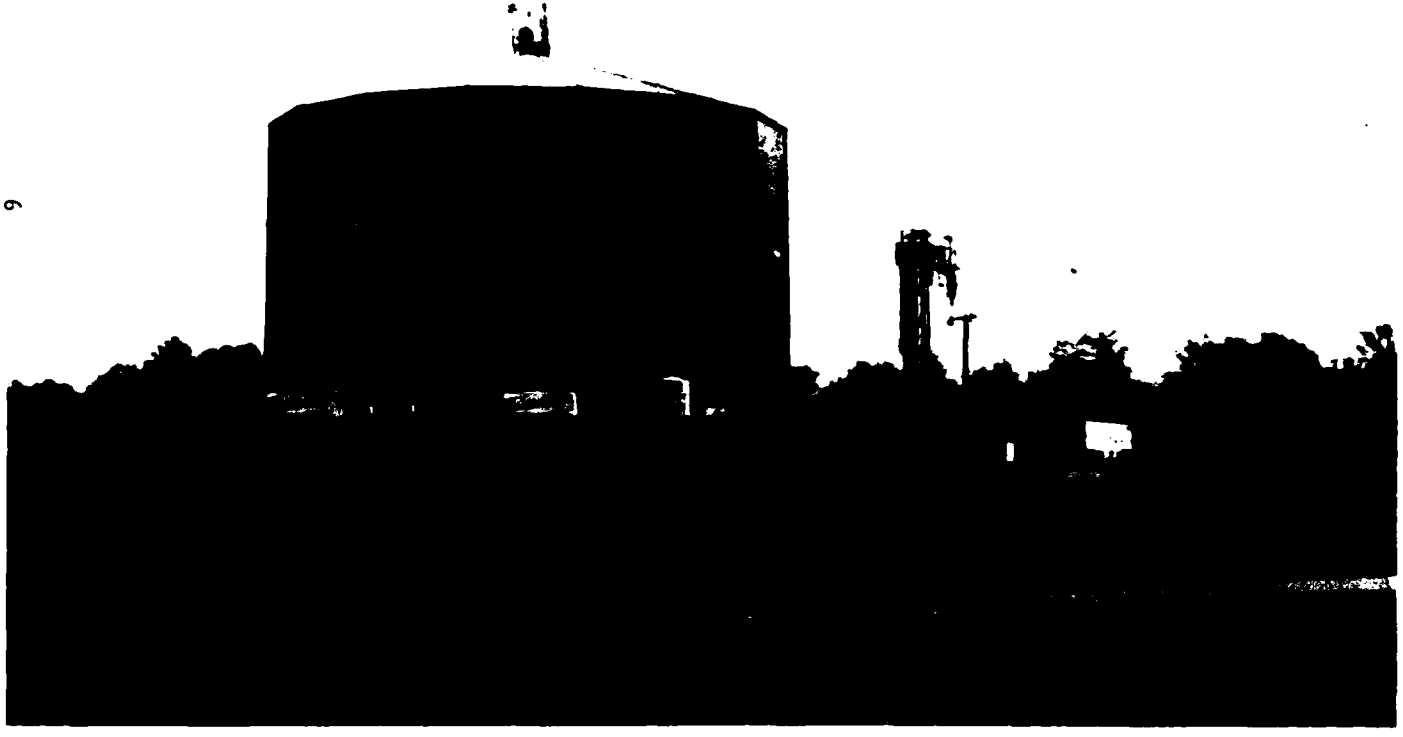

FIGURE 1. APRD Reactor with DREO nuclear instrument van in foreground. This van is used to make spectrum measurements at 1.1 KM range.

FIGURE 2. Set up of NE 213 spectrometer at 170m range. Tissue equivalent ion chamber is on ground at left.

FIGURE 3. US and Canadian radiation detectors in place at 170m range for intercomparison measurements. Tent is used in inclement weather and does not affect data.

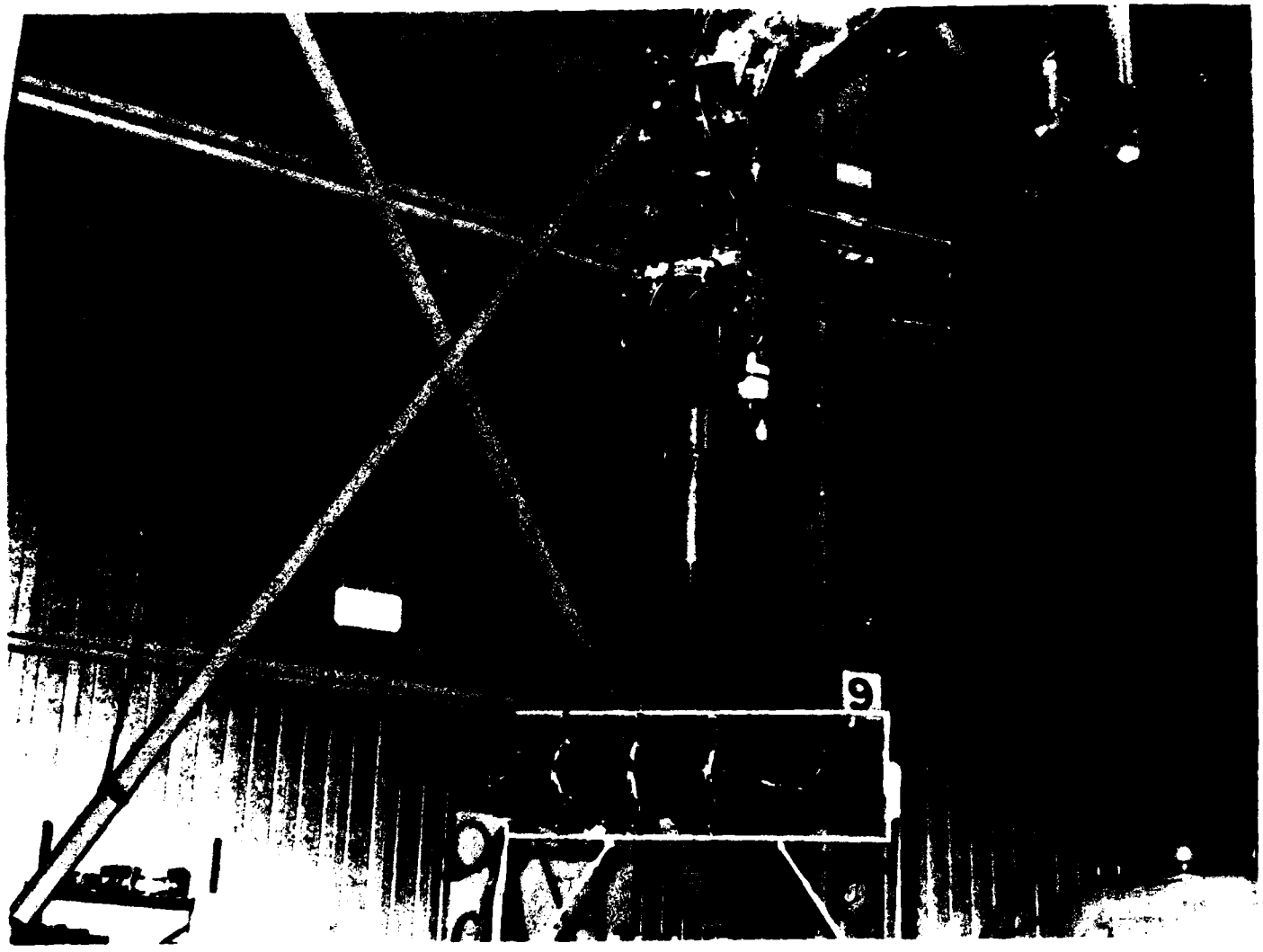

FIGURE 4. DREO anthropomorphic phantom in position underneath APRD reactor.

Actual weather conditions at 1250 hours on 15 October 1980, when the 1.1 Km spectrum measurements were made, were: Temperature 16.0°C, barometric pressure 1023.3 mb, relative humidity 60%, air density 1.2276 Kg/m^3. The sky was clear with broken clouds. Average measured dry soil density was 1.5 g/cm^3. Average water content of soil was 20% by weight. Typical soil composition is given in Annex C of reference 1.

2.0 DETAILS OF MEASUREMENTS

2.1 Measurement of Total Tissue Kerma and Comparison with Calculations

Total tissue kerma (K_T) determinations in the range of 100 to 1100m from the reactor are summarized in Table I and compared in Table II. Overall agreement is excellent. As noted before, the APRD and DREO measurements involve very different techniques, so that this agreement is noteworthy. Agreement of the measurements is also good with two currently available calculations. Both calculations use the DOT transport theory code and the DLC-31 cross sections (8). Otherwise the calculations represent two independent models of the APRD reactor air-over-ground environment. The ORNL calculation was performed by J. Pace (9). The DREO calculation was performed by Robitaille (7). For this calculation the measured-to-calculated K_T ratio at 100m is 1.20 while at 1100m it is 0.80. In between the ratio is very close to unity. The ORNL calculation shows a measured-to-calculated ratio of 0.86 at 400m.

TABLE I. TOTAL TISSUE KERMA (K_T) DETERMINATIONS AS A FUNCTION OF RANGE FROM APRD REACTOR

(Kerma in Rads Per Source Neutron)

Range M	DREO Measurement	APRD Measurement	DREO Calculation	ORNL Calculation
100	2.38×10^{-18}	2.56×10^{-18}	2.06×10^{-18}	2.63×10^{-18}
170	6.81×10^{-19}	6.78×10^{-19}	6.85×10^{-19}	6.90×10^{-19}
300	1.06×10^{-19}	1.14×10^{-19}	1.18×10^{-19}	1.17×10^{-19}
400	3.65×10^{-20}	3.68×10^{-20}	3.79×10^{-20}	4.26×10^{-20}
1100	1.77×10^{-22}	1.84×10^{-22}	2.04×10^{-22}	---

TABLE II. COMPARISON OF APRD AND DREO TOTAL TISSUE KERMA MEASUREMENTS AND CALCULATIONS

Range, M	DREO Meas / APRD Meas	AV Meas / DREO Calc	AV Meas / ORNL Calc
100	0.93	1.20	0.94
170	1.00	0.99	0.98
300	0.93	0.93	0.94
400	0.99	0.97	0.86
1100	0.96	0.80	----
AV RATIO:	0.96	0.98	0.93

2.2 Neutron Kerma Determinations

Neutron kerma determinations are summarized in Table III. The DREO determinations are based on the NE 213 and BF_3 measurements discussed previously. The APRD measurements listed in Table III are obtained by taking the difference between a K_T ion chamber measurement and a gamma kerma K_G measurement obtained with a Geiger counter. The one exception is the 400m data point for which the K_G was determined with an air equivalent ion chamber. The APRD thermal energy range data are based on gold foil activation. As summarized in reference (1), APRD has also made a number of K_N measurements using proton recoil and NE 213 spectroscopy. These are generally in good agreement with the data of Table III.

In Table III, the fast neutron energy range corresponds to the range measured with NE 213, which is $\geq$ 550 keV. The thermal energy ranges corresponds to $\leq$ 0.414 ev. The rest is the epithermal range.

The WWD data are the NE 213 measurements made by Schänzler and his group as reported in reference (1). Overall agreement is reasonable. Thus at 170m the average fast neutron kerma is (4.34 ± 15%) 10^{-19} rads per source neutron. The ratios of the measured DREO to APRD thermal and total neutron kerma are given in Table IV. Agreement is satisfactory. A comparison between measured and calculated values is given in Table V. The DREO 100m calculated point appears low, and at the larger ranges the calculations appear to be systematically slightly high. At 1100m the measured thermal neutron dose is less than half of the calculated value. Overall, there is satisfactory agreement among all these measurements and calculations.

2.3 Gamma Kerma Determinations

Gamma kerma measurements and calculations are summarized in Table VI. Both the DREO and WWD data are obtained with NE 213 spectrometers, using however different data reduction techniques. Agreement is excellent. The APRD data are obtained with a Geiger Müller counter, except for the 400m value which is obtained from an air equivalent ionization chamber. Agreement is very good with the NE 213 data except at 1100m where the APRD value is 12% higher. This APRD measurement at 1100m is not very accurate mainly due to poor counting statistics of the Geiger counter.

Agreement between the two sets of calculations, and between the calculations and the measurements, is reasonable but not as good as was the case with total and neutron kerma. This is probably due at least in part to the influence of different ground and air composition on the production of capture gamma rays. Overall, agreement is acceptable.

TABLE III. NEUTRON KERMA (K_N) DETERMINATIONS

(Kerma in Rads Per Source Neutron)

Range M		DREO Measurement	APRD Measurement	WWD Measurement	DREO Calculated	ORNL Calculated
100	Thermal	7.73×10^{-21}	7.9×10^{-21}		6.22×10^{-21}	
	Epithermal	6.36×10^{-19}			4.35×10^{-19}	
	Fast	1.35×10^{-18}		1.72×10^{-18}	1.27×10^{-18}	
	TOTAL	2.00×10^{-18}	2.24×10^{-18}		1.71×10^{-18}	2.17×10^{-18}
170	Thermal	2.79×10^{-21}	2.6×10^{-21}		2.80×10^{-21}	
	Epithermal	1.83×10^{-19}	1.99×10^{-19}		1.60×10^{-19}	
	Fast	3.64×10^{-19}	4.92×10^{-19}	4.46×10^{-19}	4.12×10^{-19}	
	TOTAL	5.49×10^{-19}	5.53×10^{-19}		5.75×10^{-19}	5.51×10^{-19}
300	Thermal	6.63×10^{-22}	6.7×10^{-22}		5.78×10^{-22}	
	Epithermal	2.60×10^{-20}			2.79×10^{-20}	
	Fast	5.07×10^{-20}		6.31×10^{-19}	6.78×10^{-20}	
	TOTAL	7.73×10^{-20}	8.75×10^{-20}		9.62×10^{-20}	9.54×10^{-20}
400	Thermal	2.32×10^{-22}	2.1×10^{-22}		2.21×10^{-22}	
	Epithermal	8.78×10^{-21}			8.82×10^{-21}	
	Fast	1.65×10^{-20}			2.04×10^{-20}	
	TOTAL	2.55×10^{-20}	2.64×10^{-20}		2.94×10^{-20}	3.11×10^{-20}
1100	Thermal	7.05×10^{-25}			1.77×10^{-24}	
	Epithermal	3.35×10^{-23}			3.94×10^{-23}	
	Fast	5.88×10^{-23}			7.22×10^{-23}	
	TOTAL	9.30×10^{-23}	8.27×10^{-23}		1.13×10^{-22}	

TABLE IV. RATIOS OF MEASURED DREO-TO-APRD THERMAL AND TOTAL NEUTRON KERMA

Range, M	DREO/APRD Thermal	DREO/APRD Total
100	0.98	0.89
170	1.07	0.99
300	0.99	0.88
400	1.10	0.97
1100	----	1.12
AV:	1.04	0.97
	±6%	±10%

TABLE V. RATIOS OF AVERAGE MEASURED TOTAL NEUTRON KERMA TO CALCULATIONS

Range, M	Measured / DREO Calc.	Measured / ORNL Calc.
100	1.24	0.98
170	0.96	1.00
300	0.86	0.86
400	0.88	0.84
1100	0.78	----

TABLE VI. GAMMA KERMA (K_G) DETERMINATIONS

(Kerma in Rads per Source Neutron)

Range M	DREO Measurement	APRD Measurement	WWD Measurement	DREO Calculated	ORNL Calculated
100	3.84×10^{-19}	3.23×10^{-19}	3.89×10^{-19}	3.50×10^{-19}	4.61×10^{-19}
170	1.32×10^{-19}	1.25×10^{-19}	1.34×10^{-19}	1.10×10^{-19}	1.39×10^{-19}
300	2.87×10^{-20}	2.60×10^{-20}	2.67×10^{-20}	2.20×10^{-20}	2.14×10^{-20}
400	1.10×10^{-20}	1.04×10^{-20}	---	8.47×10^{-21}	1.15×10^{-20}
1100	8.39×10^{-23}	1.01×10^{-22}	---	9.02×10^{-23}	---

2.4 Spectrum and Fluence Measurements

Annex A lists the differential neutron and gamma spectra measured by DREO at 100 to 1100 meters range. An APRD neutron spectrum measurement made on 24 November 1980 at 170m range is listed in Table VII. This spectrum is based, similarly to the DREO data, on NE 213 above ~800 keV and on BF_3 data for the epithermal energy range. The total number of particles of 8.70×10^{-10} neutrons per source neutron agrees with the DREO value of 8.68×10^{-10} (Table A3). As seen from the DREO/APRD ratio shown in Table VII, the shape of the two spectral determinations varies with DREO being higher at the higher energies, where statistics are poor, to somewhat lower at middle energies where most of the neutrons are.

The $\geq$ 3 MeV neutron fluence can be obtained from both NE 213 spectrometer data or from sulfur pellet activation. $\geq$ 3 MeV data are compared in Table VIII. Two sets of sulfur measurements using 2.54 and 5.08 cm diameter pellets were made by APRD in September 1980. An earlier measurement was made in 1978. German WWD measurements are given in reference ( ). Note the very good agreement between the Canadian and the German measurements. Although both groups use NE 213, the analysis and data treatment is quite different. The overall agreement of all measurements is quite good. It is well within ±15%. The agreement between the two sets of $\geq$ 3 MeV fluence calculations is good, however both calculations are well below the average measured values. This discrepancy does not increase with increasing range. Indeed, at 1.1 KM agreement between the measured and calculated DREO values is good.

3.0 CONCLUSIONS

The present measurements have demonstrated that good quality neutron and gamma spectrum and kerma measurements can be made to as far as 1.1 KM from a fission source. At this distance, simulation of an actual tactical nuclear environment is very good. Also, this presents a good case for comparison with calculations.

The approximate method to determine the epithermal neutron spectrum, as developed by DREO, appears to be satisfactory for the present conditions and is useful to determine quantities such as mid head dose which show a significant response in the epithermal energy range.

Further work is required to obtain good Geiger Müller counter data at 1.1 KM. The presently used counters are small and have poor statistics. Further work is also required to better correlate soil and weather data with the radiation measurements. Present indications are that effects can be significant, but the available data are inconclusive.

TABLE VII. APRD MEASURED NEUTRON SPECTRUM AT 170M

Group*	Particles per Group $\phi(E)\Delta E$	DREO/APRD Group Ratio
1-7	0	---
8	8.13-14	1.06
9	1.48-13	1.48
10	2.65-13	1.23
11	3.82-13	1.23
12	1.00-12	1.30
13	3.31-12	1.29
14	1.03-12	1.18
15	3.86-12	1.05
16	8.36-12	1.21
17	1.42-11	0.91
18	2.56-12	0.93
19	1.87-11	0.86
20	3.84-11	0.83
21	6.16-11	0.81
22	8.94-11	0.95
23	2.54-11	0.88
24	4.94-11	0.92
25	4.57-11	0.93
26	7.51-12	0.90
27	4.19-11	0.95
28	5.40-11	1.01
29	4.37-11	1.00
30	3.07-11	1.02
31	5.42-11	1.18
32	3.58-11	1.12
33	2.62-11	1.11
34	2.82-11	1.17
35	2.06-11	1.16
36	1.87-11	1.18
37	1.45-10	1.02
SUM	9.70-10	1.00

* Energy group structure as given in reference 8.

TABLE VIII. COMPARISON OF $\geq$ 3 MeV NEUTRON FLUENCE DETERMINATIONS AS A FUNCTION OF RANGE

(neutrons per cm^2 and per source neutron)

Range M	APRD Sulfur System Sept '80 (2.54cm Pellets)	APRD Sulfur System Sept '80 (5.08cm Pellets)	1978 (a)	APRD NE 213	WWD NE 213	DREO NE 213
100	8.35×10^{-11}	9.60×10^{-11}	9.24×10^{-11}	9.35×10^{-11} (a)	8.20×10^{-11}	8.72×10^{-11}
170	2.32×10^{-11}	2.38×10^{-11}	2.52×10^{-11}	2.31×10^{-11} (b)	2.12×10^{-11}	2.23×10^{-11}
300	3.90×10^{-12}	3.23×10^{-12}	4.24×10^{-12}	3.79×10^{-12} (a)	2.86×10^{-12}	3.14×10^{-12}
400	---	1.0×10^{-12}	---	---	---	9.94×10^{-13}
1100	---	---	---	---	---	3.27×10^{-15}

Range M	Average All Measurements	DREO Calc	ORNL Calc (c)	AV Calc	AV Meas / AV Calc
100	8.89×10^{-11} (±7%)	6.62×10^{-11}	7.32×10^{-11}	6.98×10^{-11}	1.27
170	2.31×10^{-11} (±6%)	1.71×10^{-11}	1.67×10^{-11}	1.69×10^{-11}	1.37
300	3.51×10^{-12} (±15%)	2.40×10^{-12}	2.65×10^{-12}	2.53×10^{-12}	1.39
400	1.0×10^{-12}	7.90×10^{-13}	---	7.90×10^{-13}	1.27
1100	3.27×10^{-15}	3.01×10^{-15}	---	3.01×10^{-15}	1.09

(a) From reference (1).
(b) Average of value of reference (1) and August and November 1980 measurements.
(c) Reference (9).

Agreement between calculations and measurements are good in terms of kerma. Significant discrepancies can occur when comparisons are made in terms of fluence and spectra. Presently available results show 30 to 40% more measured than calculated fast ($\geq$3MeV) neutron fluence at 100 to 400m. However, this discrepancy does not necessarily get worse with range: At 1.1 KM the measured fast fluence agrees with the single calculated value within 9%. While this good agreement could be fortuitous, it does show that both measurements and calculations are on the whole reasonable. In summary, state-of-the-art experimental and theoretical radiation transport methods can be satisfactory enough so that they can be used as required for specific applications.

4.0 REFERENCES

1. A. H. Kazi, C. R. Heimbach, R. C. Harrison, L. Schänzler and F. W. Buchholz, "Measurements of the Free Field Radiation Environment at the APRD Reactor", Report APG-MT-5279, July 1979.

2. A. H. Kazi, C. R. Heimbach, R. C. Harrison, L. Schänzler, F. W. Buchholz and S. Stücker, "Measurement of the Initial Radiation Protection Factors of the M60A1 Tank", Report APG-MT-5277, July 1979.

3. A. H. Kazi, C. R. Heimbach, R. C. Harrison, "Measurement of the Initial Radiation Protection Factor of the XM-1 Tank," Interim Test Report, TECOM Project No. 2-CO-435-000-019, 8 January 1979.

4. C. R. Heimbach, R. C. Harrison, A. H. Kazi, "XM1 Radiation Shielding Demonstration Experiment (U)," Report APG-MT-5430, August 1980, Confidential.

5. C. R. Heimbach, "Measurement of the Initial Radiation Protection Factors of the M113A1 Armored Personnel Carrier (U)," Report APG-MT-5329, February 1980, Confidential.

6. A. H. Kazi, C. R. Heimbach, R. C. Harrison, "Interim Progress Report #1: Nuclear Vulnerability of the XM2/XM3: Initial Radiation Protection Factors," 29 December 1980, Army Pulse Radiation Division, Materiel Testing Directorate, Aberdeen Proving Ground, MD, 21005. Unpublished.

7. H. A. Robitaille and B. E. Hoffarth, "A Comparison of Measured and Calculated Air-Transported Radiation From A Fast, Unshielded Nuclear Reactor", DREO Report 835, Defence Research Establishment Ottawa, Canada, (December 1980).

8. D. E. Bartine et al, "Production and Testing of the DNA Few-Group Coupled Neutron-Gamma Cross Section Library," ORNL/TM-4840 (March 1977).

9. A. H. Kazi, C. R. Heimbach, L. Schänzler, J. V. Pace III, A. E. Rainis, "Comparison of Experimental Radiation Transport with Calculation," Trans. American Nuclear Society 33: 706 (November 1979).

ANNEX A

DREO MEASURED NEUTRON AND GAMMA SPECTRA AT 100, 170, 300, 400 AND 1100M

(All Data Normalized Per Source Neutron)

TABLE A1. NEUTRON SPECTRUM AT 100M

Group *	Particles/Group	E * PHI (E)
1	0.0000	0.0000
2	0.0000	0.0000
3	0.0000	0.0000
4	0.0000	0.0000
5	0.0000	0.0000
6	0.0000	0.0000
7	0.0000	0.0000
8	3.4838E-13	3.3383E-12
9	7.1144E-13	7.1272E-12
10	1.3244E-12	1.3264D-11
11	1.8339E-12	1.8324E-11
12	4.4111E-12	2.9474E-11
13	1.5975E-11	6.3964E-11
14	4.8405E-12	9.3788E-11
15	1.5697E-11	1.0594E-10
16	4.0949E-11	1.3573E-10
17	4.7551E-11	2.0616E-10
18	8.5972E-12	2.5252E-10
19	5.8160E-11	2.4969E-10
20	1.1970E-10	2.3942E-10
21	1.8109E-10	2.9436E-10
22	2.9995E-10	2.4047E-10
23	7.7463E-11	2.1940E-10
24	1.5434E-10	2.0613E-10
25	1.4197E-10	1.8931E-10
26	2.2394E-11	1.8006E-10
27	1.2926E-10	1.7136E-10
28	1.7305E-10	1.5407E-10
29	1.3471E-10	1.3665E-10
30	9.4959E-11	1.2366E-10
31	1.8761E-10	1.0733E-10
32	1.1288E-10	9.0460E-10
33	7.9367E-11	7.9602E-11
34	8.7721E-11	7.0074E-11
35	6.1417E-11	6.1652E-11
36	5.5254E-11	5.5028E-11
37	4.1065E-10	3.8627E-11
SUM	2.7242E-09	

* Energy group structure as given in reference 8.

TABLE A2. GAMMA SPECTRUM AT 100M

Group *	Particles/Group	E * PHI (F)
1	0.0000	0.0000
2	0.0000	0.0000
3	1.0806E-11	8.0925E-11
4	1.3946E-11	9.0472E-11
5	1.5054E-11	8.2567E-11
6	1.9684E-11	8.8214E-11
7	2.7506E-11	9.5612E-11
8	1.9690E-11	1.0800E-10
9	5.3116E-11	2.3803E-10
10	6.6243E-11	2.3026E-10
11	6.8889E-11	1.6990E-10
12	5.5377E-11	1.5526E-10
13	1.0607E-10	2.4007E-10
14	1.2145E-10	2.9954E-10
SUM:	5.7784E-10	

* Energy group structure as given in reference 8.

TABLE A3. NEUTRON SPECTRUM AT 170M

Group	Particles/Group	E * PHI (E)
1	0.0000	0.0000
2	0.0000	0.0000
3	0.0000	0.0000
4	0.0000	0.0000
5	0.0000	0.0000
6	0.0000	0.0000
7	0.0000	0.0000
8	8.6475E-14	8.2862E-13
9	2.1929E-13	2.1969E-12
10	3.2681E-13	3.2729E-12
11	4.6950E-13	4.6911E-12
12	1.2986E-12	8.6766E-12
13	4.2614E-12	1.7063E-11
14	1.2166E-12	2.3573E-11
15	4.0710E-12	2.7476E-11
16	1.0103E-11	3.3486E-11
17	1.2961E-11	5.6194E-11
18	2.3930E-12	7.0288E-11
19	1.5975E-11	6.8583E-11
20	3.2038E-11	6.4082E-11
21	5.0054E-11	8.1364E-11
22	8.5039E-11	6.8178E-11
23	2.2438E-11	6.3553E-11
24	4.5358E-11	6.0580E-11
25	4.2560E-11	5.6748E-11
26	6.7918E-12	5.4615E-11
27	3.9657E-11	5.2572E-11
28	5.4418E-11	4.8450E-11
29	4.3562E-11	4.1189E-11
30	3.1430E-11	4.0931E-11
31	6.4161E-11	3.6707E-11
32	4.0176E-11	3.2197E-11
33	2.9103E-11	2.9189E-11
34	3.3133E-11	2.6468E-11
35	2.3901E-11	2.3992E-11
36	2.2078E-11	2.1988E-11
37	1.4836E-10	1.3955E-11
SUM:	8.6764E-10	

TABLE A4. GAMMA SPECTRUM AT 170M

Group	Particles/Group	E * PHI (E)
1	0.0000	0.0000
2	0.0000	0.0000
3	3.5263E-12	2.6406E-11
4	4.9172E-12	3.1899E-11
5	5.3699E-12	2.9453E-11
6	7.8191E-12	3.5040E-11
7	9.2258E-12	3.2069E-11
8	6.2952E-12	3.4528E-11
9	1.8719E-11	8.3880E-11
10	2.3074E-11	8.0205E-11
11	2.1528E-11	5.3095E-11
12	1.7767E-11	4.9614E-11
13	3.5780E-11	8.0980E-11
14	4.2194E-11	1.0406E-10
SUM:	1.9622E-10	

TABLE A5. NEUTRON SPECTRUM AT 300M

Group	Particles/Group	E * PHI (E)
1	0.0000	0.0000
2	0.0000	0.0000
3	0.0000	0.0000
4	0.0000	0.0000
5	0.0000	0.0000
6	0.0000	0.0000
7	0.0000	0.0000
8	1.8261E-14	1.7468E-13
9	3.4953E-14	3.5016E-13
10	4.6074E-14	4.6143E-13
11	8.2794E-14	8.2725E-13
12	1.9060E-13	1.2735E-12
13	6.6619E-13	2.6674E-12
14	2.0886E-13	4.0468E-12
15	5.1913E-13	3.5037E-12
16	1.3048E-12	4.3249E-12
17	1.8942E-12	8.2125E-12
18	3.5494E-13	1.0425E-11
19	2.3657E-12	1.0156E-11
20	4.2756E-12	8.5519E-12
21	6.7778E-12	1.1017E-11
22	1.1888E-11	9.5304E-12
23	3.2127E-12	9.0995E-12
24	6.6006E-12	8.8159E-12
25	6.3324E-12	8.4436E-12
26	1.0239E-12	8.2332E-12
27	6.0559E-12	8.0280E-12
28	8.5433E-12	7.6083E-12
29	7.0564E-12	7.1579E-12
30	5.2255E-12	6.8052E-12
31	1.1067E-11	6.3318E-12
32	7.2467E-12	5.8074E-12
33	5.4275E-12	5.4435E-12
34	6.3877E-12	5.1027E-12
35	4.7643E-12	4.7825E-12
36	4.5334E-12	4.5149E-12
37	3.5186E-11	3.3097E-12
SUM:	1.4929E-10	

TABLE A6. GAMMA SPECTRUM AT 300M

Group	Particles/Group	E * PHI (E)
1	0.0000	0.0000
2	0.0000	0.0000
3	9.2520E-13	6.9287E-12
4	9.8241E-13	6.3731E-12
5	1.2539E-12	6.8775E-12
6	1.8073E-12	8.0992E-12
7	1.8201E-12	6.3268E-12
8	1.3483E-12	7.3951E-12
9	4.6257E-12	2.0730E-11
10	5.1477E-12	1.7894E-11
11	4.1712E-12	1.0287E-11
12	3.2336E-12	9.0659E-12
13	7.1659E-12	1.6218E-11
14	8.5296E-12	2.1037E-11
SUM:	4.1011E-11	

TABLE A7. NEUTRON SPECTRUM AT 400M

Group	Particles/Group	E * PHI (E)
1	0.0000	0.0000
2	0.0000	0.0000
3	0.0000	0.0000
4	0.0000	0.0000
5	0.0000	0.0000
6	0.0000	0.0000
7	0.0000	0.0000
8	8.4996E-15	8.1445E-14
9	1.1479E-14	1.1500E-13
10	1.7346E-14	1.7372E-13
11	2.7654E-14	2.7631E-13
12	7.2055E-14	4.8145E-13
13	2.3614E-13	9.4551E-13
14	6.1466E-14	1.1909E-12
15	1.5464E-13	1.0437E-12
16	3.8924E-13	1.2902E-12
17	6.2990E-13	2.7310E-12
18	1.1863E-13	3.4845E-12
19	7.6770E-13	3.2958E-12
20	1.3749E-12	2.7501E-12
21	2.2380E-12	3.6379E-12
22	3.9816E-12	3.1921E-12
23	1.0879E-12	3.0812E-12
24	2.2518E-12	3.0075E-12
25	2.1823E-12	2.9099E-12
26	3.5495E-13	2.8542E-12
27	2.1120E-12	2.7997E-12
28	3.0174E-12	2.6865E-12
29	2.5282E-12	2.5646E-12
30	1.8946E-12	2.4674E-12
31	4.0812E-12	2.3349E-12
32	2.7272E-12	2.1856E-12
33	2.0740E-12	2.0801E-12
34	2.4783E-12	1.9797E-12
35	1.8769E-12	1.8841E-12
36	1.8103E-12	1.8029E-12
37	1.2341E-11	1.1609E-12
SUM:	5.2907E-11	

TABLE A8. GAMMA SPECTRUM AT 400M

Group	Particles/Group	E * PHI (E)
1	0.0000	0.0000
2	0.0000	0.0000
3	3.7951E-13	2.8421E-12
4	3.7357E-13	2.4234E-12
5	5.5050E-13	3.0194E-12
6	6.8073E-13	3.0506E-12
7	7.2600E-13	2.5236E-12
8	5.1534E-13	2.8266E-12
9	1.8648E-12	8.3570E-12
10	1.5476E-12	5.3795E-12
11	1.4238E-12	3.5115E-12
12	1.1306E-12	3.1697E-12
13	2.6939E-12	6.0972E-12
14	3.1111E-12	7.6729E-12
SUM:	1.4997E-11	

TABLE A9. NEUTRON SPECTRUM AT 1100M

Group	Particles/Group	E * PHI (E)
1	0.0000	0.0000
2	0.0000	0.0000
3	0.0000	0.0000
4	0.0000	0.0000
5	0.0000	0.0000
6	0.0000	0.0000
7	0.0000	0.0000
8	3.1482E-17	3.0167E-16
9	5.5554E-17	5.5654E-16
10	3.6175E-17	3.6229E-16
11	8.8060E-17	8.7987E-16
12	2.3342E-16	1.5597E-15
13	8.9029E-16	3.5647E-15
14	2.8512E-16	5.5244E-15
15	6.0965E-16	4.1147E-15
16	1.0376E-15	3.4392E-15
17	2.0630E-15	8.9442E-15
18	4.5975E-16	1.3504E-14
19	2.9161E-15	1.2519E-14
20	5.0392E-15	1.0079E-14
21	8.2786E-15	1.3457E-14
22	1.4990E-14	1.2018E-14
23	4.1603E-15	1.1783E-14
24	8.7040E-15	1.1625E-14
25	8.5595E-15	1.1413E-14
26	1.4042E-15	1.1291E-14
27	8.4260E-15	1.1170E-14
28	1.2260E-14	1.0915E-14
29	1.0485E-14	1.0636E-14
30	7.9931E-15	1.0409E-14
31	1.7642E-14	1.0099E-14
32	1.2139E-14	9.7282E-15
33	9.4355E-15	9.4634E-15
34	1.1524E-14	9.2057E-15
35	8.9207E-15	8.9548E-15
36	8.7734E-15	8.7375E-15
37	3.7419E-14	3.5198E-15
SUM:	2.0486E-13	

TABLE A10. GAMMA SPECTRUM AT 1100M

Group	Particles/Group	E * PHI (E)
1	0.0000	0.0000
2	0.0000	0.0000
3	1.5251E-15	1.1422E-14
4	3.0715E-15	1.9925E-14
5	5.9599E-15	3.2689E-14
6	7.3452E-15	3.2917E-14
7	6.5805E-15	2.2874E-14
8	3.8668E-15	2.1209E-14
9	8.4719E-15	3.7966E-14
10	9.1278E-15	3.1729E-14
11	1.0744E-14	2.6498E-14
12	8.7471E-15	2.4524E-14
13	1.8561E-14	4.2008E-14
14	2.1236E-14	5.2373E-14
SUM:	1.0524E-13	

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: TECOM Project 7CO-ILO-API-001

2. GOVT ACCESSION NO.: AD-A098243

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): NEUTRON AND GAMMA RADIATION MEASUREMENTS AND CALCULATIONS UP TO 1.1 KILOMETERS FROM A FISSION SOURCE.

5. TYPE OF REPORT & PERIOD COVERED: Research Report, Aug-Dec 80

6. PERFORMING ORG. REPORT NUMBER: APG-MT-5490

7. AUTHOR(s): A. H. Kazi, R. C. Harrison, C. R. Heimbach

8. CONTRACT OR GRANT NUMBER(s):

9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Materiel Testing Directorate, Army Pulse Radiation Division, Aberdeen Proving Ground, MD 21005

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Program Element-61101A/Project 1T061101A91A/Task Area-33/Work Unit #001-K2-09

11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Materiel Testing Directorate, Army Pulse Radiation Division, Aberdeen Proving Ground, MD 21005

12. REPORT DATE: 26 Jan 1981

13. NUMBER OF PAGES: 36

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 38

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

This work was performed in cooperation with scientists from the Defence Research Establishment Ottawa (DREO) Canada.

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Radiation Transport	Spectroscopy
Neutrons	Tactical Nuclear Simulation
Gammas	Army Pulse Radiation Facility
Dosimetry	Radiation Shielding

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The primary objective of this study was to attempt to verify by experimental data whether state-of-the-art radiation transport codes and models, such as DOT TII used by Oak Ridge National Laboratory (ORNL) and the Defence Research Establishment Ottawa (DREO) are suitable for predicting radioactive dose and spectra versus distance for fission nuclear weapons. To accomplish this, neutron and gamma spectra, tissue kerma, and dose were measured and calculated at ranges of 100 to 1100 meters from the Army Pulse Radiation Division's (APRD)

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reactor at Aberdeen Proving Ground, Maryland. This fast, unshielded reactor simulates a tactical nuclear burst, and was operated outdoors at 14 meters above ground.

It was found that APRD measurements were quite close to those predicted by calculations for total (gamma plus neutrons) kerma. For example, at 170 meter range, the measured kerma was 6.78×10^{-19} rads per source neutron while the calculated value was 6.85×10^{-19}. At 1.1 KM range, the measured value was 1.84×10^{-22} and the calculated value 2.04×10^{-22} rads per source neutron.

In terms of fluence and spectra, however, there were significant differences between calculations and measurements. For example, there was a 30 to 40% greater measured dose for fast ($\geq$ 3 MeV) neutrons than was predicted by calculations at 100 to 400 m. However, improvement was shown at 1.1 KM where measured exceeded calculated by only 9%.

This effort was accomplished in collaboration with scientists from the DREO, Canada. Agreement between the US and Canadian measurements was excellent. APRD uses primarily integral radiation detectors such as ion chambers while DREO used differential spectrometers. These techniques and the calibrations involved are quite different. Agreement in the results is therefore noteworthy.

The present data are also compared to earlier measurements made to a range of 300 meters by scientists from the Wehrwissenschaftliche Dienststelle, Munster, Germany. Agreement with these data is also very good.

It is concluded that, within the state of the art, calculated kerma or dose are close enough to experimental results to consider using existing transport theory codes for typical applications such as dose versus range for fission nuclear weapons. Caution must be exercised when these codes are used to determine differential quantities such as neutron or gamma spectra and fluences.

It is premature to suggest that changes be made to current codes or cross sections. Further data are required at the larger ranges with better accuracy and energy resolution, particularly in the energy range below 0.8 MeV. This requirement is currently being investigated.

It is also concluded that agreement between current US, Canadian and German radiation measurement techniques is excellent. These techniques can be used with good confidence for experimental tests and other applications in a simulated tactical nuclear environment.

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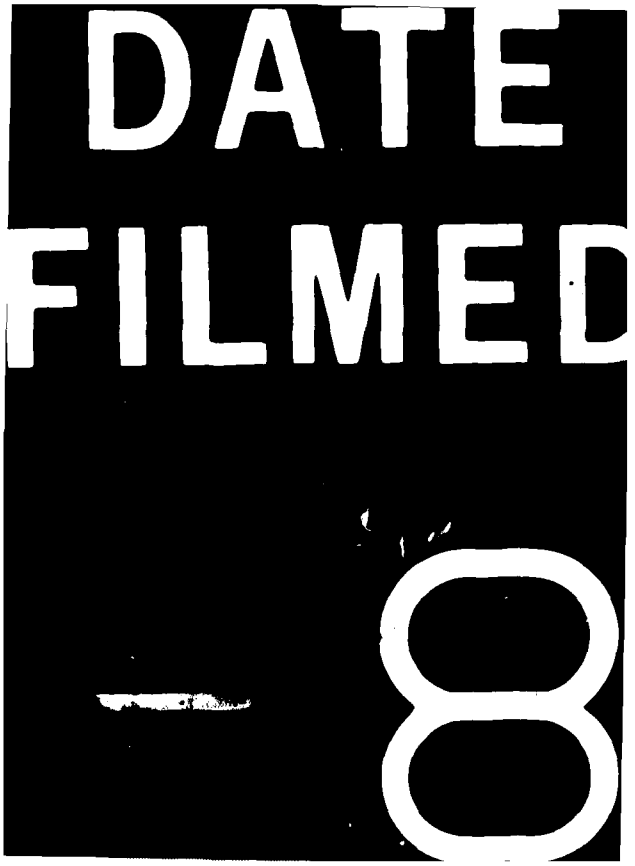
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