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TITLE: SOURCE TERMS FOR THE INITIAL RADIATIONS

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SUBMITTED TO: US-JAPAN JOINT WORKSHOP ON THE REASSESSMENT OF A-BOMB RADIATION DOSIMETRY IN HIROSHIMA AND NAGASAKI

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SOURCE TERMS FOR THE INITIAL RADIATION *

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I. Introduction

The Los Alamos National Laboratory is supporting the United States Department of Energy Working Group for the Reassessment of A-Bomb Dosimetry. One Los Alamos task is to provide calculations of the prompt neutron and gamma-ray outputs of the Hiroshima and Nagasaki bombs and to provide calibration data to support these calculations. Another Los Alamos task is to provide estimates with uncertainties of the yields of the Hiroshima and Nagasaki explosions.

Calibration data for the Nagasaki bomb output calculation consists of the calculated outputs of several other test nuclear devices of the Nagasaki type for which dose measurements were obtained in test explosions. With this information, the entire Nagasaki dose calculational sequence can be repeated for the test explosions and the validity of the results established by comparison with the test observations.

Calibration data for the Hiroshima bomb output calculation consists of spectral measurements of the neutron and gamma-ray outputs of a replica of the Hiroshima bomb operated as a critical assembly. The replica is installed at the Los Alamos Critical Assembly (LACAF) and one set of measurements has been completed. In addition to these measurements, output calculations have been done for the Grable test device to allow comparisons with the doses measured on the Grable explosion.

*Work performed under the auspices of the U. S. Department of Energy.

II. Background

The wartime use of nuclear weapons is shown in Table I.

TABLE I

WARTIME USE

	HIROSHIMA	NAGASAKI
Date	Aug. 6, 1945	Aug. 9, 1945
Weapon	Little Boy	Fat Man
Yield (kT)	12 - 20	22 ± 2
Height of burst (m)	580	503

The two weapons were of radically different design. The Hiroshima bomb was a gun-assembled uranium design which was very two-dimensional in character. The Nagasaki bomb was an implosion assembled plutonium design which was nearly spherical. The Nagasaki-type design was tested in the Trinity event and used in the Cross Roads Able and Baker tests. Some radiation-exposure data are available from these tests and from other test firings of similar weapons. In contrast, there was no test firing of the Hiroshima-type weapon and there have been no test firings of similar weapons.

Photographs of the Hiroshima and Nagasaki bombs are shown in Figures 1 and 2.

III. Calculations

The output spectra are calculated with classified special purpose computer codes which follow the evolution of the explosions. The neutron and gamma-ray transport is done by Monte Carlo techniques using continuous energy tracking through the moving material of the weapon with a thermal gas treatment for scattering from heated material. The cross sections for the calculation are continuous energy cross sections processed from several sources including the Evaluated Nuclear Data Files (ENDF) library.

IV. Preeg Spectra

In 1975, Dr. W. E. Preeg of Los Alamos did one-dimensional (spherical) calculations of the neutron and gamma-ray output spectra of both the Hiroshima and Nagasaki bombs. The calculations were done for inclusion in the Defense Nuclear Agency (DNA) classified Nuclear Weapons Output Handbook as part of a larger project of providing the output spectra of U.S. weapons of special interest. At the request of Los Alamos, the

Hiroshima and Nagasaki output spectra were declassified by the U. S. Department of Energy in 1976 and released in the form of a letter to Dr. C. P. Knowles (Preeg, 1976). In addition to the output spectra, the letter contained a comparison of dose as a function of distance from model calculations with the dose inferences of Dr. Hashizume et al. The calculated dose-distance relations were from a computer model for infinite dry air and were not very accurate. The Preeg spectra are shown in different displays in Figures 3, 4, 5, and 6. For reference a U^{235} fission spectrum is shown on each Figure. Figure 3 is the usual spectral display which shows the great differences between the three spectra. The fission spectrum is quite hard. The Nagasaki (Fat Man) spectrum contains a large number of neutrons which have been moderated to low energies by the tons of high explosive in the weapon. These low energy neutrons provide a localized source of air capture gammas for a weapon of this type. Figure 4 is the DNA standard output display which splits the abcissa between log and linear to display the high energy portion of the spectrum. The same three spectra are shown again in Figure 5 in the form of the integral of n(E) above E. This display allows one to determine at a glance the total number of output neutrons and the fraction of those neutrons with energy greater than a selected energy. Figure 6 is a similar display of the neutron energy output. That is, the ordinate is the integral of E x n(E) above E. This display allows one to determine at a glance the total output neutron energy and the fraction of that energy above a selected energy. One can see, for instance, that nearly all of the neutron energy (related to dose) of the fission spectrum and of the Nagasaki device is carried by neutrons with energy greater than 1 MeV while only approximately one-third of the neutron energy of the Hiroshima device is carried by neutrons with energy greater than 1 MeV.

V. Nagasaki and Calibration Test Spectra

The calculated (one-dimensional) neutron output spectra for the Nagasaki bomb (Fat Man) and for a calibration test device are shown in Figure 7 and the data are presented in Tables II and III. The results of two Fat Man calculations are presented. These are the 1975 calculation by Dr. Preeg and a 1981 calculation by Dr. R. Streetman. The data are presented in Table II on the Preeg energy grid and in Table III on a finer energy grid used by Dr. Streetman for his output. The agreement between the 1975 and 1981 Fat Man calculations is very good. Interestingly, the test spectrum contains fewer neutrons but a higher total neutron energy.

Similar data for the gamma-ray output spectra are presented in Figure 8 and Tables IV and V. In the case of the gamma-ray output there is a large (factor of two) change in the calculated gamma-ray energy output between the 1975 and 1981 calculations. This is primarily due to changes in cross sections and calculational techniques. The difference in calculated gamma-ray energy is shown more clearly in Figure 9. The effect of this change in calculated output on the dose estimates is small because the contribution of device gamma-rays to the dose is small.

VI. Hiroshima and Test Output Spectra

The neutron output spectra for the Hiroshima (Little Boy) bomb from the Preeg 1975 one-dimensional calculation is compared with the results from a 1982 two-dimensional calculation in Figure 10 and Tables VI and VII. The two-dimensional calculations were done by Dr. J. Kammerdiener and Dr. R. Streetman. In Table VI the results are shown on the Preeg energy grid and in Table VII on an energy grid with more high energy resolution. In the very non-spherical Hiroshima bomb, two dimensional effects reduce the neutron output by 16% from the spherical calculation; from .206 to .177 moles per kiloton. The neutron energy output (dose) is reduced by 21% from .064 to .053 MeV moles per kiloton. Figures 11 and 12 compare the Little Boy one-dimensional and two-dimensional output spectra in terms of neutrons out with energy above E and neutron energy out (approximate dose) with energy above E.

The results of one-dimensional (1975) and two-dimensional calculations of the gamma-ray output spectra of the Hiroshima bomb are presented in Figure 13 and Tables VIII and IX. As a note of caution, some of the low energy gamma rays from the two-dimensional calculation are lost when presented on the grid in Table VIII. The calculated output gamma-ray energy is greatly reduced in the two-dimensional calculation, going from the one-dimensional value .019 to the two-dimensional value of .007 MeV moles per kiloton.

The calculated two-dimensional neutron and gamma ray output is given in Tables IX and X. The output is given in energy bins for 20 equal solid angle bins. Units in the bodies of the tables are moles of neutrons or gamma rays per kiloton.

The direction $\cos\Theta = -1$ is toward the nose of the device; $\cos\Theta = 1$ is toward the tail. The column headings should be read as $(X - 0.1) \leq \cos\Theta \leq X$ with the first entry $-1.0 \leq \cos\Theta \leq 0.9$, and the last entry $0.9 \leq \cos\Theta \leq 1.0$. The column headed total is the sum over the 20 columns in the body of the table $-1.0 \leq \cos\Theta \leq 1.0$.

The Monte Carlo relative error for each entry in the tables is indicated to the right of each entry. The statistics for the neutron table are pretty good except in the two energy bins above 10 MeV where there were only about 6 Monte Carlo particles counted.

The neutron output in the six lower energy bins (<9 keV) has been adjusted on the basis of the 4π output to improve the statistics -- more accurately, the appearance of the statistics. This may be seen in the tables by noticing that the relative errors for all of the cosine bins in these low-energy groups are the same as the relative error of the total. These neutrons represent only three percent of the total number of neutrons and less than 0.1 percent of the output neutron energy.

In the case of the Hiroshima bomb there are no dose measurements made on tests of similar devices. The nearest event for which dose measurements exist was the Upshot-Knothole Grable event. The Grable test device was a gun-assembled device fired as a shell from a 280 mm canon. This shell was much smaller and lighter than the Hiroshima bomb and the calculated (two-dimensional) spectral output of the Grable device is much different from that of the Hiroshima bomb, Figure 14.

Simply because the Hiroshima bomb is so massive, however, one would expect the high energy part of the output neutron spectrum to be primarily determined by the transmission of neutrons from the fissioning region to the outside of the bomb. For high energy neutrons, the motion of the material being traversed is a small pertubation and thermal effects are not important. So a measurement of the neutron output spectrum from a static Little Boy assembly should provide a good code calibration experiment for the high energy part of the spectrum.

In May of 1981, four objects were located in field storage at Los Alamos. Three of these objects were identified by Mr. Harlow Russ, a retired employee, as non-fissile components of Little Boy bombs which had been retired from stockpile. The fourth object was a training device without the proper materials. Dr. Harold Agnew, the former Director of the Laboratory, had wisely stored these four samples. These components were transferred to the Los Alamos Critical Assembly Facility. One of the bomb assemblies was mounted on a stand over the Comet Assembly Machine, Figure 16. By means of a hydraulic ram, fissile material could then be raised into the center of the bomb assembly until a critical configuration was achieved. Dr. H. M. Forehand and particularly Dr. R. Malenfant of the Critical Assembly Facility were primarily responsible for making this experiment possible.

Measurements of the output neutron spectrum from this improvised critical assembly were made at several angular positions by Dr. F. J. Muckenthaler of the Oak Ridge National Laboratory and by Dr. H. A. Robitaille and Dr. B. E. Hoffarth of the Canadian Defense Research Establishment (DREO). A very-very preliminary comparison of the neutron spectrum results obtained by Drs. Robitaille and Hoffarth with the calculated spectrum is shown in Figure 17. This figure is reproduced exactly from a letter by Dr. Robitaille and shows the DREO measurements (integrated over angle) plotted on a curve taken from the Drs. Loewe and Mendelsohn (NSE 81, 325) article. The DREO spectrum was arbitarily normalized for plotting purposes (as were the other spectra in the figure). These preliminary results are extremely encouraging with respect to the high energy portion of the calculated spectrum.

The measurements on the static critical assembly should, of course, be compared with calculations of the static assembly; not with the calculations of the exploding bomb. The calculations of the static assembly are underway at Los Alamos.

This first set of measurements was done inside a building with thick concrete walls and floor. Because of the room return, the low energy part of the neutron spectrum is distorted and it was impossible to measure the gamma-ray output spectrum. To avoid the room return problem, the Comet Assembly Machine is being moved out of doors and will be mounted on a (small) platform. In this configuration, it is hoped to get better measurements of the low energy portion of the neutron spectrum and some gamma-ray spectrum measurements. These measurements will occur in the spring when the weather at Los Alamos has improved. Experimenters from the Oak Ridge National Laboratory and from the Lawrence Livermore National Laboratory will participate in these measurements. A meeting to formally present the results of the experimental measurements is tentatively scheduled in September 1983 at Los Alamos.

VII. Other Calibration Calculations

The air transport calculations being done by other organizations are being calibrated against measurements made using reactor sources. There are two sets of measurements; those made in Operation BREN and those made at the U. S. Army Aberdeen Proving Ground, Maryland. In both cases the source reactor is a bare Godiva-type design. The Health Physics Research Reactor (HPRR) developed at Oak Ridge National Laboratory was the source reactor for Operation BREN. The Army Pulse Radiation Division (APRD) reactor is based on the design of the HPRR and differs only in minor details.

In the course of doing air transport calculations at Los Alamos, Dr. R. Little did a one-dimensional calculation of the neutron output spectrum of the APRD reactor. The results of this calculation are shown in Table XII, taken from (Estes, 82). Also listed in the table as "Given" is the APRD reactor neutron spectrum as published by Dr. Kazi et al. and the ratio of the Calculated (Dr. Little) to "Given" (Dr. Kazi).

Mr. D. Kaul (Kaul 82) reports that the Los Alamos neutron source spectrum improves the agreement with foil measurements made 28.5 inches from the axis of the BREN reactor when compared with the ORNL spectrum used by Dr. Kazi. This is shown in Table XIII.

TABLE XIII

NEUTRON SPECTRUM FROM FOIL MEASUREMENTS

Energy Range (Mev)	Neutron Source Fraction Meas.	Los Alamos	ORNL
> 2.5	.206	.204	.168
1.5 - 2.5	.126	.185	.168
.75 - 1.5	.294	.248	.238
.01 - .75	.374	.363	.426
.01 -	1.000	1.000	1.000

VIII. Yields of Explosions

All of the output spectra reported in this paper have been in terms of output per kiloton of yield (1 kiloton = 10^{12} calories). The yield of the Nagasaki explosion based on measurements from tests of identical weapons is taken to be 22 $\pm$ 2 kilotons (Malik, 1981). There were no other test firings of weapons similar to the Hiroshima bomb so yield estimates must be made indirectly.

In a review of the Hiroshima yield (Malik, 1981) Dr. J. Malik proposed the value of 15 $\pm$ 3 kilotons. In an extension of this work he suggests the value of 17 $\pm$ 4 kilotons. When funding is arranged, Dr Malik will be directing two small programs to review the indirect evidence for the yield estimates.

Using calculational techniques combined with criticality measurements it is possible to make good estimates of the maximum yield of the Hiroshima explosion. The yield predicted in this fashion in 1945 was 15 kilotons (Schiff, 1945). This program is being repeated in 1983 using our current calculational tools and new criticality measurements at the Critical Assembly Facility. One measurement has been completed. The casting of fissile material duplicating that in the Hiroshima bomb will start on January 17, 1983. The criticality measurement made with these parts will allow the upper limit yield of the Hiroshima explosion to be defined to $\pm$10%.

IX. Acknowledgements

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X-4 Nuclear Application Group

Dr. B. Rogers Dr. R. Worlton	for one-dimensional bomb models and explosion calculations
Dr. J. Kammerdiener	for two-dimensional explosion calculations of the Hiroshima bomb

X-5 Diagnostics Physics Group

Dr. R. Streetman	for the calculations of the outputs of the explosions

X-6 Radiation Transport Group

Dr. G. Estes	for air transport calculations and interaction with diagnostic ions
Dr. R. Little	for the APRD reactor output calculations
Dr. P. Soran	for providing cross sections

Q-2 Detection and Verification Group

Dr. M. Forehand	for setting up the Little Boy critical assembly
Dr. R. Malenfant	for enthusiastic support of the critical assembly work and for providing technical guidance

NSP/T&V

Dr. J. Malik	for sharing his encyclopedic knowledge of measurements made on nuclear explosions and his vast collection of material on the Hiroshima-Nagasaki explosions
Mr. H. Russ (retired)	for locating lost drawings

X. References

Estes, G. P., Little, R. C., Seamon, R. E. Soran, P.D., **Air Transport in Connection with the Hiroshima-Nagasaki Dose Reevaluation Effort,** July 1982, LA-9369-MS.

Kaul, D. C., **Calculations of BREN and APR Experiments** , performed under DNA-001-81-C-0206, June 4, 1982, Memo to Record.

Kazi, A. H., Heimbach, C. R., Harrison, Schanzler, L. Bucholz, F. W., **Measurements of the Free Field Radiation Environment at the APRD Reactor** , July 1979, Test Agency Report APG-MT-5279 (Limited Access).

Malik, J., **Yields of the Hiroshima and Nagasaki Explosions,** September 1981, Reevaluations of Dosimetric Factors, Hiroshima and Nagasaki, DOE Symposium Series 55.

Preeg, W. E., **Neutron and Gamma-Ray Output for Fat Man and Little Boy,** April 5, 1976, Reevaluations of Dosimetric Factors, Hiroshima and Nagasaki, DOE Symposium Series 55.

TABLE II

NAGASAKI-TYPE NEUTRON SPECTRA ON PREEG ENERGY GRID
(Moles/Kiloton)

Energy Bounds (MeV)		FAT MAN Preeg	FAT MAN Streetman	TEST Spectrum
6.070E+00	7.790E+00	8.865E-05	8.265E-05	7.776E-05
3.680E+00	6.070E+00	1.826E-04	2.233E-04	3.055E-04
2.865E+00	3.680E+00	1.466E-04	1.415E-04	1.628E-04
2.232E+00	2.865E+00	2.513E-04	3.021E-04	3.579E-04
1.738E+00	2.232E+00	1.973E-04	2.198E-04	3.404E-04
1.353E+00	1.738E+00	1.900E-04	1.844E-04	2.614E-04
8.230E-01	1.353E+00	3.939E-04	2.656E-04	4.122E-04
5.000E-01	8.230E-01	2.753E-04	2.588E-04	4.151E-04
3.030E-01	5.000E-01	1.313E-04	1.232E-04	2.134E-04
1.840E-01	3.030E-01	1.353E-04	1.055E-04	1.780E-04
6.760E-02	1.840E-01	1.640E-04	1.672E-04	2.336E-04
2.480E-02	6.760E-02	8.265E-05	9.102E-05	1.528E-04
9.120E-03	2.480E-02	8.799E-05	6.911E-05	1.242E-04
3.350E-03	9.120E-03	1.053E-04	8.214E-05	1.341E-04
1.235E-03	3.350E-03	1.133E-04	6.423E-04	1.063E-03
4.540E-04	1.235E-03	2.806E-02	4.369E-02	3.908E-02
1.670E-04	4.540E-04	1.013E-01	1.179E-01	8.774E-02
6.140E-05	1.670E-04	8.799E-02	6.950E-02	7.131E-02
2.260E-05	6.140E-05	4.413E-02	2.792E-02	3.333E-02
8.320E-06	2.260E-05	1.400E-02	8.677E-03	1.031E-02
3.060E-06	8.320E-06	3.733E-03	2.202E-03	2.477E-03
1.130E-06	3.060E-06	1.586E-03	4.413E-04	5.761E-04
4.140E-07	1.130E-06	1.027E-04	9.638E-05	1.022E-04
0.000E+00	4.140E-07	0.000E+00	0.000E+00	0.000E+00
Total Neutron (M/Kt)		0.2835	0.2734	0.2494
Avg.Neutron Energy (MeV)		0.014	0.015	0.022

TABLE III

NAGASAKI-TYPE NEUTRON SPECTRA ON EXTENDED ENERGY GRID
(Moles/Kiloton)

Energy Bounds (MeV)		FAT MAN		TEST
		Preeg	Streetman	Spectrum
1.450E+01	1.600E+01	0.000E+00	9.657E-08	0.000E+00
1.400E+01	1.450E+01	0.000E+00	1.441E-07	0.000E+00
1.350E+01	1.400E+01	0.000E+00	3.648E-08	0.000E+00
1.275E+01	1.350E+01	0.000E+00	4.974E-07	0.000E+00
1.200E+01	1.275E+01	0.000E+00	7.669E-07	0.000E+00
1.100E+01	1.200E+01	0.000E+00	1.531E-06	1.605E-06
1.000E+01	1.100E+01	0.000E+00	2.173E-06	2.776E-06
8.830E+00	1.000E+01	0.000E+00	7.068E-06	4.477E-06
7.790E+00	8.830E+00	0.000E+00	1.188E-05	1.050E-05
6.880E+00	7.790E+00	4.690E-05	2.249E-05	1.711E-05
6.070E+00	6.880E+00	4.175E-05	3.596E-05	4.129E-05
4.730E+00	6.070E+00	7.287E-05	9.721E-05	1.431E-04
3.680E+00	4.730E+00	1.098E-04	1.261E-04	1.624E-04
2.865E+00	3.680E+00	1.466E-04	1.415E-04	1.628E-04
2.232E+00	2.865E+00	2.513E-04	3.021E-04	3.579E-04
1.738E+00	2.232E+00	1.973E-04	2.198E-04	3.404E-04
1.353E+00	1.738E+00	1.900E-04	1.844E-04	2.614E-04
1.060E+00	1.353E+00	2.002E-04	1.495E-04	2.228E-04
8.230E-01	1.060E+00	1.938E-04	1.161E-04	1.894E-04
6.400E-01	8.230E-01	1.530E-04	1.231E-04	2.268E-04
5.000E-01	6.400E-01	1.223E-04	1.347E-04	1.883E-04
3.030E-01	5.000E-01	1.313E-04	1.232E-04	2.134E-04
1.840E-01	3.030E-01	1.353E-04	1.055E-04	1.780E-04
6.760E-02	1.840E-01	1.640E-04	1.672E-04	2.336E-04
2.480E-02	6.760E-02	8.265E-05	9.102E-05	1.528E-04
9.120E-03	2.480E-02	8.799E-05	6.911E-05	1.242E-04
9.350E-03	9.120E-03	1.053E-04	8.214E-05	1.341E-04
1.235E-03	3.350E-03	1.133E-04	6.423E-04	1.063E-03
4.540E-04	1.235E-03	2.806E-02	4.369E-02	3.906E-02
1.670E-04	4.540E-04	1.013E-01	1.179E-01	8.774E-02
6.140E-05	1.670E-04	8.799E-02	6.950E-02	7.131E-02
2.260E-05	6.140E-05	4.413E-02	2.792E-02	3.333E-02
8.320E-06	2.260E-05	1.400E-02	8.677E-03	1.031E-02
3.060E-06	8.320E-06	3.733E-03	2.302E-03	2.477E-03
1.130E-06	3.060E-06	1.586E-03	4.413E-04	5.761E-04
4.140E-07	1.130E-06	1.027E-04	9.638E-05	1.022E-04
1.520E-07	4.140E-07	0.000E+00	2.072E-05	2.419E-05
1.390E-10	1.520E-07	0.000E+00	4.552E-06	4.190E-06
Total Neutrons		0.2835	0.2734	0.2494
Avg Neutron Energy (MeV)		0.014	0.015	0.022

TABLE IV

NAGASAKI-TYPE GAMMA RAY SPECTRA ON FREEG ENERGY GRID
(Moles/Kiloton)

Energy Bounds (MeV)		Fat Man		Test
		Freeg	Streetman	Spectrum
9.000E+00	1.000E+01	1.580E-05	9.939E-07	0.000E+00
8.000E+00	9.000E+00	6.079E-06	7.935E-06	3.035E-06
7.000E+00	8.000E+00	1.580E-03	5.828E-05	6.724E-05
6.000E+00	7.000E+00	4.253E-04	2.992E-05	1.380E-04
5.000E+00	6.000E+00	3.026E-04	7.413E-05	2.582E-04
4.000E+00	5.000E+00	7.399E-04	3.606E-04	1.483E-03
3.000E+00	4.000E+00	1.166E-03	4.983E-03	3.327E-03
2.000E+00	3.000E+00	3.226E-03	9.734E-03	1.003E-02
1.000E+00	2.000E+00	6.059E-03	1.797E-02	1.920E-02
5.000E-01	1.000E+00	1.626E-03	1.362E-02	1.494E-02
1.000E-01	5.000E-01	3.326E-04	1.515E-02	1.566E-02
TOTAL	MOLES/kT	1.549E-02	6.198E-02	6.519E-02
TOTAL	MeV-MOLES/kT	4.148E-02	8.225E-02	8.677E-02
Gamma Efficiency %		.040	---	---

TABLE V

NAGASAKI-TYPE GAMMA RAY SPECTRA ON EXTENDED ENERGY GRID (Moles/Kiloton)

Energy Bounds (MeV)		Fat Man Preeg	Fat Man Streetman	Test Spectrum
9.000E+00	1.000E+01	1.580E-05	9.939E-07	0.000E+00
8.000E+00	9.000E+00	6.079E-06	7.935E-06	3.035E-06
7.000E+00	8.000E+00	1.580E-03	5.828E-05	6.724E-05
6.000E+00	7.000E+00	4.253E-04	2.992E-05	1.380E-04
5.000E+00	6.000E+00	3.026E-04	7.413E-05	2.582E-04
4.000E+00	5.000E+00	7.399E-04	3.606E-04	1.483E-03
3.000E+00	4.000E+00	1.166E-03	4.983E-03	3.327E-03
2.500E+00	3.000E+00	1.338E-03	3.245E-03	3.476E-03
2.000E+00	2.500E+00	1.888E-03	6.489E-03	6.550E-03
1.500E+00	2.000E+00	2.662E-03	8.615E-03	8.650E-03
1.000E+00	1.500E+00	3.397E-03	9.351E-03	1.055E-02
8.000E-01	1.000E+00	6.000E-04	4.440E-03	4.354E-03
6.000E-01	8.000E-01	6.703E-04	5.524E-03	6.043E-03
5.000E-01	6.000E-01	3.562E-04	3.656E-03	4.544E-03
4.000E-01	5.000E-01	3.326E-04	3.884E-03	3.983E-03
3.000E-01	4.000E-01	0.000E+00	3.724E-03	3.969E-03
2.000E-01	3.000E-01	0.000E+00	3.679E-03	3.962E-03
1.000E-01	2.000E-01	0.000E+00	3.863E-03	3.749E-03
5.000E-02	1.000E-01	0.000E+00	9.494E-04	6.102E-04
0.000E+00	5.000E-02	0.000E+00	2.723E-05	0.000E+00
TOTAL	MOLES/kT	1.548E-02	6.296E-02	6.571E-02
TOTAL	MeV-MOLES/kT	4.179E-02	8.410E-02	8.833E-02
Gamma Efficiency %		.040	.082	.086

TABLE VI

LITTLE BOY

NEUTRON OUTPUT ON PREEG ENERGY GRID
(MOLES/KT)

Energy (MeV)		Preeg	2D
6.070E+00	7.790E+00	1.583E-04	9.515E-05
3.680E+00	6.070E+00	6.052E-04	3.500E-04
2.865E+00	3.680E+00	7.286E-04	3.510E-04
2.232E+00	2.865E+00	1.294E-03	6.850E-04
1.738E+00	2.232E+00	2.000E-03	1.080E-03
1.353E+00	1.738E+00	2.562E-03	1.690E-03
8.230E-01	1.353E+00	8.597E-03	8.310E-03
5.000E-01	8.230E-01	1.983E-02	1.818E-02
3.030E-01	5.000E-01	3.073E-02	2.850E-02
1.840E-01	3.030E-01	2.732E-02	2.510E-02
6.760E-02	1.840E-01	4.596E-02	4.350E-02
2.480E-02	6.760E-02	1.966E-02	1.620E-02
9.120E-03	2.480E-02	2.996E-02	2.750E-02
3.350E-03	9.120E-03	6.613E-03	2.390E-03
1.235E-03	3.350E-03	5.320E-03	1.830E-03
4.540E-04	1.235E-03	3.507E-03	1.110E-03
1.670E-04	4.540E-04	9.533E-04	3.610E-04
6.140E-05	1.670E-04	2.800E-04	9.020E-05
2.260E-05	6.140E-05	6.247E-05	2.310E-05
TOTAL	MOLES/KT	2.061E-01	1.773E-01
TOTAL MEV	-MOLES/KT	6.409E-02	5.330E-02

TABLE VII

LITTLE BOY

NEUTRON OUTPUT ON 2D ENERGY GRID
(MOLES/KT)

Energy (MeV)		Preeg	2D
1.100E+01	2.000E+01	0.000E+00	4.040E-06
1.000E+01	1.100E+01	0.000E+00	3.600E-06
8.830E+00	1.000E+01	0.000E+00	7.010E-06
7.790E+00	8.830E+00	0.000E+00	2.050E-05
6.880E+00	7.790E+00	8.376E-05	1.880E-05
6.070E+00	6.880E+00	7.456E-05	4.120E-05
4.740E+00	6.070E+00	1.999E-04	1.300E-04
3.680E+00	4.740E+00	4.053E-04	2.200E-04
2.865E+00	3.680E+00	7.286E-04	3.510E-04
2.232E+00	2.865E+00	1.294E-03	6.850E-04
1.738E+00	2.232E+00	2.000E-03	1.080E-03
1.353E+00	1.738E+00	2.562E-03	1.690E-03
1.060E+00	1.353E+00	3.358E-03	3.160E-03
8.230E-01	1.060E+00	5.238E-03	5.150E-03
6.400E-01	8.230E-01	8.608E-03	6.080E-03
5.000E-01	6.400E-01	1.122E-02	1.210E-02
3.030E-01	5.000E-01	3.073E-02	2.850E-02
1.840E-01	3.030E-01	2.732E-02	2.510E-02
6.760E-02	1.840E-01	4.596E-02	4.350E-02
2.480E-02	6.760E-02	1.966E-02	1.620E-02
9.120E-03	2.480E-02	2.996E-02	2.750E-02
3.350E-03	9.120E-03	6.613E-03	2.390E-03
1.235E-03	3.350E-03	5.320E-03	1.830E-03
4.540E-04	1.235E-03	3.507E-03	1.110E-03
1.670E-04	4.540E-04	9.533E-04	3.610E-04
6.140E-05	1.670E-04	2.800E-04	9.020E-05
2.260E-05	6.140E-05	6.247E-05	2.310E-05
TOTAL	MOLES/KT	2.061E-01	1.773E-01
TOTAL	MEV-MOLES/KT	6.372E-02	5.276E-02

TABLE VIII

LITTLE BOY

GAMMA-RAY OUTPUT ON PREEG ENERGY GRID
(MOLES/KT)

Energy (MeV)		Preeg	2D
9.000E+00	1.000E+01	2.766E-05	2.600E-05
8.000E+00	9.000E+00	2.613E-05	3.380E-05
7.000E+00	8.000E+00	8.597E-04	1.220E-04
6.000E+00	7.000E+00	2.256E-04	5.520E-05
5.000E+00	6.000E+00	1.745E-04	6.130E-05
4.000E+00	5.000E+00	4.111E-04	1.050E-04
3.000E+00	4.000E+00	6.273E-04	1.930E-04
2.000E+00	3.000E+00	8.852E-04	4.110E-04
1.000E+00	2.000E+00	1.319E-03	7.240E-04
5.000E-01	1.000E+00	2.383E-03	1.638E-03
1.000E-01	5.000E-01	1.038E-04	1.641E-03
TOTAL	MOLES/KT	7.043E-03	5.010E-03
TOTAL KEV	MOLES/KT	1.909E-02	6.834E-03

TABLE IX

LITTLE BOY

GAMMA-RAY OUTPUT ON 2D ENERGY GRID
(MOLES/KT)

Energy (MeV)		Preeg	2D
9.000E+00	1.000E+01	2.766E-05	2.600E-05
8.000E+00	9.000E+00	2.613E-05	3.380E-05
7.000E+00	8.000E+00	8.597E-04	1.220E-04
6.000E+00	7.000E+00	2.256E-04	5.520E-05
5.000E+00	6.000E+00	1.745E-04	6.130E-05
4.000E+00	5.000E+00	4.111E-04	1.050E-04
3.000E+00	4.000E+00	6.273E-04	1.930E-04
2.500E+00	3.000E+00	3.931E-04	1.710E-04
2.000E+00	2.500E+00	4.921E-04	2.400E-04
1.500E+00	2.000E+00	4.579E-04	2.700E-04
1.000E+00	1.500E+00	8.614E-04	4.540E-04
8.000E-01	1.000E+00	8.049E-04	8.040E-04
6.000E-01	8.000E-01	1.003E-03	4.930E-04
5.000E-01	6.000E-01	5.750E-04	3.410E-04
4.000E-01	5.000E-01	1.038E-04	3.430E-04
3.000E-01	4.000E-01	0.000E+00	3.740E-04
2.000E-01	3.000E-01	0.000E+00	5.050E-04
1.000E-01	2.000E-01	0.000E+00	4.190E-04
5.000E-02	1.000E-01	0.000E+00	3.110E-05
0.000E+00	5.000E-02	0.000E+00	1.860E-06
TOTAL	MOLES/KT	7.043E-03	5.043E-03
TOTAL	MEV-MOLES/KT	1.915E-02	7.022E-03

TABLE X

LITTLE BOY TWO-DIMENSIONAL
NEUTRONS

neutron output. Moles/kt.

cosine: / energy	-9.0000e-01	-8.0000e-01	-7.0000e-01	-6.0000e-01	-5.0000e-01
2.2600e-05					
6.1400e-05	6.88e-07 0.15	8.70e-07 0.15	9.71e-07 0.15	1.08e-06 0.15	1.18e-06 0.15
1.6700e-04	2.69e-06 0.07	3.40e-06 0.07	3.79e-06 0.07	4.21e-06 0.07	4.61e-06 0.07
4.5400e-04	1.08e-05 0.04	1.36e-05 0.04	1.52e-05 0.04	1.69e-05 0.04	1.85e-05 0.04
1.2350e-03	3.31e-05 0.02	4.17e-05 0.02	4.66e-05 0.02	5.18e-05 0.02	5.66e-05 0.02
3.3500e-03	5.44e-05 0.01	6.88e-05 0.01	7.68e-05 0.01	8.54e-05 0.01	9.34e-05 0.01
9.1200e-03	7.15e-05 0.01	9.02e-05 0.01	1.00e-04 0.01	1.12e-04 0.01	1.22e-04 0.01
2.4800e-02	8.20e-04 0.03	1.04e-03 0.03	1.16e-03 0.02	1.28e-03 0.02	1.41e-03 0.02
6.7600e-02	4.16e-04 0.04	5.36e-04 0.04	6.42e-04 0.03	7.28e-04 0.03	8.35e-04 0.03
1.8400e-01	1.05e-03 0.03	1.48e-03 0.02	1.77e-03 0.02	1.89e-03 0.02	2.15e-03 0.02
3.0300e-01	5.78e-04 0.04	8.32e-04 0.03	1.03e-03 0.03	1.14e-03 0.03	1.24e-03 0.03
5.0000e-01	6.90e-04 0.04	9.24e-04 0.03	1.13e-03 0.03	1.29e-03 0.03	1.38e-03 0.03
6.4000e-01	2.31e-04 0.06	3.65e-04 0.05	4.43e-04 0.05	5.14e-04 0.04	5.72e-04 0.04
8.2300e-01	9.98e-05 0.09	1.70e-04 0.07	2.21e-04 0.07	2.52e-04 0.06	2.79e-04 0.06
1.0600e+00	8.20e-05 0.10	1.44e-04 0.08	1.84e-04 0.07	2.12e-04 0.07	2.42e-04 0.06
1.3530e+00	4.82e-05 0.14	7.50e-05 0.11	1.30e-04 0.08	1.57e-04 0.08	1.53e-04 0.08
1.7380e+00	2.17e-05 0.16	4.71e-05 0.13	5.36e-05 0.13	6.55e-05 0.12	7.98e-05 0.11
2.2320e+00	1.29e-05 0.24	2.40e-05 0.18	3.38e-05 0.16	4.01e-05 0.14	5.86e-05 0.12
2.8650e+00	1.15e-05 0.27	1.57e-05 0.22	1.80e-05 0.22	2.35e-05 0.18	3.64e-05 0.16
3.6800e+00	8.85e-06 0.30	4.26e-06 0.40	9.43e-06 0.25	1.46e-05 0.24	1.94e-05 0.20
4.7300e+00	2.26e-06 0.46	3.80e-06 0.45	4.50e-06 0.39	9.71e-06 0.27	1.30e-05 0.26
6.0700e+00	1.06e-06 0.73	3.63e-06 0.36	3.22e-06 0.44	6.27e-06 0.36	5.54e-06 0.36
6.8800e+00	1.09e-06 0.76	1.37e-06 0.77	1.03e-06 0.73	3.44e-06 0.59	9.98e-07 0.71
7.7900e+00	5.60e-07 1.00	0.00e+00 0.00	1.26e-06 0.59	0.00e+00 0.00	7.19e-07 0.71
8.8300e+00	5.69e-07 1.00	0.00e+00 0.00	0.00e+00 0.00	6.43e-07 1.00	1.21e-06 0.71
1.0000e+01	0.00e+00 0.00	0.00e+00 0.00	4.22e-07 1.00	0.00e+00 0.00	0.00e+00 0.00
1.1000e+01	0.00e+00 0.00	1.61e-06 0.76	9.34e-07 1.00	0.00e+00 0.00	0.00e+00 0.00
2.0000e+01	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00
total	4.25e-03 0.01	5.88e-03 0.01	7.07e-03 0.01	7.88e-03 0.01	8.77e-03 0.01

cosine: / energy	-4.0000e-01	-3.0000e-01	-2.0000e-01	-1.0000e-01	-1.1980e-14
2.2600e-05					
6.1400e-05	1.25e-06 0.15	1.31e-06 0.13	1.35e-06 0.15	1.34e-06 0.15	1.33e-06 0.15
1.6700e-04	4.88e-06 0.07	5.13e-06 0.07	5.28e-06 0.07	5.24e-06 0.07	5.22e-06 0.07
4.5400e-04	1.95e-05 0.04	2.05e-05 0.04	2.11e-05 0.04	2.10e-05 0.04	2.09e-05 0.04
1.2350e-03	5.98e-05 0.02	6.30e-05 0.02	6.51e-05 0.02	6.46e-05 0.02	6.40e-05 0.02
3.3500e-03	9.92e-05 0.01	1.04e-04 0.01	1.07e-04 0.01	1.07e-04 0.01	1.06e-04 0.01
9.1200e-03	1.30e-04 0.01	1.36e-04 0.01	1.40e-04 0.01	1.39e-04 0.01	1.38e-04 0.01
2.4800e-02	1.49e-03 0.02	1.56e-03 0.02	1.61e-03 0.02	1.60e-03 0.02	1.59e-03 0.02
6.7600e-02	8.81e-04 0.03	8.98e-04 0.03	9.89e-04 0.03	9.80e-04 0.03	1.02e-03 0.03
1.8400e-01	2.31e-03 0.02	2.48e-03 0.02	2.54e-03 0.02	2.63e-03 0.02	2.71e-03 0.02
3.0300e-01	1.34e-03 0.03	1.42e-03 0.03	1.46e-03 0.03	1.50e-03 0.03	1.53e-03 0.02
5.0000e-01	1.50e-03 0.03	1.60e-03 0.02	1.65e-03 0.02	1.69e-03 0.02	1.77e-03 0.02
6.4000e-01	6.54e-04 0.04	6.87e-04 0.04	7.41e-04 0.04	7.82e-04 0.04	7.61e-04 0.04
8.2300e-01	3.51e-04 0.05	3.64e-04 0.05	3.68e-04 0.05	3.64e-04 0.05	3.95e-04 0.05
1.0600e+00	2.42e-04 0.06	3.00e-04 0.06	3.31e-04 0.06	3.54e-04 0.05	3.24e-04 0.05
1.3530e+00	1.69e-04 0.08	1.79e-04 0.07	1.91e-04 0.07	1.93e-04 0.07	2.24e-04 0.07
1.7380e+00	8.66e-05 0.10	9.52e-05 0.10	9.98e-05 0.10	1.15e-04 0.09	1.07e-04 0.09
2.2320e+00	5.36e-05 0.13	6.66e-05 0.12	6.28e-05 0.12	7.84e-05 0.11	8.87e-05 0.10
2.8650e+00	3.85e-05 0.15	3.72e-05 0.15	5.17e-05 0.13	4.82e-05 0.13	4.76e-05 0.13
3.6800e+00	1.88e-05 0.22	2.48e-05 0.19	2.40e-05 0.19	2.59e-05 0.17	1.69e-05 0.21
4.7300e+00	1.24e-05 0.25	1.57e-05 0.24	1.90e-05 0.21	1.79e-05 0.23	2.20e-05 0.18
6.0700e+00	8.17e-06 0.34	8.35e-06 0.30	8.75e-06 0.31	1.29e-05 0.26	9.34e-06 0.30
6.8800e+00	1.18e-06 0.75	4.50e-06 0.49	2.86e-06 0.55	3.59e-06 0.55	1.85e-06 0.52
7.7900e+00	1.10e-06 0.58	1.04e-06 0.73	2.11e-06 0.63	4.63e-07 1.00	3.22e-07 1.00
8.8300e+00	0.00e+00 0.00	2.32e-06 0.50	1.52e-06 0.58	1.02e-06 0.73	1.04e-06 0.72
1.0000e+01	4.32e-07 1.00	3.73e-07 1.00	5.20e-07 1.00	3.52e-07 1.00	1.07e-06 1.00
1.1000e+01	0.00e+00 0.00	0.00e+00 0.00	5.49e-07 1.00	0.00e+00 0.00	0.00e+00 0.00
2.0000e+01	0.00e+00 0.00	1.57e-06 0.73	0.00e+00 0.00	1.08e-06 1.00	0.00e+00 0.00
total	9.47e-03 0.01	1.01e-02 0.01			

TABLE X (CONTINUED)

cosine: / energy	1.0000e-01	2.0000e-01	3.0000e-01	4.0000e-01	5.0000e-01
2.2600e-05					
6.1400e-05	1.38e-06 0.15	1.35e-06 0.15	1.38e-06 0.15	1.30e-06 0.15	1.26e-06 0.15
1.6700e-04	5.31e-06 0.07	5.28e-06 0.07	5.39e-06 0.07	5.10e-06 0.07	4.95e-06 0.07
4.5400e-04	2.12e-05 0.04	2.11e-05 0.04	2.16e-05 0.04	2.04e-05 0.04	1.98e-05 0.04
1.2350e-03	6.51e-05 0.02	6.51e-05 0.02	6.62e-05 0.02	6.24e-05 0.02	6.08e-05 0.02
3.3500e-03	1.08e-04 0.01	1.07e-04 0.01	1.09e-04 0.01	1.04e-04 0.01	1.00e-04 0.01
9.1200e-03	1.41e-04 0.01	1.40e-04 0.01	1.43e-04 0.01	1.35e-04 0.01	1.31e-04 0.01
2.4800e-02	1.62e-03 0.02	1.61e-03 0.02	1.65e-03 0.02	1.55e-03 0.02	1.51e-03 0.02
6.7600e-02	1.03e-03 0.03	9.80e-04 0.03	9.43e-04 0.03	9.71e-04 0.03	9.00e-04 0.03
1.8400e-01	2.63e-03 0.02	2.63e-03 0.02	2.69e-03 0.02	2.59e-03 0.02	2.49e-03 0.02
3.0300e-01	1.56e-03 0.02	1.52e-03 0.02	1.53e-03 0.02	1.49e-03 0.03	1.49e-03 0.03
5.0000e-01	1.08e-03 0.02	1.73e-03 0.02	1.72e-03 0.02	1.70e-03 0.02	1.65e-03 0.02
8.4000e-01	7.32e-04 0.04	7.80e-04 0.04	7.88e-04 0.04	7.11e-04 0.04	7.28e-04 0.04
1.2300e-01	3.90e-04 0.05	4.07e-04 0.05	3.94e-04 0.05	3.59e-04 0.05	3.78e-04 0.05
1.0600e+00	3.20e-04 0.06	3.43e-04 0.05	3.29e-04 0.06	3.49e-04 0.05	3.06e-04 0.06
1.3530e+00	2.12e-04 0.07	2.20e-04 0.07	2.01e-04 0.07	1.97e-04 0.07	1.67e-04 0.08
1.7380e+00	1.21e-04 0.09	1.05e-04 0.09	1.10e-04 0.09	1.28e-04 0.09	1.05e-04 0.09
2.2320e+00	8.19e-05 0.11	7.22e-05 0.11	6.16e-05 0.12	6.91e-05 0.11	6.42e-05 0.12
2.8650e+00	5.71e-05 0.13	4.82e-05 0.14	4.40e-05 0.13	3.83e-05 0.18	3.08e-05 0.16
3.6800e+00	1.21e-05 0.23	2.82e-05 0.18	2.63e-05 0.19	2.84e-05 0.17	2.80e-05 0.17
4.7300e+00	1.52e-05 0.24	1.01e-05 0.26	1.28e-05 0.24	1.19e-05 0.24	1.43e-05 0.24
6.0700e+00	7.73e-06 0.35	7.03e-06 0.30	8.64e-06 0.30	1.14e-05 0.28	8.22e-06 0.29
6.8800e+00	5.35e-06 0.42	1.77e-06 0.66	4.10e-07 1.00	2.95e-06 0.51	3.29e-06 0.57
7.7300e+00	1.09e-06 0.73	2.82e-06 0.61	1.93e-06 0.52	1.53e-06 0.50	8.73e-07 0.71
8.8300e+00	4.31e-07 1.00	2.96e-06 0.50	2.17e-06 0.50	7.13e-07 1.00	3.31e-06 0.54
1.0000e+01	7.54e-07 1.00	0.00e+00 0.00	5.18e-07 1.00	1.55e-06 0.72	0.00e+00 0.00
1.1000e+01	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00
2.0000e+01	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00
total	1.08e-02 0.01	1.08e-02 0.01	1.09e-02 0.01	1.05e-02 0.01	1.02e-02 0.01

cosine: / energy	6.0000e-01	7.0000e-01	8.0000e-01	9.0000e-01	1.0000e+00
2.2600e-05					
6.1400e-05	1.25e-06 0.15	1.16e-06 0.15	1.05e-06 0.15	9.55e-07 0.15	8.35e-07 0.15
1.6700e-04	4.91e-06 0.07	4.55e-06 0.07	4.09e-06 0.07	3.73e-06 0.07	2.49e-06 0.07
4.5400e-04	1.96e-05 0.04	1.82e-05 0.04	1.64e-05 0.04	1.49e-05 0.04	9.98e-06 0.04
1.2350e-03	6.03e-05 0.02	5.60e-05 0.02	5.03e-05 0.02	4.58e-05 0.02	3.06e-05 0.02
3.3500e-03	9.98e-05 0.01	9.23e-05 0.01	8.32e-05 0.01	7.58e-05 0.01	5.06e-05 0.01
9.1200e-03	1.30e-04 0.01	1.21e-04 0.01	1.08e-04 0.01	9.87e-05 0.01	6.62e-05 0.01
2.4800e-02	1.50e-03 0.02	1.39e-03 0.02	1.25e-03 0.02	1.14e-03 0.02	7.59e-04 0.03
6.7600e-02	9.16e-04 0.03	8.51e-04 0.03	7.44e-04 0.03	5.82e-04 0.04	3.48e-04 0.05
1.8400e-01	2.39e-03 0.02	2.18e-03 0.02	2.09e-03 0.02	1.73e-03 0.02	1.11e-03 0.03
3.0300e-01	1.39e-03 0.03	1.35e-03 0.03	1.13e-03 0.03	1.01e-03 0.03	8.06e-04 0.04
5.0000e-01	1.64e-03 0.02	1.55e-03 0.03	1.30e-03 0.03	1.16e-03 0.03	7.56e-04 0.04
8.4000e-01	6.49e-04 0.04	6.41e-04 0.04	5.69e-04 0.04	4.73e-04 0.05	2.55e-04 0.06
1.2300e-01	3.32e-04 0.05	3.06e-04 0.06	2.88e-04 0.06	2.03e-04 0.07	1.51e-04 0.08
1.0600e+00	2.67e-04 0.06	2.67e-04 0.06	2.36e-04 0.06	2.09e-04 0.07	1.15e-04 0.09
1.3530e+00	1.78e-04 0.07	1.55e-04 0.08	1.28e-04 0.09	1.28e-04 0.08	7.14e-05 0.11
1.7380e+00	9.43e-05 0.10	8.60e-05 0.10	6.13e-05 0.12	6.49e-05 0.11	4.06e-05 0.15
2.2320e+00	5.69e-05 0.13	5.80e-05 0.12	5.10e-05 0.13	3.21e-05 0.16	1.31e-05 0.23
2.8650e+00	3.23e-05 0.16	3.16e-05 0.16	3.36e-05 0.16	2.84e-05 0.18	1.42e-05 0.23
3.6800e+00	1.69e-05 0.22	1.31e-05 0.23	1.28e-05 0.22	1.28e-05 0.25	7.19e-06 0.33
4.7300e+00	1.15e-05 0.26	5.61e-06 0.31	7.13e-06 0.33	6.90e-06 0.32	3.29e-06 0.41
6.0700e+00	8.43e-06 0.33	2.66e-06 0.45	2.69e-06 0.42	4.08e-06 0.43	2.05e-06 0.51
6.8800e+00	1.65e-06 0.50	8.07e-07 0.71	2.29e-06 0.63	7.86e-07 0.71	0.00e+00 0.00
7.7900e+00	6.25e-07 1.00	7.50e-07 1.00	1.11e-06 1.00	0.00e+00 0.00	0.00e+00 0.00
8.8300e+00	5.16e-07 1.00	8.60e-07 1.00	7.61e-07 0.71	4.77e-07 1.00	0.00e+00 0.00
1.0000e+01	0.00e+00 0.00	0.00e+00 0.00	5.30e-07 1.00	4.81e-07 1.00	0.00e+00 0.00
1.1000e+01	0.00e+00 0.00	0.00e+00 0.00	5.08e-07 1.00	0.00e+00 0.00	0.00e+00 0.00
2.0000e+01	0.00e+00 0.00	3.32e-07 1.00	0.00e+00 0.00	1.05e-06 0.75	0.00e+00 0.00
total	9.79e-03 0.01	9.18e-03 0.01	8.17e-03 0.01	7.03e-03 0.01	4.41e-03 0.01

TABLE X (CONTINUED)

cosine: energy	total	
2.2600e-05		
6.1400e-05	2.31e-05	0.15
1.6700e-04	9.02e-05	0.07
4.5400e-04	3.61e-04	0.04
1.2350e-03	1.11e-03	0.02
3.3500e-03	1.83e-03	0.01
9.1200e-03	2.39e-03	0.01
2.4800e-02	2.75e-02	0.00
6.7600e-02	1.62e-02	0.01
1.8400e-01	4.35e-02	0.00
3.0300e-01	2.51e-02	0.01
5.0000e-01	2.85e-02	0.01
6.4000e-01	1.21e-02	0.01
8.2300e-01	8.08e-03	0.01
1.0600e+00	5.15e-03	0.01
1.3530e+00	3.16e-03	0.02
1.7380e+00	1.69e-03	0.02
2.2320e+00	1.08e-03	0.03
2.8630e+00	6.95e-04	0.04
3.6800e+00	3.51e-04	0.05
4.7300e+00	2.20e-04	0.06
6.0700e+00	1.30e-04	0.08
6.8800e+00	4.12e-05	0.14
7.7900e+00	1.88e-05	0.19
8.8300e+00	2.05e-05	0.18
1.0000e+01	7.01e-06	0.31
1.1000e+01	3.60e-06	0.47
2.0000e+01	4.04e-06	0.46
total	1.77e-01	0.01

TABLE XI

LITTLE BOY TWO-DIMENSIONAL
GAMMA RAYS

gamma-ray output Moles/kt. cosine: / energy	-9.0000e-01	-8.0000e-01	-7.0000e-01	01	-5.0000e-01
0.0000e+00					
5.0000e-02	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00
1.0000e-01	5.22e-06 0.58	0.00e+00 0.00	1.68e-06 1.00	3.43e-06 1.00	0.00e+00 0.00
2.0000e-01	1.51e-05 0.36	1.08e-05 0.38	1.93e-05 0.28	1.03e-05 0.38	1.86e-05 0.33
3.0000e-01	1.83e-05 0.30	1.55e-05 0.30	2.66e-05 0.27	1.96e-05 0.30	3.47e-05 0.21
4.0000e-01	4.37e-06 0.58	6.45e-06 0.52	2.08e-05 0.34	1.97e-05 0.27	2.30e-05 0.27
5.0000e-01	0.00e+00 0.00	1.40e-05 0.34	9.82e-06 0.38	1.31e-05 0.34	1.33e-05 0.34
6.0000e-01	1.23e-05 0.43	5.36e-06 0.51	1.47e-05 0.35	1.05e-05 0.37	2.22e-05 0.37
8.0000e-01	8.27e-06 0.46	1.13e-05 0.35	1.54e-05 0.33	2.24e-05 0.26	2.30e-05 0.25
1.0000e+00	3.21e-05 0.20	2.37e-05 0.25	2.33e-05 0.25	3.49e-05 0.21	5.13e-05 0.17
1.5000e+00	3.60e-06 0.58	1.24e-05 0.45	2.95e-05 0.25	2.55e-05 0.27	1.58e-05 0.35
2.0000e+00	4.41e-06 0.71	5.91e-06 0.50	1.28e-05 0.45	2.43e-05 0.26	2.69e-06 0.71
2.5000e+00	1.27e-06 1.00	9.74e-06 0.38	9.18e-06 0.41	2.84e-06 0.71	1.40e-05 0.41
3.0000e+00	2.59e-06 1.00	1.27e-05 0.33	6.78e-05 0.53	8.39e-06 0.41	4.08e-06 0.58
4.0000e+00	2.75e-06 0.71	8.55e-06 0.41	8.51e-06 0.41	7.72e-06 0.46	6.41e-06 0.51
5.0000e+00	2.57e-06 0.71	1.23e-05 0.44	4.27e-06 0.58	7.06e-06 0.45	2.70e-06 0.71
6.0000e+00	1.45e-06 1.00	0.00e+00 0.00	1.40e-06 1.00	1.47e-06 1.00	1.44e-06 1.00
7.0000e+00	0.00e+00 0.00	4.06e-06 0.58	0.00e+00 0.00	3.95e-06 0.58	1.36e-06 1.00
8.0000e+00	1.42e-06 1.00	9.36e-06 0.42	8.60e-06 0.41	1.45e-06 1.00	1.00e-05 0.38
9.0000e+00	0.00e+00 0.00	2.92e-06 0.71	2.78e-06 0.71	2.82e-06 0.71	2.97e-06 0.71
1.0000e+01	0.00e+00 0.00	1.36e-06 1.00	4.04e-06 0.58	1.36e-06 1.00	2.72e-06 0.71
total	1.16e-04 0.19	1.66e-04 0.15	2.19e-04 0.14	2.21e-04 0.13	2.50e-04 0.14

cosine: / energy	-4.0000e-01	-3.0000e-01	-2.0000e-01	-1.0000e-01	-1.1990e-14
0.0000e+00					
5.0000e-02	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00
1.0000e-01	1.55e-06 1.00	5.05e-06 1.00	3.30e-06 0.71	1.86e-06 1.00	0.00e+00 0.00
2.0000e-01	2.12e-05 0.28	2.02e-05 0.28	3.56e-05 0.26	2.88e-05 0.24	2.75e-05 0.28
3.0000e-01	2.38e-05 0.34	2.90e-05 0.31	2.78e-05 0.26	3.54e-05 0.23	3.75e-05 0.23
4.0000e-01	2.19e-05 0.32	1.78e-05 0.31	2.92e-05 0.25	3.32e-05 0.23	2.48e-05 0.30
5.0000e-01	1.85e-05 0.32	1.24e-05 0.33	2.50e-05 0.25	2.46e-05 0.28	2.13e-05 0.35
6.0000e-01	1.82e-05 0.30	2.20e-05 0.29	2.93e-05 0.25	2.18e-05 0.33	2.15e-05 0.30
8.0000e-01	2.75e-05 0.27	4.39e-05 0.21	3.33e-05 0.25	3.18e-05 0.22	3.04e-05 0.22
1.0000e+00	4.87e-05 0.16	5.16e-05 0.19	3.70e-05 0.20	4.06e-05 0.19	5.44e-05 0.17
1.5000e+00	2.59e-05 0.28	1.59e-05 0.36	2.73e-05 0.26	3.05e-05 0.25	2.56e-05 0.30
2.0000e+00	1.29e-05 0.34	8.48e-06 0.41	1.41e-05 0.32	1.96e-05 0.29	7.70e-06 0.46
2.5000e+00	1.49e-05 0.35	1.78e-05 0.34	1.25e-05 0.41	1.53e-05 0.39	2.83e-05 0.26
3.0000e+00	6.18e-06 0.50	8.17e-06 0.51	1.38e-05 0.46	7.15e-06 0.45	1.16e-05 0.43
4.0000e+00	1.15e-05 0.39	9.00e-06 0.42	1.39e-05 0.35	1.17e-05 0.36	2.39e-05 0.28
5.0000e+00	5.13e-06 0.61	2.82e-06 0.71	7.07e-06 0.45	5.25e-06 0.50	6.87e-06 0.45
6.0000e+00	1.49e-06 1.00	1.31e-06 1.00	7.89e-06 0.53	5.63e-06 0.50	7.92e-06 0.45
7.0000e+00	6.33e-06 0.82	7.07e-06 0.54	1.29e-06 1.00	2.62e-06 0.71	1.29e-06 1.00
8.0000e+00	7.54e-06 0.45	4.26e-06 0.58	8.51e-06 0.41	3.55e-06 0.50	5.74e-06 0.50
9.0000e+00	0.00e+00 0.00	4.09e-06 0.58	1.35e-05 1.00	1.36e-06 1.00	0.00e+00 0.00
1.0000e+01	1.37e-06 1.00	1.36e-06 1.00	0.00e+00 0.00	4.10e-06 0.58	0.00e+00 0.00
total	2.75e-04 0.14	2.81e-04 0.13	3.28e-04 0.12	3.27e-04 0.11	3.36e-04 0.11

TABLE XI (CONTINUED0

cosine:	[illegible]	[illegible]	3.0000e-01	4.0000e-01	5.0000e-01
energy					
0.0000e+00					
5.0000e-02	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00
1.0000e-01	1.60e-06 1.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00
2.0000e-01	2.72e-05 0.25	1.96e-05 0.32	2.27e-05 0.28	3.91e-05 0.25	3.36e-05 0.25
3.0000e-01	3.16e-05 0.22	3.41e-05 0.23	2.36e-05 0.30	2.86e-05 0.31	2.33e-05 0.29
4.0000e-01	1.20e-05 0.36	2.15e-05 0.27	1.57e-05 0.35	2.34e-05 0.27	1.18e-05 0.39
5.0000e-01	1.70e-05 0.33	2.88e-05 0.26	3.08e-05 0.28	2.25e-05 0.30	1.63e-05 0.35
6.0000e-01	1.38e-05 0.37	2.05e-05 0.29	2.49e-05 0.27	2.29e-05 0.28	1.91e-05 0.28
8.0000e-01	2.34e-05 0.27	3.40e-05 0.21	3.05e-05 0.23	2.36e-05 0.24	2.88e-05 0.24
1.0000e+00	4.51e-05 0.18	7.00e-05 0.15	4.62e-05 0.17	4.26e-05 0.18	3.87e-05 0.19
1.5000e+00	2.51e-05 0.28	2.67e-05 0.25	2.68e-05 0.25	3.58e-05 0.24	2.37e-05 0.31
2.0000e+00	2.24e-05 0.28	2.94e-05 0.28	2.56e-05 0.32	1.67e-05 0.35	1.78e-05 0.31
2.5000e+00	9.03e-06 0.42	2.57e-05 0.25	4.03e-06 0.58	1.76e-05 0.31	1.13e-05 0.41
3.0000e+00	1.44e-05 0.39	7.45e-06 0.45	1.61e-05 0.41	1.24e-05 0.33	7.82e-06 0.46
4.0000e+00	1.62e-05 0.31	6.94e-06 0.45	6.26e-06 0.50	1.03e-05 0.45	1.34e-05 0.34
5.0000e+00	4.90e-06 0.59	4.11e-06 0.58	8.63e-06 0.41	7.51e-06 0.46	4.05e-06 0.58
6.0000e+00	1.30e-06 1.00	6.11e-06 0.63	2.71e-06 0.71	6.46e-06 0.52	1.30e-06 1.00
7.0000e+00	2.79e-06 0.71	4.04e-06 0.58	0.00e+00 0.00	5.43e-06 0.50	4.13e-06 0.58
8.0000e+00	4.26e-06 0.58	4.25e-06 0.58	1.29e-05 0.33	1.07e-05 0.38	5.70e-06 0.50
9.0000e+00	0.00e+00 0.00	1.36e-06 1.00	1.32e-06 1.00	1.36e-06 1.00	2.80e-06 0.71
1.0000e+01	0.00e+00 0.00	1.28e-06 1.00	1.40e-06 1.00	1.36e-06 1.00	1.36e-06 1.00
total	2.72e-04 0.11	3.48e-04 0.10	3.00e-04 0.12	3.28e-04 0.11	2.65e-04 0.12

cosine:	6.0000e-01	7.0000e-01	8.0000e-01	9.0000e-01	1.0000e+00
energy					
0.0000e+00					
5.0000e-02	1.86e-06 1.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00	0.00e+00 0.00
1.0000e-01	3.23e-06 0.71	0.00e+00 0.00	0.00e+00 0.00	1.70e-06 1.00	2.47e-06 1.00
2.0000e-01	1.63e-05 0.34	2.05e-05 0.30	1.87e-05 0.31	4.43e-06 0.60	9.43e-06 0.49
3.0000e-01	3.14e-05 0.23	2.06e-05 0.29	2.62e-05 0.28	1.00e-05 0.38	6.54e-06 0.52
4.0000e-01	2.36e-05 0.28	2.53e-05 0.33	1.07e-05 0.35	1.78e-05 0.32	1.13e-05 0.40
5.0000e-01	2.16e-05 0.30	2.16e-05 0.31	2.10e-05 0.33	4.44e-06 0.58	6.70e-06 0.52
6.0000e-01	1.45e-05 0.37	1.75e-05 0.37	9.44e-06 0.43	7.66e-06 0.52	1.30e-05 0.48
8.0000e-01	2.82e-05 0.29	2.36e-05 0.25	1.91e-05 0.31	2.11e-05 0.28	1.38e-05 0.34
1.0000e+00	4.93e-05 0.17	3.68e-05 0.20	2.79e-05 0.24	3.07e-05 0.21	1.90e-05 0.29
1.5000e+00	2.01e-05 0.31	3.02e-05 0.24	2.31e-05 0.25	1.60e-05 0.36	1.27e-05 0.37
2.0000e+00	1.75e-05 0.31	1.23e-05 0.33	6.03e-06 0.51	7.46e-06 0.45	1.93e-06 1.00
2.5000e+00	1.26e-05 0.40	1.82e-05 0.39	6.65e-06 0.52	8.74e-06 0.41	0.00e+00 0.00
3.0000e+00	4.24e-06 0.58	1.41e-05 0.39	4.74e-06 0.59	5.56e-06 0.50	4.26e-06 0.58
4.0000e+00	8.37e-06 0.41	7.93e-06 0.59	8.10e-06 0.41	9.30e-06 0.43	2.59e-06 0.71
5.0000e+00	9.47e-06 0.50	2.58e-06 0.71	3.86e-06 0.58	2.17e-06 1.00	1.54e-06 1.00
6.0000e+00	1.66e-06 1.00	2.83e-06 0.71	4.45e-06 0.58	4.31e-06 0.58	0.00e+00 0.00
7.0000e+00	1.32e-06 1.00	5.41e-06 0.50	4.13e-06 0.58	0.00e+00 0.00	0.00e+00 0.00
8.0000e+00	7.19e-06 0.45	4.33e-06 0.58	4.54e-06 0.58	2.87e-06 0.71	3.03e-06 0.71
9.0000e+00	2.82e-06 0.71	1.36e-06 1.00	1.36e-06 1.00	3.16e-06 1.00	0.00e+00 0.00
1.0000e+01	1.46e-06 1.00	0.00e+00 0.00	0.00e+00 0.00	1.36e-06 1.00	1.36e-06 1.00
total	2.77e-04 0.13	2.65e-04 0.12	2.00e-04 0.14	1.59e-04 0.17	1.10e-04 0.20

TABLE XI (CONTINUED)

cosine: energy	total	
0.0000e+00		
5.0000e-02	1.86e-06	1.00
1.0000e-01	2.11e-05	0.28
2.0000e-01	4.19e-04	0.07
3.0000e-01	5.05e-04	0.06
4.0000e-01	3.74e-04	0.07
5.0000e-01	3.43e-04	0.08
6.0000e-01	3.41e-04	0.08
8.0000e-01	4.93e-04	0.06
1.0000e+00	8.04e-04	0.04
1.5000e+00	4.54e-04	0.07
2.0000e+00	2.70e-04	0.08
2.5000e+00	2.40e-04	0.09
3.0000e+00	1.71e-04	0.11
4.0000e+00	1.93e-04	0.09
5.0000e+00	1.05e-04	0.13
6.0000e+00	6.13e-05	0.17
7.0000e+00	5.52e-05	0.18
8.0000e+00	1.22e-04	0.11
9.0000e+00	2.38e-05	0.21
1.0000e+01	2.80e-05	0.23
total	5.04e-03	0.03

TABLE XII

GIVEN AND CALCULATED LEAKAGE SPECTRUM OF APRD REACTOR

Group	Emin(MeV)	Emax(MeV)	Leakage Fraction Given	Leakage Fraction Calculated	Calc/Given
1	16.9	19.64		3.781-7	
2	14.92	16.9	1.-5	1.286-5	1.286
3	14.19	14.92	2.-5	2.370-5	1.185
4	13.84	14.19	2.-5	7.986-6	.399
5	12.84	13.84	6.-5	5.849-5(14%)	.975
6	12.21	12.84	7.-5	6.362-5	.909
7	11.05	12.21	2.3-4	2.354-4	1.023
8	10.0	11.05	4.5-4	5.131-4(5%)	1.140
9	9.048	10.0	9.8-4	1.066-3	1.088
10	8.187	9.048	1.59-3	2.001-3	1.258
11	7.408	8.187	2.63-3	3.258-3	1.239
12	6.376	7.408	6.19-3	7.645-3	1.235
13	4.965	6.376	2.059-2	2.450-2(1%)	1.190
14	4.724	4.965	5.47-3	6.862-3	1.254
15	4.066	4.724	2.068-2	2.574-2	1.245
16	3.012	4.066	5.892-2	7.296-2	1.238
17	2.385	3.012	6.184-2	7.386-2	1.194
18	2.307	2.385	1.058-2	1.136-2	1.074
19	1.827	2.307	7.637-2	8.338-2	1.092
20	1.108	1.827	1.750-1	1.903-1(.3%)	1.088
21	.5502	1.108	2.376-1	2.390-1	1.006
22	.1576	.5502	2.581-1	2.144-1	.831
23	.1111	.1576	2.460-2	1.881-2	.765
24	5.248-2	.1111	2.483-2	1.753-2	.706
25	2.479-2	5.248-2	8.91-3	4.896-3(2%)	.549
26	2.188-2	2.479-2	6.7-4	3.066-4	.458
27	1.033-2	2.188-2	2.54-3	8.517-4	.335
28	3.355-3	1.033-2	8.9-4	2.303-4(10%)	.259
29	1.234-3	3.355-3	1.6-4	1.504-5	.094
30	5.829-4	1.234-3	3.-5	7.318-7	.024
31	1.013-4	5.829-4	1.-5	1.203-6	.120

Ratio of Calculated to Given Leakage

Above 3.012 MeV	1.23
.5502 MeV - 3.012 MeV	1.07
Below .5502 MeV	.80

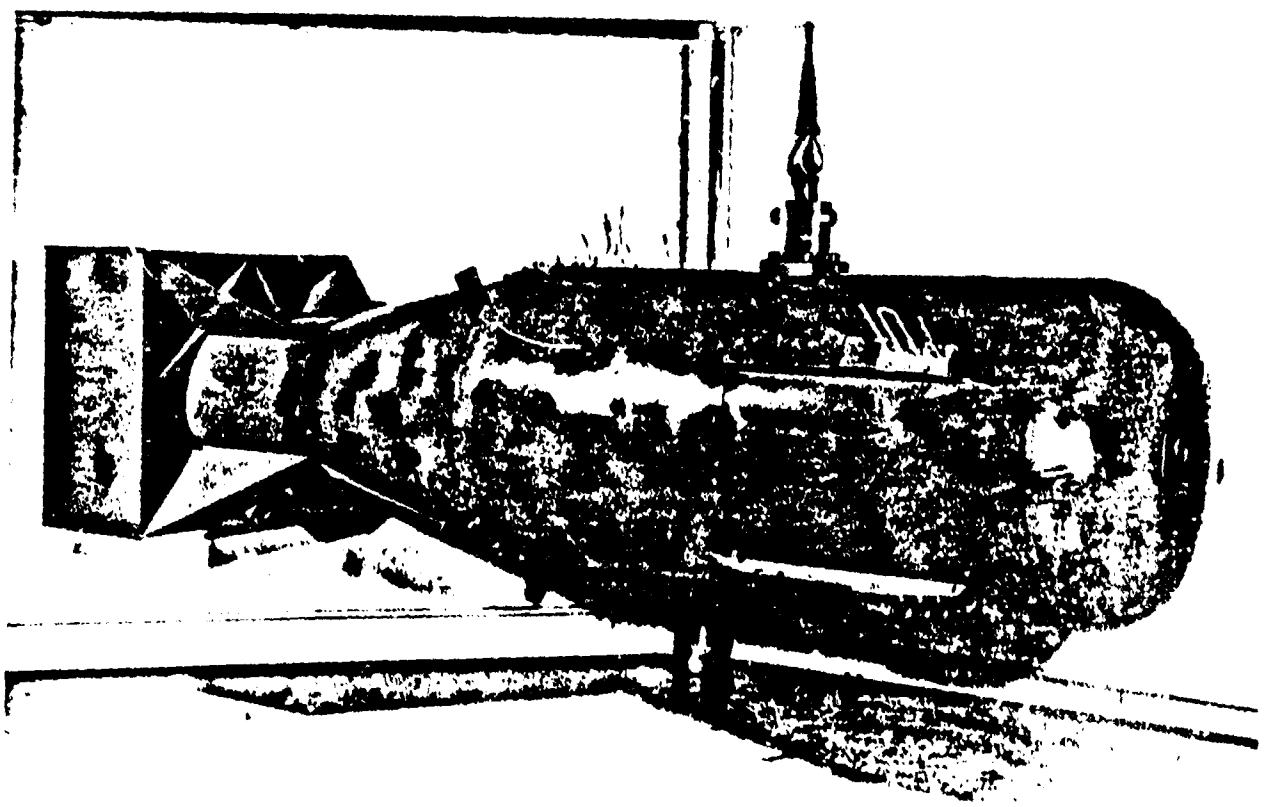


FIGURE 1. HIROSHIMA BOMB (LITTLE BOY)

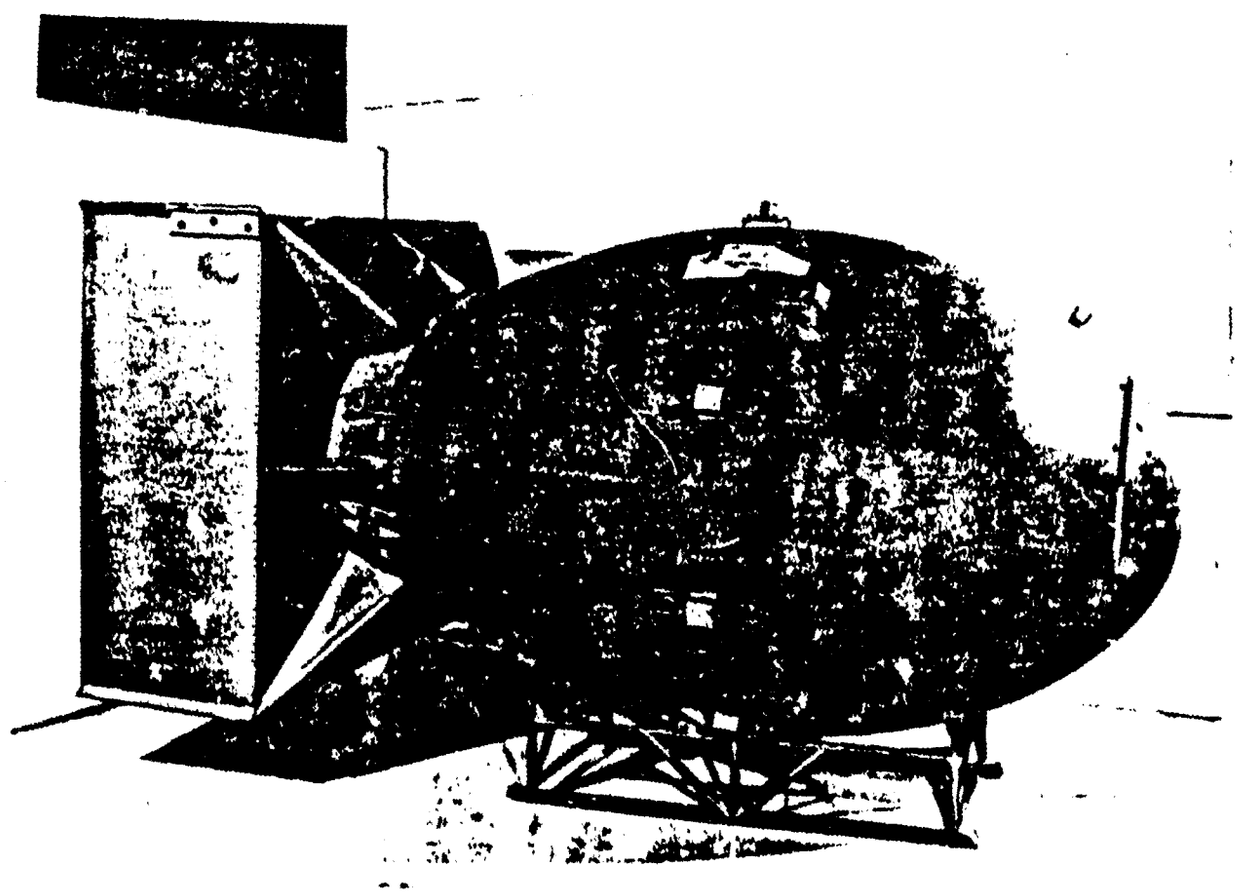


FIGURE 2. NAGASAKI BOMB (FAT MAN)

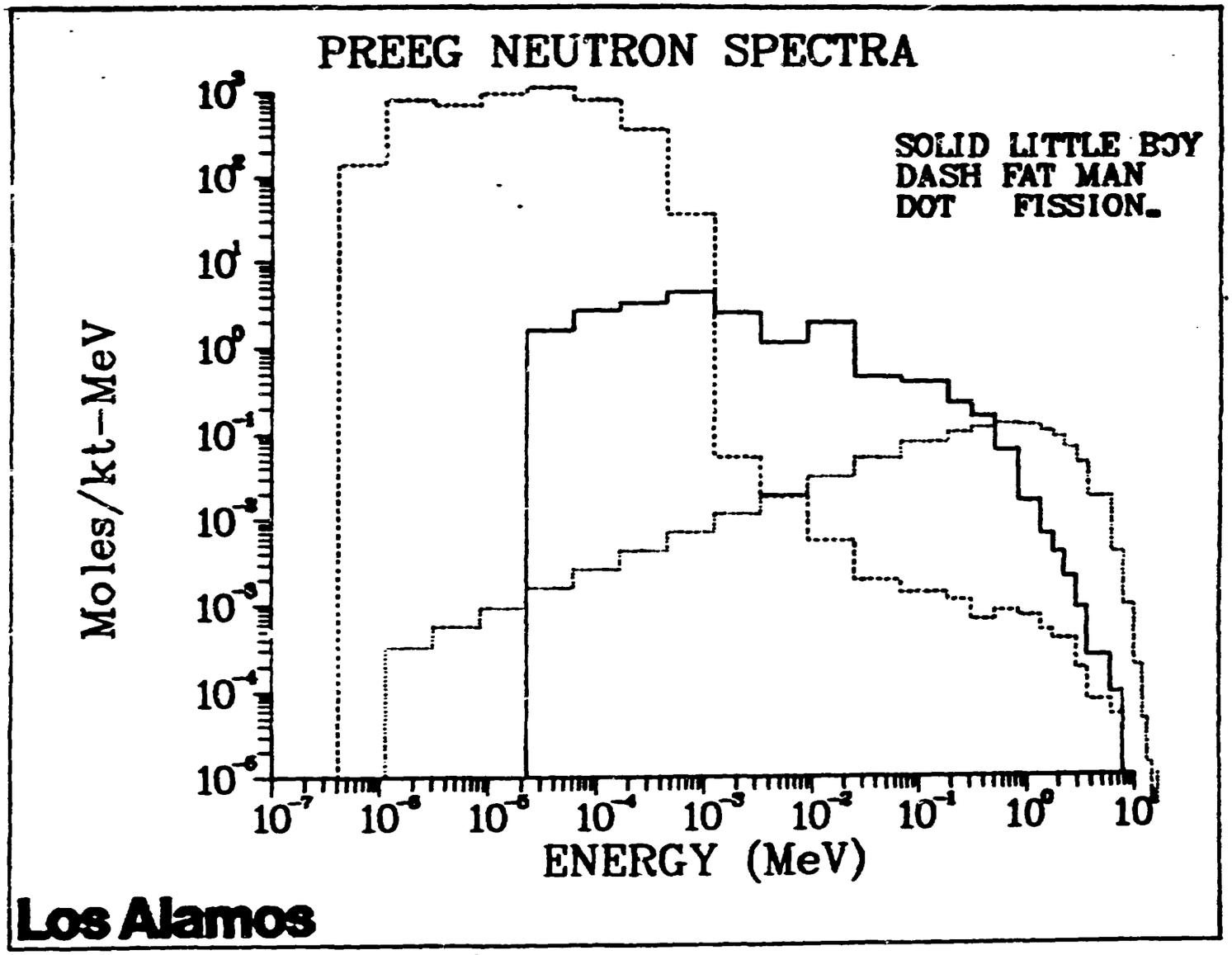

PREEG NEUTRON SPECTRA
SOLID LITTLE BOY
DASH FAT MAN
DOT FISSION
Moles/kt-MeV
ENERGY (MeV)
Los Alamos

FIGURE 3

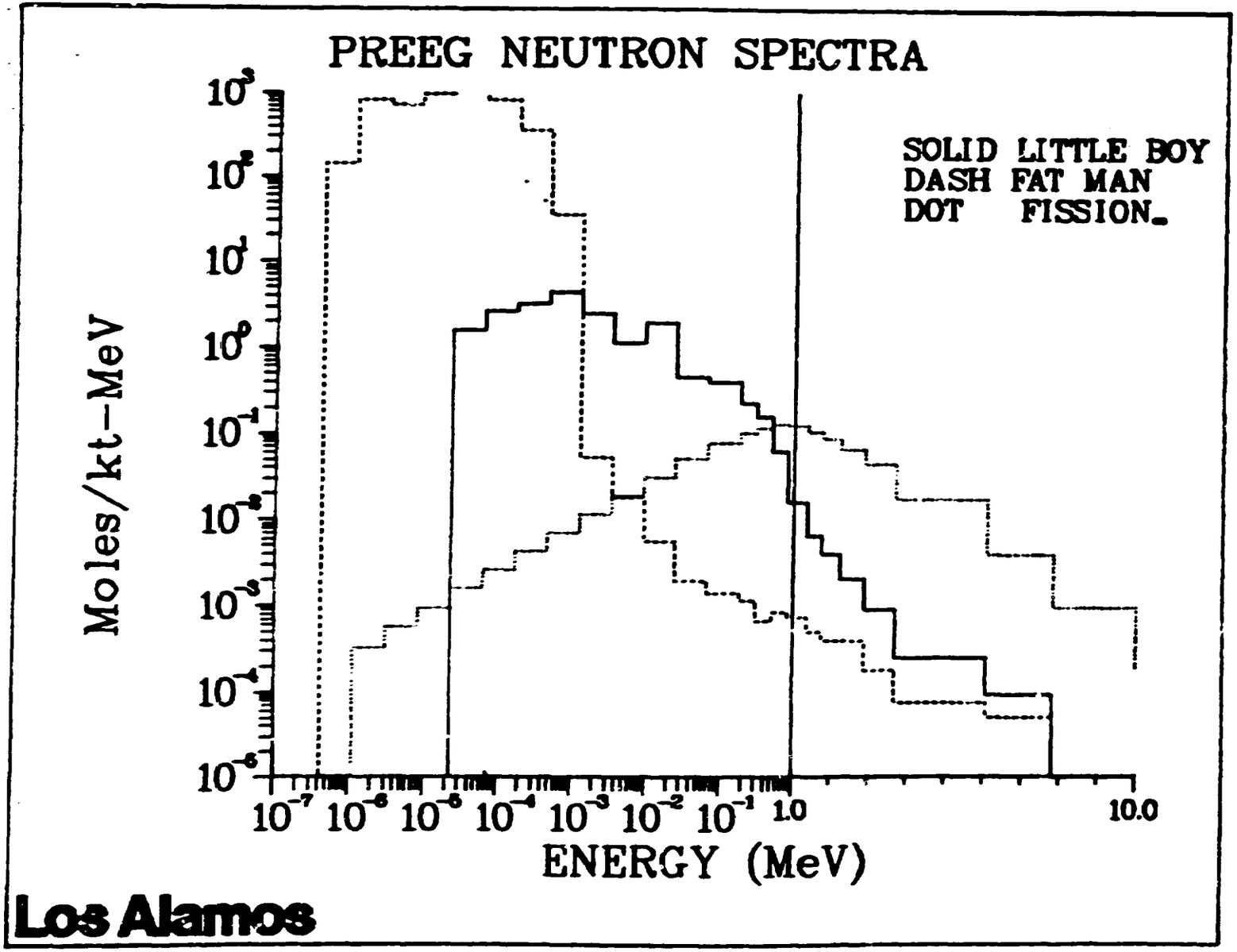

PREEG NEUTRON SPECTRA
SOLID LITTLE BOY
DASH FAT MAN
DOT FISSION
Moles/kt-MeV
ENERGY (MeV)
10.0
Los Alamos

FIGURE 4

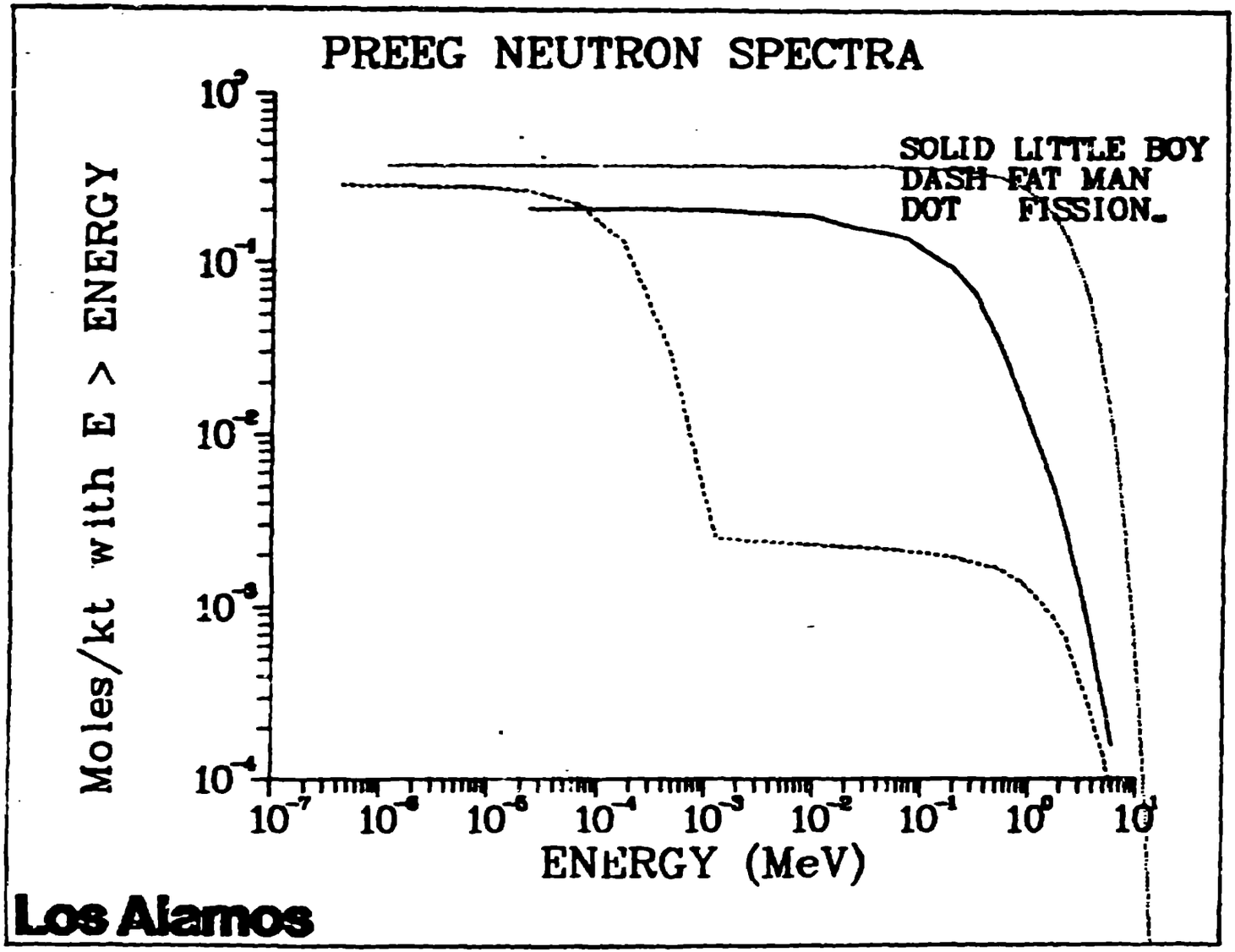

PREEG NEUTRON SPECTRA
SOLID LITTLE BOY
DASH FAT MAN
DOT FISSION
Moles/kt with E > ENERGY
ENERGY (MeV)
Los Alamos

FIGURE 5

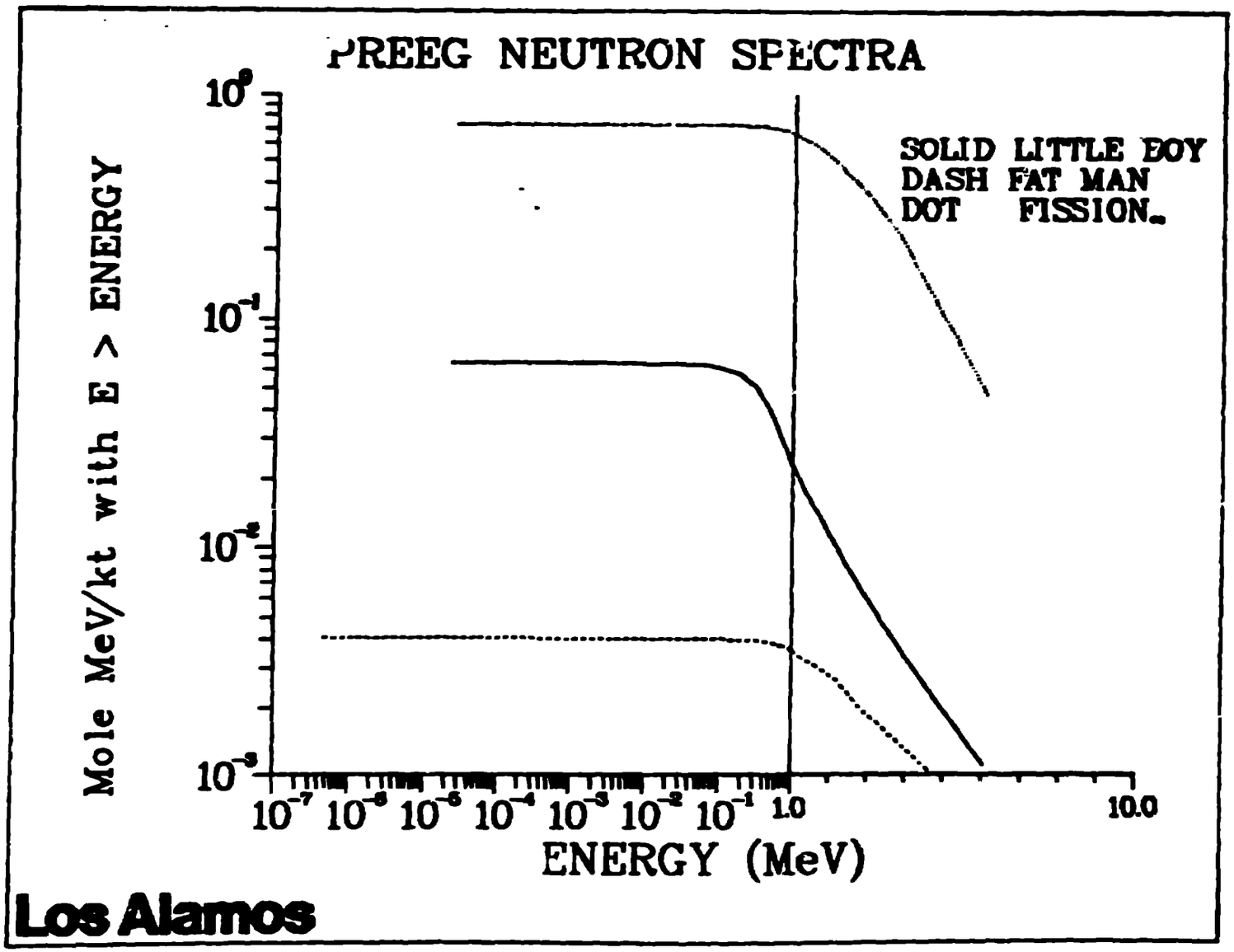

PREEG NEUTRON SPECTRA
SOLID LITTLE BOY
DASH FAT MAN
DOT FISSION
Mole MeV/kt with E > ENERGY
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1.0 10.0
ENERGY (MeV)
Los Alamos

FIGURE 6

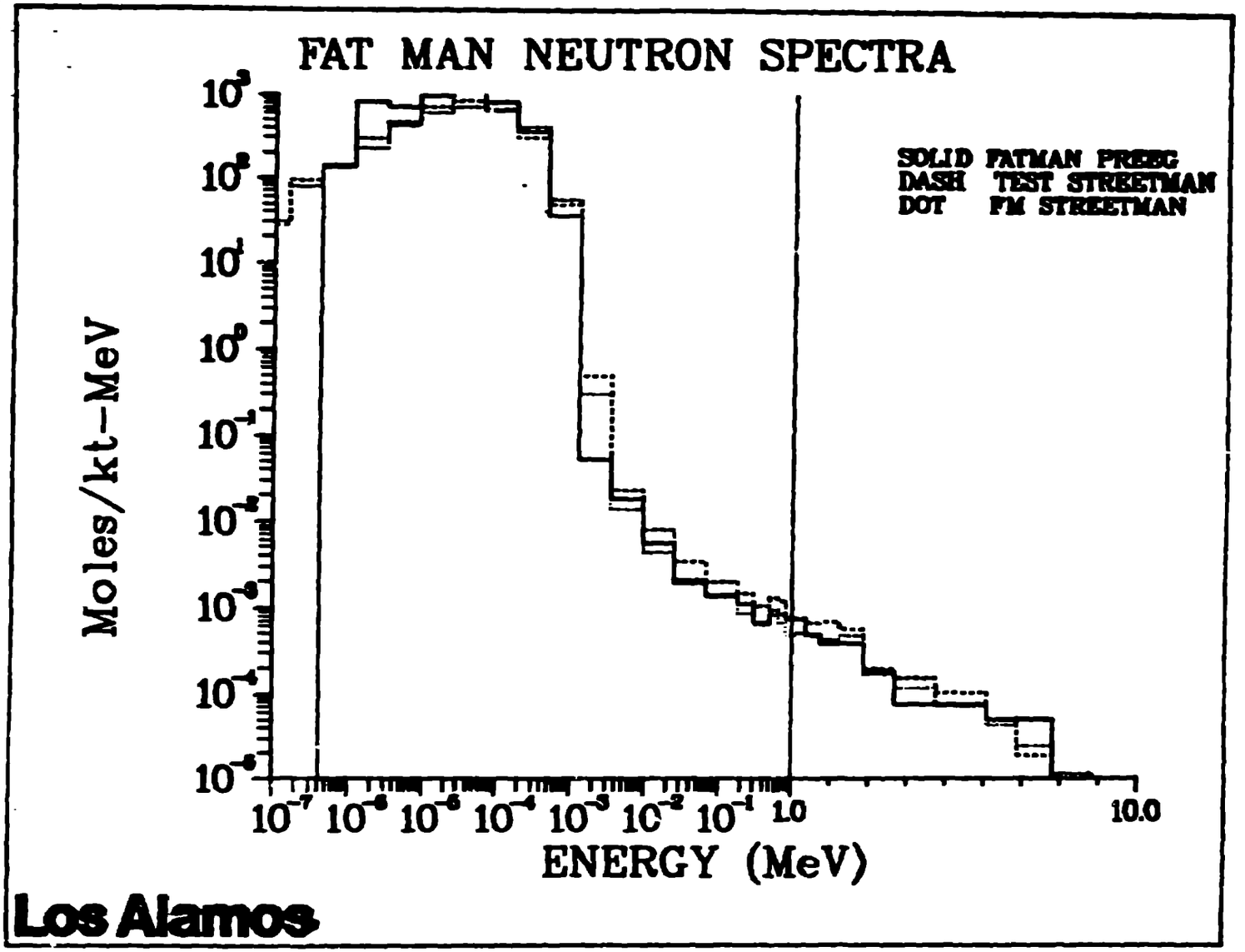

FAT MAN NEUTRON SPECTRA
SOLID FATMAN PREEC
DASH TEST STREETMAN
DOT FM STREETMAN
Moles/kt-MeV
ENERGY (MeV)
Los Alamos

FIGURE 7

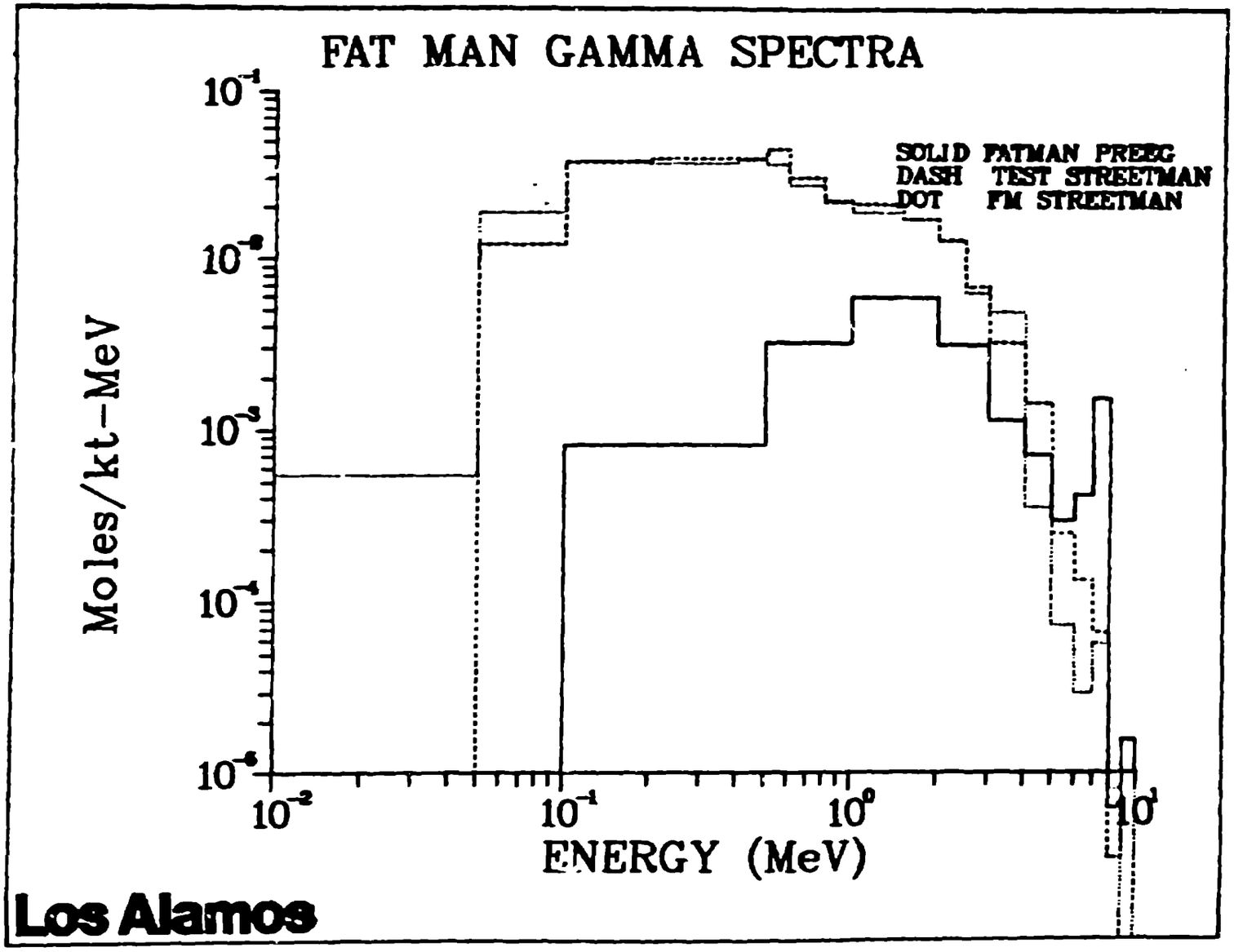

FAT MAN GAMMA SPECTRA
SOLID FATMAN PREEG
DASH TEST STREETMAN
DOT FM STREETMAN
Moles/kt-MeV
ENERGY (MeV)
Los Alamos

FIGURE 3

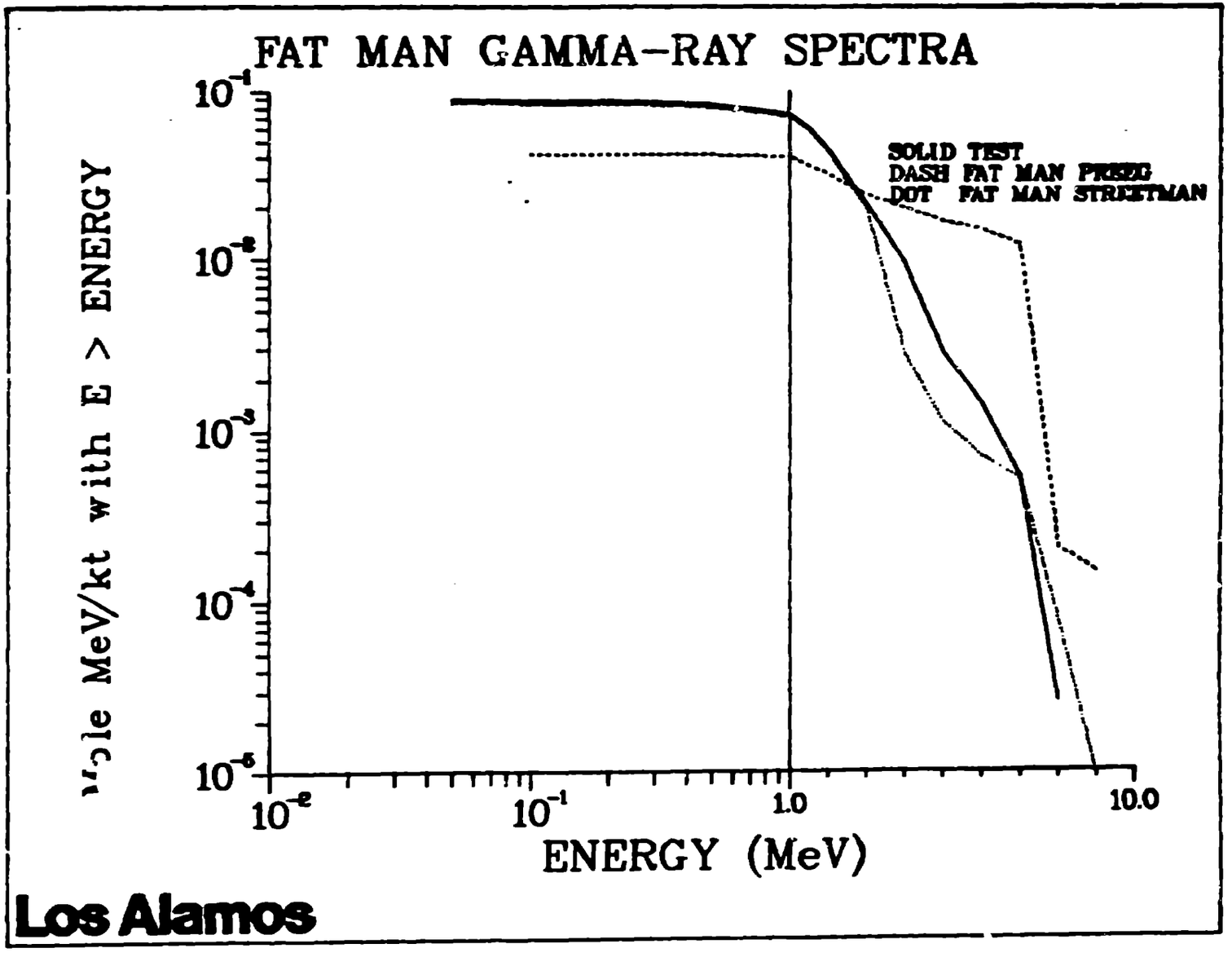

FAT MAN GAMMA-RAY SPECTRA
SOLID TEST
DASH FAT MAN PRESENT
DOT FAT MAN STREETMAN
ENERGY (MeV)
Los Alamos

FIGURE 9

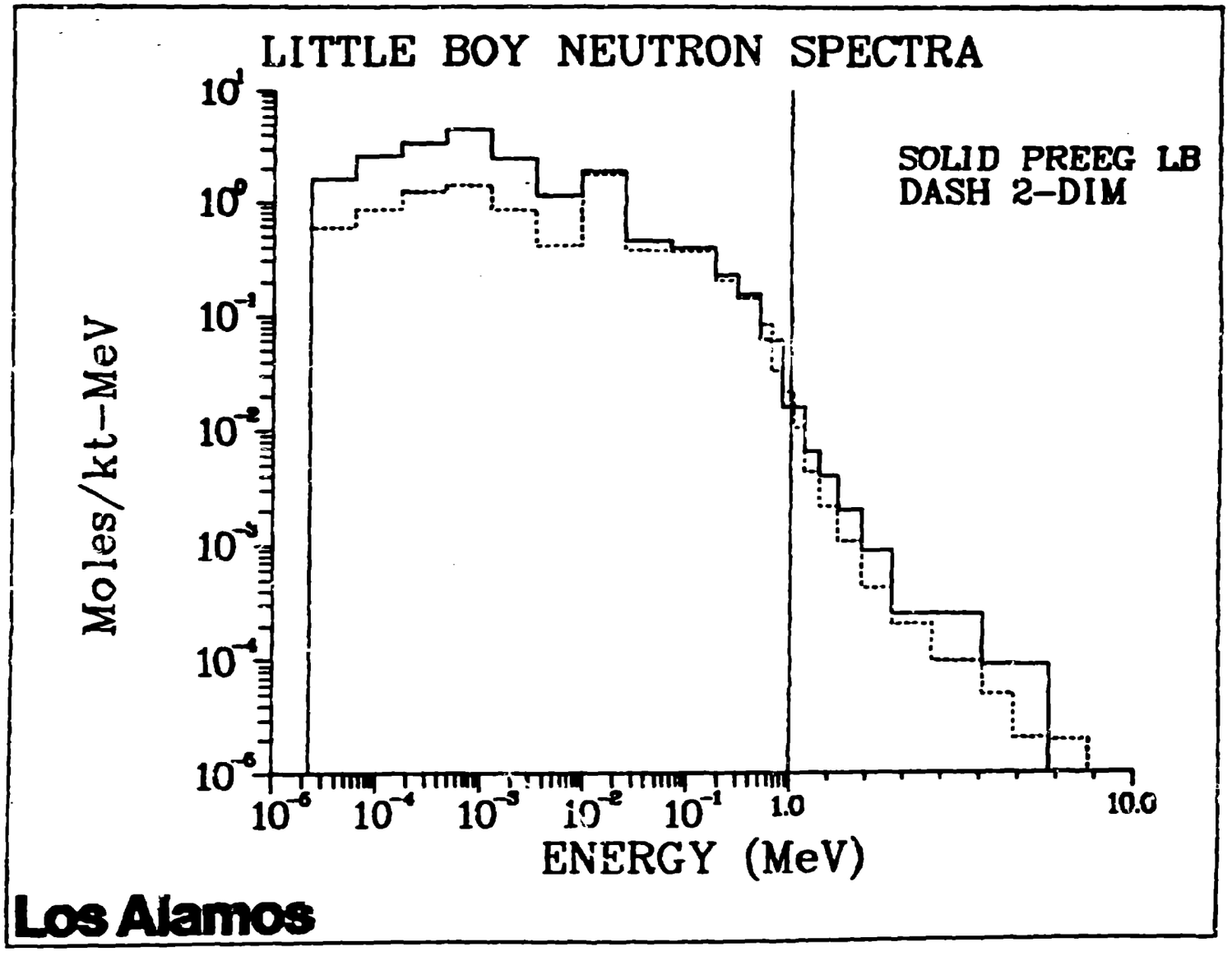

LITTLE BOY NEUTRON SPECTRA
SOLID PREEG LB
DASH 2-DIM
Moles/kt-MeV
ENERGY (MeV)
Los Alamos

FIGURE 10

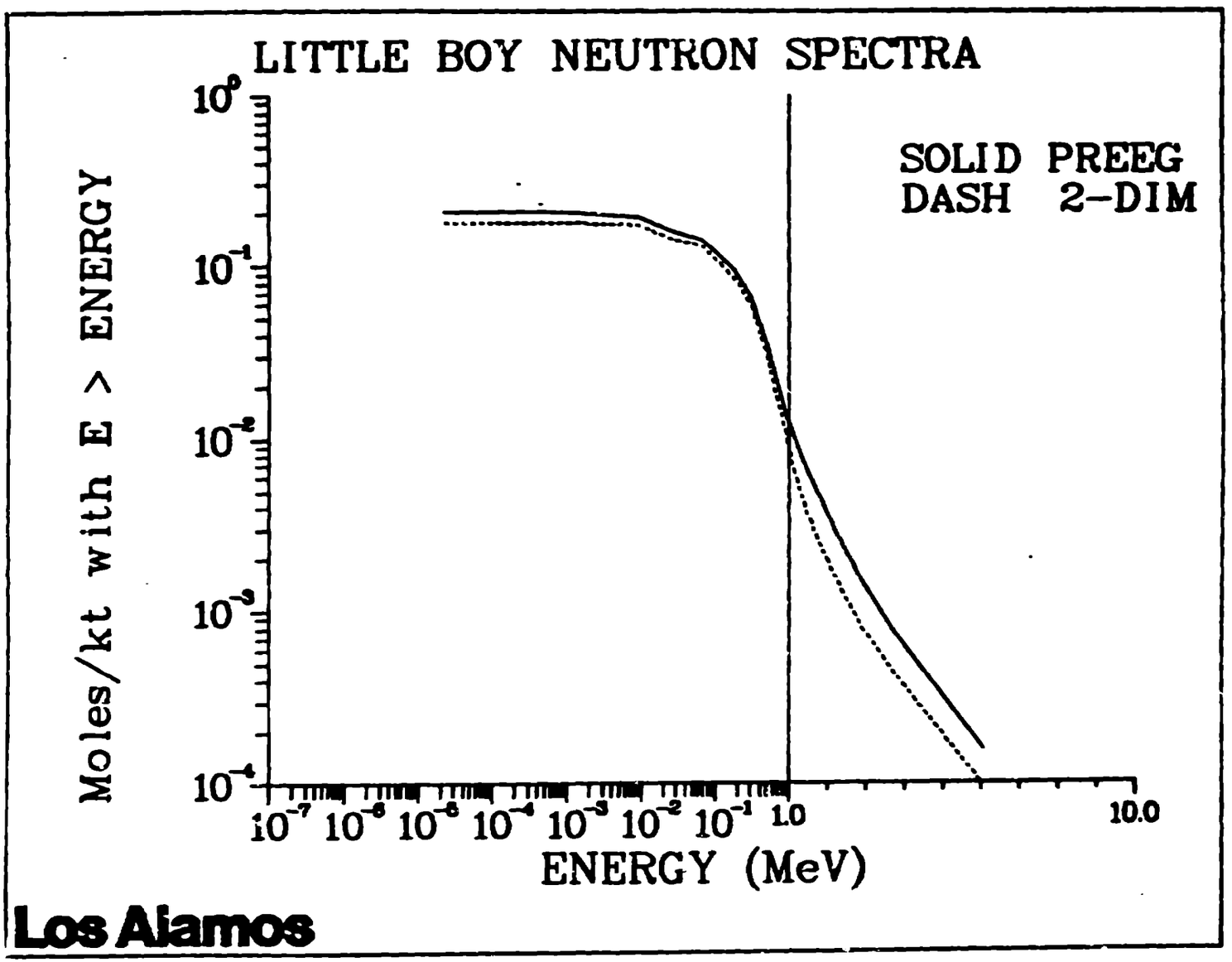

LITTLE BOY NEUTRON SPECTRA
SOLID PREEG
DASH 2-DIM
Moles/kt with E > ENERGY
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1.0 10.0
ENERGY (MeV)
Los Alamos

FIGURE 11

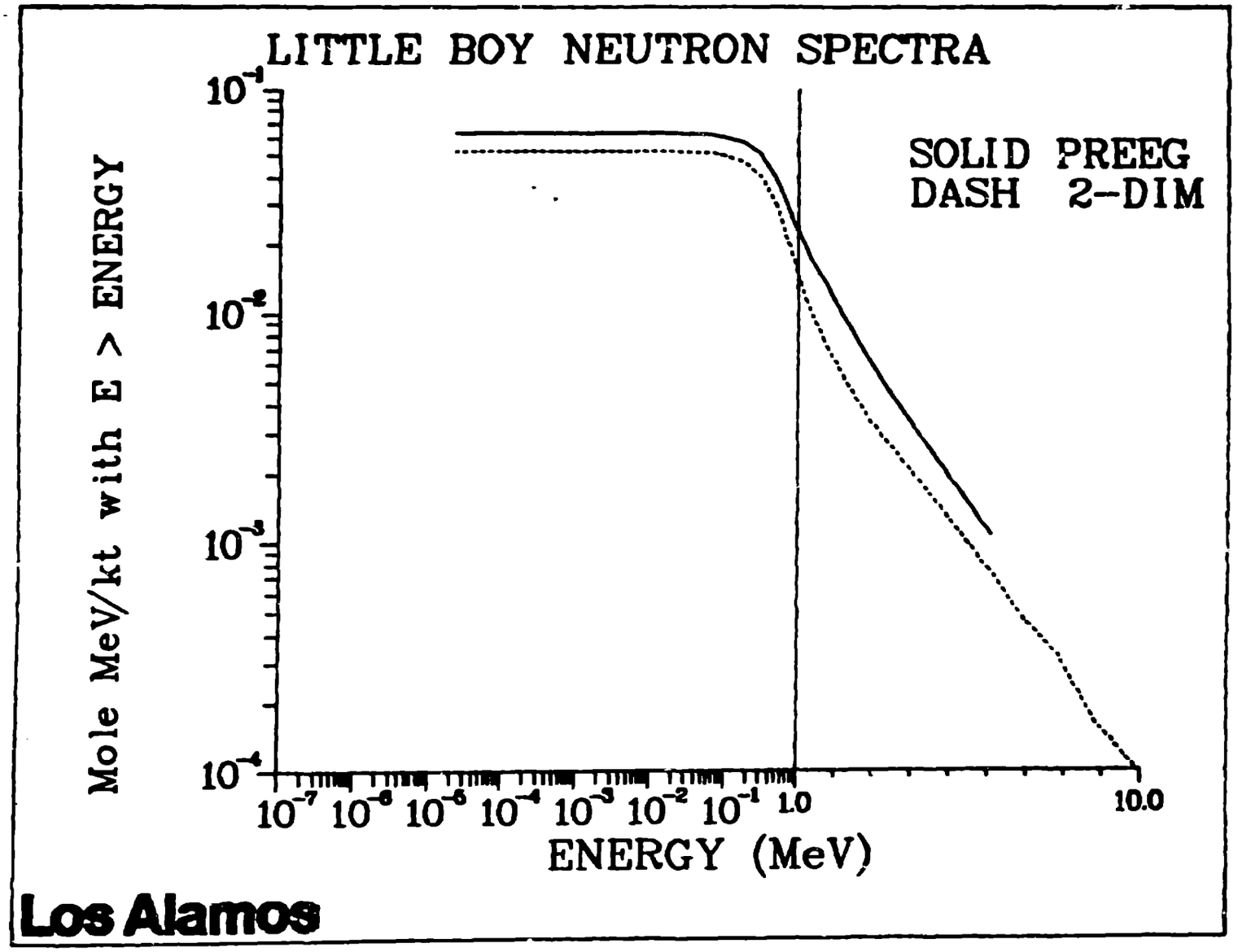

LITTLE BOY NEUTRON SPECTRA
SOLID PREEG
DASH 2-DIM
Mole MeV/kt with E > ENERGY
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1.0
10.0
ENERGY (MeV)
Los Alamos

FIGURE 12

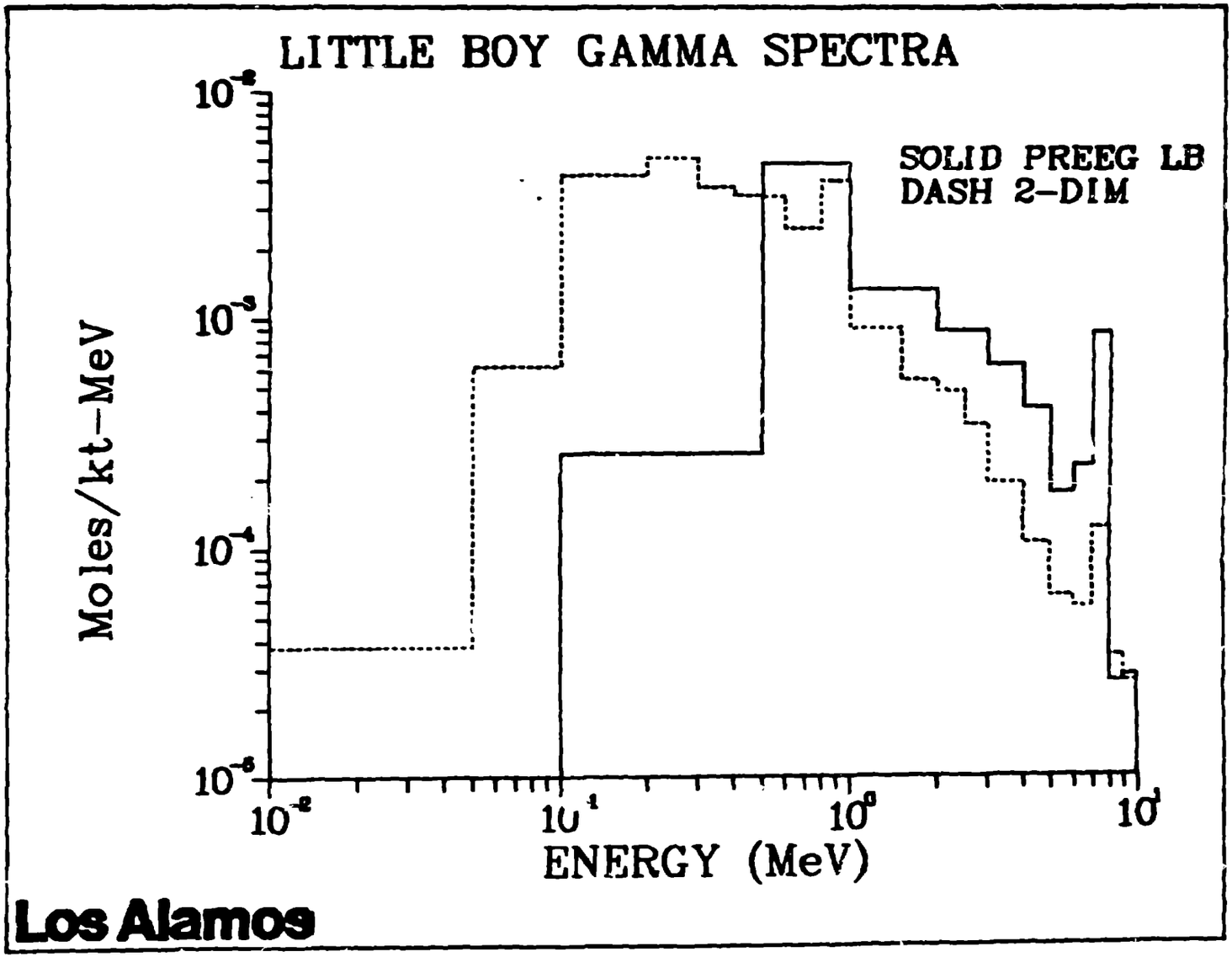

LITTLE BOY GAMMA SPECTRA
SOLID PREEG LB
DASH 2-DIM
Moles/kt-MeV
ENERGY (MeV)
Los Alamos

FIGURE 13

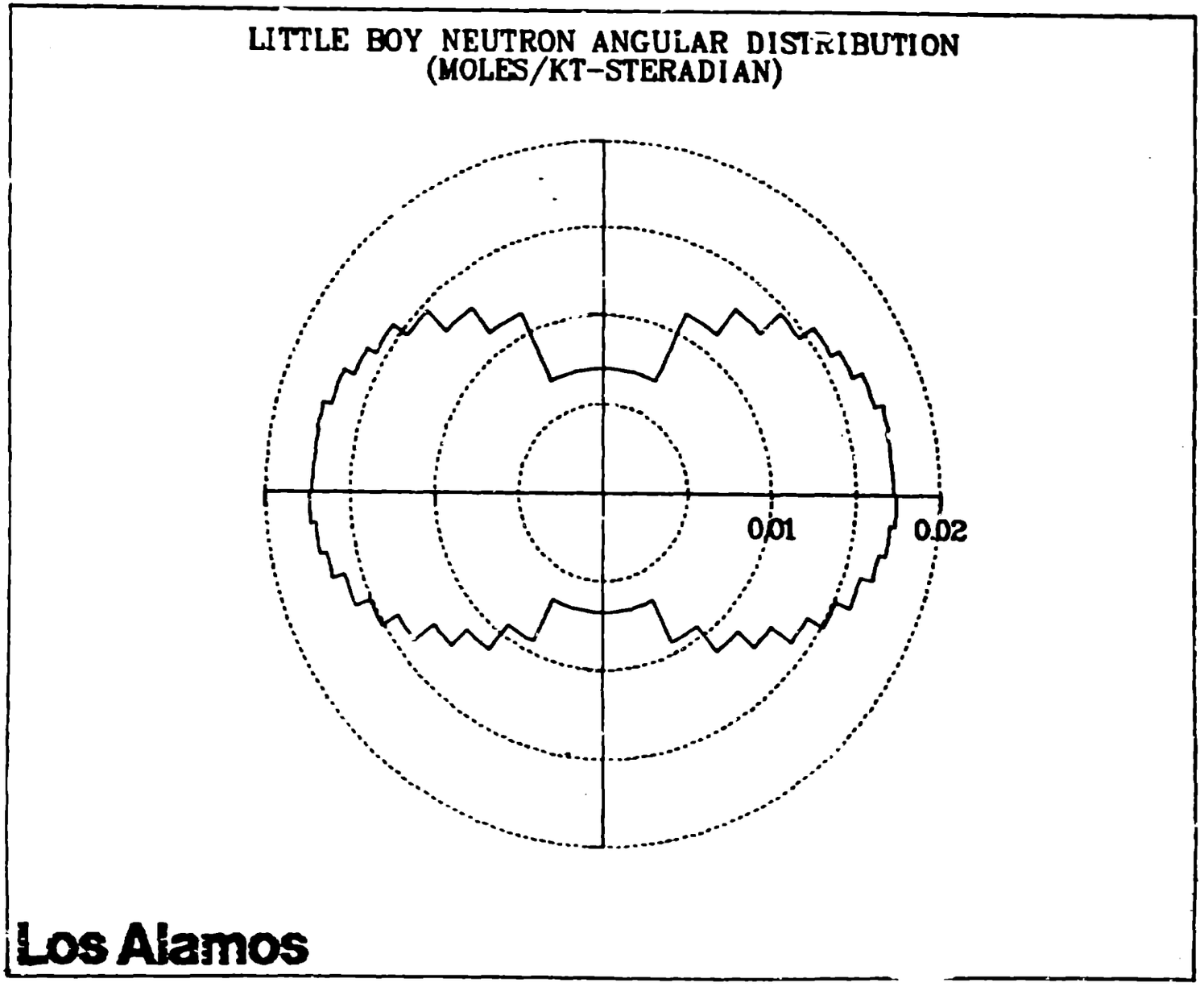

LITTLE BOY NEUTRON ANGULAR DISTRIBUTION
(MOLES/KT-STERADIAN)
0.01
0.02
Los Alamos

FIGURE 11

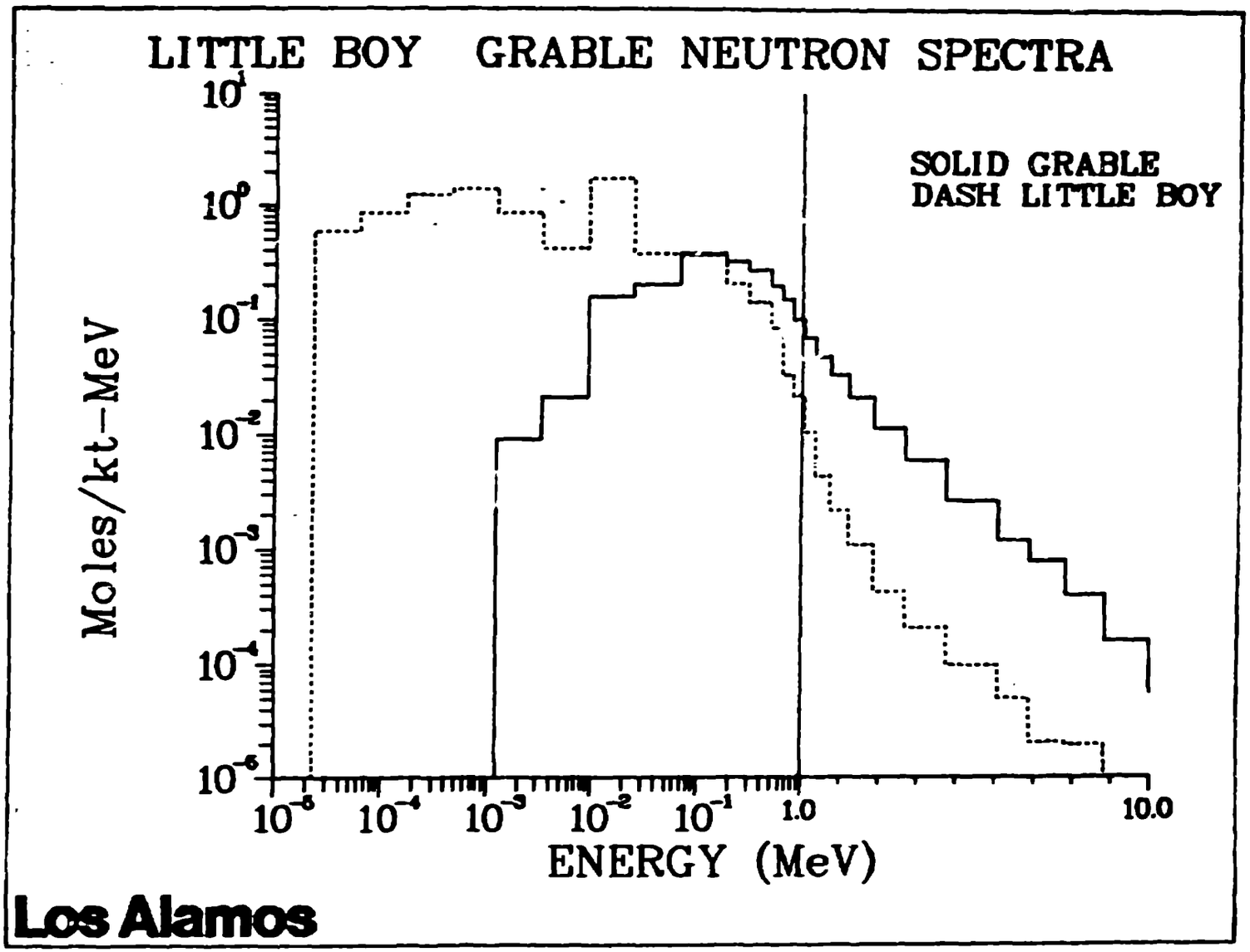
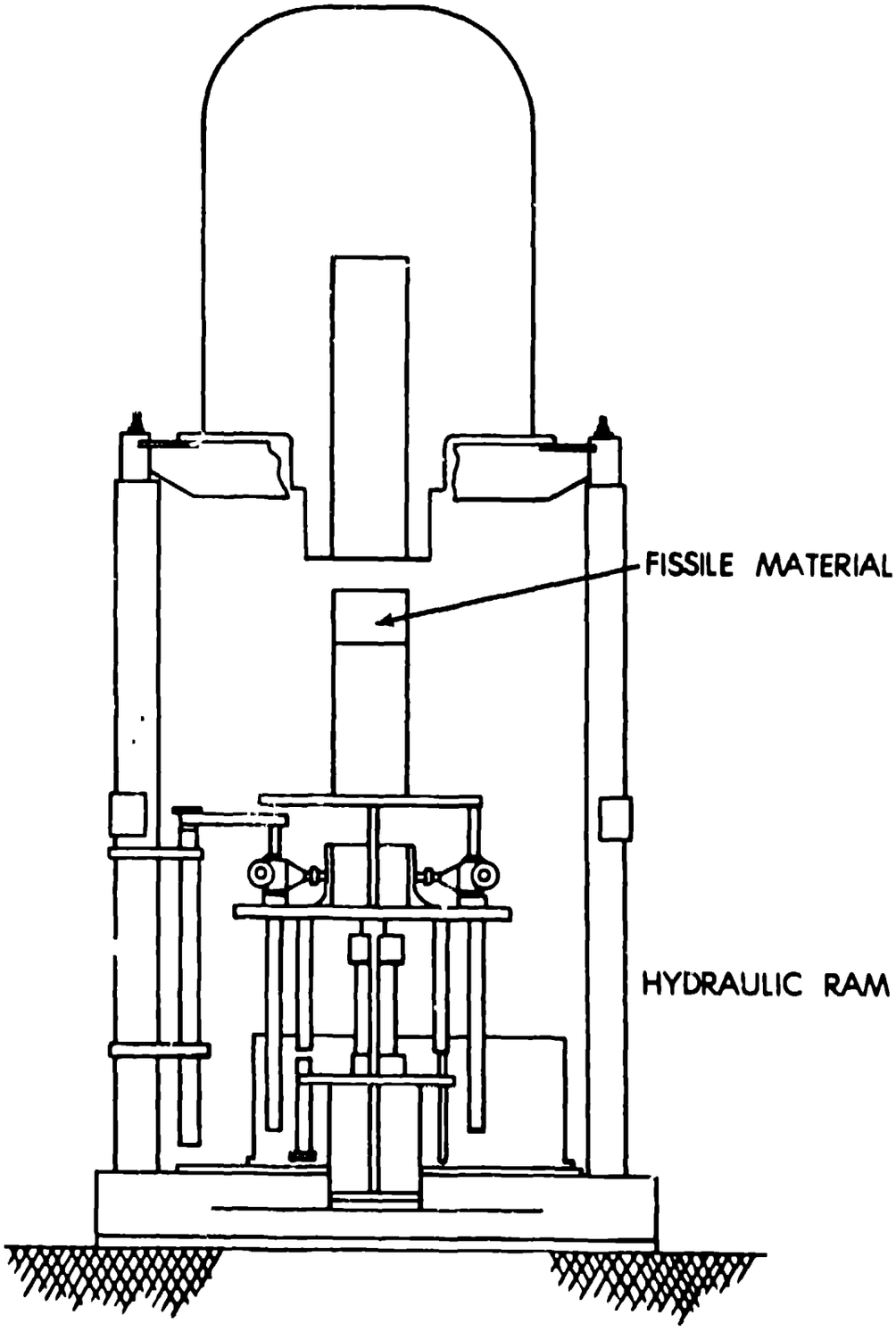

LITTLE BOY GRABLE NEUTRON SPECTRA
SOLID GRABLE
DASH LITTLE BOY
Moles/kt-MeV
ENERGY (MeV)
Los Alamos

FIGURE 15

LITTLE BOY ASSEMBLY



Comet Assembly Machine Showing Little Boy Assembly and Fissile Material Mounted on Hydraulic Ram.

FIGURE 16

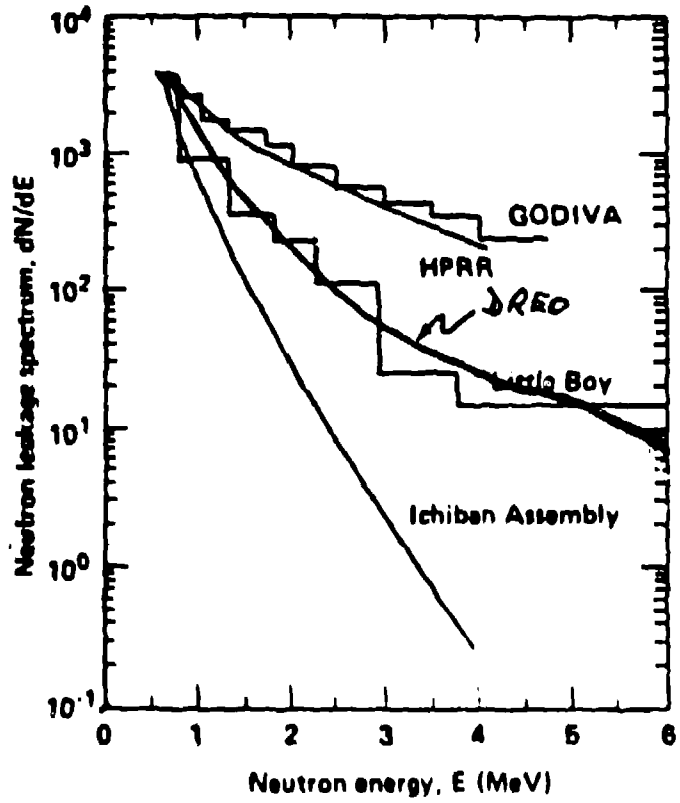


Fig. 7. Neutron leakage energy spectra, normalized at 0.6 MeV.

Two measur
the results supp
in Fig. 7. A ker
1 m was measu
In comparison
spectrum is tol
have used.[18] a
1 m is obtaine
fiss/kt from Rel
from the LAN
scale directly w
value is in fact
integral quantit
kerma at some
between calcula
credibility to t
trum as a sour
transport is det
trons,[19] and th
spectrum is weig

Also suppor
trum is the n
Hiroshima Bec
neutron transpo
sion of the go
obtained is dete

Table V sho
Little Boy and t
of these spectr
is apparent. It
Man spectrum i

FIGURE 17. COPY OF VERY PRELIMINARY LITTLE BOY CRITICAL ASSEMBLY NEUTRON SPECTRUM AS RECEIVED FROM DREO.