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TITLE: SUBCRITICAL MULTIPLICATION DETERMINATION STUDIES

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MASTER

Subcritical Multiplication Determination Studies

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Introduction

A series of measurements and improvements to computational techniques are in progress at Los Alamos National Laboratory that are aimed at better understanding the determination of the reactivity of subcritical systems from measurements of the apparent multiplication of the system. Such studies are being performed in order to improve the special nuclear material (SNM) assays of unknown systems such as those encountered in SNM safeguards, arms-control verification, imports of foreign-generated SNM, etc. Improved techniques and understanding are needed since measured multiplication is not always an invariant characteristic of a subcritical system, especially if one has a system with no significant intrinsic internal neutron [illegible] that is illuminated non-uniformly with an external source (i.e. a non-normal mode system).

Theory

The measurement techniques being used are based on the Feynman variance-to-mean method, and have been previously documented [?] and applied successfully to normal mode systems such as plutonium spheres, etc. These techniques have been applied to non-normal mode problems with less success, and the current study is an attempt to better understand both the measurement techniques and subcritical multiplication in general.

The Feynman technique measures the deviation of the data from Poisson statistics and relates this difference to the multiplicity of the system. The data is taken by opening a time window and counting the number of events in that window. Approximately one million windows are used to ensure good statistics. A second histogram is formed from the square of the number of counts. The averages of the two histograms are then computed and the deviation from Poisson statistics calculated.

The effect of three major assumptions in the analysis of the data are tested by the experiments and calculations:

1). The system does not have a sharp dead time cutoff, i.e. the assumption that no events will be recorded at times between t and t+δ, where δ is the dead time, is not correct.

2.) The efficiency of the system is independent of the neutron production location.

3) Point kinetics hold, i.e. the system is in normal mode.

Description of Experiments

Measurements and Monte Carlo calculations are planned with sources of ^{252}Cf, plutonium (6 w/o ^{240}Pu), and enriched uranium (93 w/o ^{235}U). To date, only the ^{252}Cf measurements have been made due to scheduling conflicts at the Los Alamos Critical Assembly Facility (LACAF). The initial Cf experiments serve to provide simple benchmarks with calculations of the basic detector efficiency and time history behavior. The Pu measurements will be with a 4.5 kg Pu sphere to test the measurements and calculations for a normal mode system. Later experiments will use ^{252}Cf and PuBe sources externally irradiating enriched uranium disks. This final experiment will be a strong test of the point kinetics assumption since the system will be far from the normal mode, and will provide insight into techniques for interpreting subcritical system reactivity from measurements of this type.

The cf source had a source strength of 1.80e6 n/s at the time of the measurement.

Description of detectors

The two detector pods were placed parallel to one another, with one meter distance between the inside faces of the pods. The sources were placed 63 cm above the floor. In the cf experiments, the detectors were placed over a 1/4 inch thick aluminum false floor in order that scattering from concrete was minimized. The building walls were about 15 feet away, and consisted mostly of thin metal. For the Pu ball measurements, the detectors were placed directly on a concrete floor. This floor was modeled for the calculations.

Computational Methodology

A patch to the Los Alamos MCNP Monte Carlo code [3] has been developed that simulates the measurement technique described above. Two major modifications were necessary in order to simulate the experiments: (1) releasing a statistically correct number of neutrons ranging from zero to n rather than sampling only the two integer number of neutrons surrounding $\bar{\nu}$, and (2) starting fission events rather than neutron events. The calculations produce multiplicity histograms that are analogous to those measured, and are processed in the same manner as the experimental data. At present all calculations are performed in the analog mode. The attempt in the calculations is to calculate exactly what the detectors are measuring, namely the time history of 3He captures in the detectors.

In MCNP simulations of this problem, one must consider both neutrons from the input MCNP "source" (i.e.from spontaneous fission), as well as those "induced" neutrons produced from fissions caused by the "source" neutrons. The fission $\bar{\nu}$ sampling uses the methodology of [4Terrel], and 0-9 neutrons per fission are released and transported individually. Different parameters are available for different nuclides and reactions (e.g. spontaneous fission and induced fission). The outgoing neutron energies are sampled such that the total energy release of the fission event is conserved.

In sampling fission events instead of neutron events, one first determines the number of neutrons released in an event, then transports each in turn starting all neutrons at the time of the fission event. The starting time of fission events are sampled randomly over the time interval of the calculation. We start exactly the number of fission events that occur in nature during the time interval, and sample them randomly in time over the time interval chosen for the calculation. Normally the measurements are taken over one million 250 *mu*second intervals for a total time of 250 seconds. Depending on the statistical accuracy desired, the calculations are performed for 10, 100, or the full 250 sec times. Results will be presented later on the accuracies achieved with these calculational time intervals.

The calculated data is processed just like the measured data to (1) bin the counts in the total time interval into the appropriate number of 250 ms bins, (2) make dead time corrections, (3) count the number of bins having 0, 1, 2, ... counts each, and construct the multiplicity histogram from which the moments are calculated. These moments can be used in normal mode systems to determine the keff or multiplication of the system. It is not clear that this can be done for for non-normal mode systems, and investigation of this is the primary intent of this paper.

The time history of each 3He absorption is written to a file by MCNP for later post-processing. This time history file is then sorted to put the times in monoatonically increasing order. The post-processing code then looks at each 250 ms snapshot to determine 1) if any counts should be eliminated because of dead time considerations, and 2) how many counts remain in that interval. The post-processing code then counts the number of intervals of the one million total that have 0, 1, 2, .. , n counts. This is the so-called multiplicity histogram from which the quantities C, C2, C3, and C4, discussed in the THEORY section, are calculated.

RESULTS: cf benchmark

It was the first intent of this work to demonstrate that MCNP could accurately replicate the multiplicity historgram of the detectors for a pure cf source. This is effect a calculation of the efficiency of the detector system and its environment as well as a test of the mechanics of the time and nu sampling of the source. The normalized histogram results of this first calculation are shown in Fig. ?? where the cf experimental results are plotted against the 250 s calculation. In this and subsequent plots of this type, the result for the number of time bins with 0 counts was arbitrarily plotted at 0.5, 1 count at 1.5, etc.

From Fig. ??, it can be seen that the shape of the two curves is very similiar, but the calculated peak occurs about 0.3 units lower in the multiplicity than the measured data. The calculated peak is also slightly higher. In order to test the "goodness" of the calculated results relative to the measured, this data was processed by the Feynman methodology to determine how well it produced the expected 1.29 multiplication that one should get in theory when processing cf data (Chuck - you can provide better wording!!). Use of the calculated data yields a multiplication of 1.35, about 5 % higher than expected. This is considered very good agreement since neutron measurements are generally only accurate to about 15% due to ??.

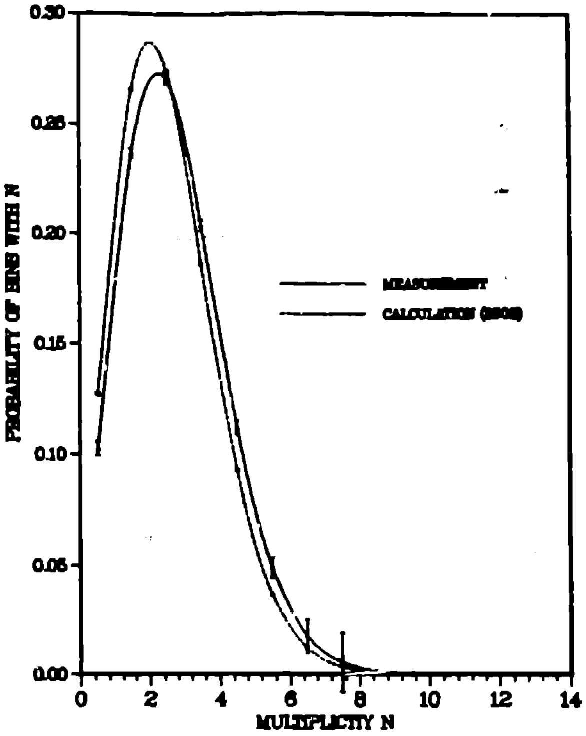

Figure 1: test graph

As noted above, the first 250 s cf calculation was performed to demonstrate that MCNP could indeed reproduce the experimental results in a calculation that mimiced the measurement as exactly as possible. This included not only analog physics, but also calculating the exact time interval, or number of fission events, that were in fact measured. Next, calculations were performed to determine if one could get accurate results by calculating a smaller time interval and fewer number of fission events that were measured. If so, then one could reduce the computer time needed for meaningful calculations and comparisons with experiment. (do we need to talk about computational time??).

Calculations were performed for intervals of 100s, 10s, 2s and 1s. The normalized histogram plots are given in Fig. ??, and the C, C2, ... and multiplication results in Table I. The plots on Fig. ?? are too closely spaced to give an indication of the accuracy of the shorter calculations, but the results for C, C2, ... in Table I do give some insight. Although the multiplication appears to be reasonable for the 1 s case, the fact that it is so far off for the 2 s case indicates that 1 s is not sufficient. This conclusion is also supported by the magnitude of the error estimates. However, based on this data, little can be said about the accuracy of the 10 s calculation.

In order to determine the importance of the various multiplicies in constructing the C, C2, C3, and C4 values, the cumulative value of these quantities as the multiplicities N increase was calculated in the analysis. These results are plotted for C in Fig. ?? for the 1, 10, 100, and 250 s calculations. It can be seen that the 250 s curve is effectively replicated down to 10 s runs, with the 1 s run having a discernable difference. This same type of behavior was found to occur in C2, C3 and C4 to a somewhat greater extent. It would appear from this data that a 10 s calculation is adequate for at least for sensitivity studies.

RESULTS: Pu Ball

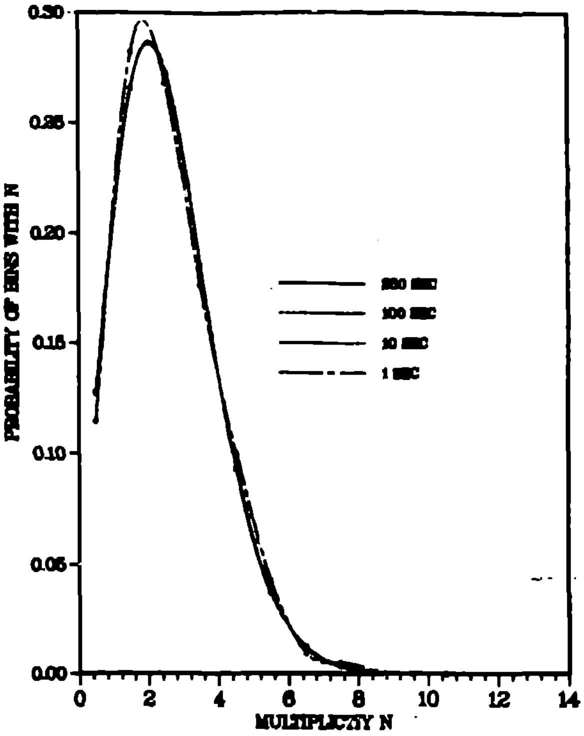

Figure 2: test graph

Due to LACAF scheduling problems, the plutonium and enriched uranium measurements have not been done at this time. However, calculations of the Pu ball, both alone and stimulated by the same cf source used above have been performed. A total of three calculations were performed as follows:

- Pu ball alone at detector center
- Pu ball with cf source 20 cm from its center (near edge of detectors)
- Pu ball with cf source 4 cm from its center (just outside Pu)

The normalized histograms predicted by these calculations a Fig. ??. It is clear from this figure that the apparent multiplication of the system systematically increases from the Pu alone case to the Pu + cf (4cm) case. Table II presents the C, C1, C2, and C4 values as well as the multiplications predicted by the Feynman method. As expected, the predicted multiplication for the case for the cf source at 4 cm is much higher than for the

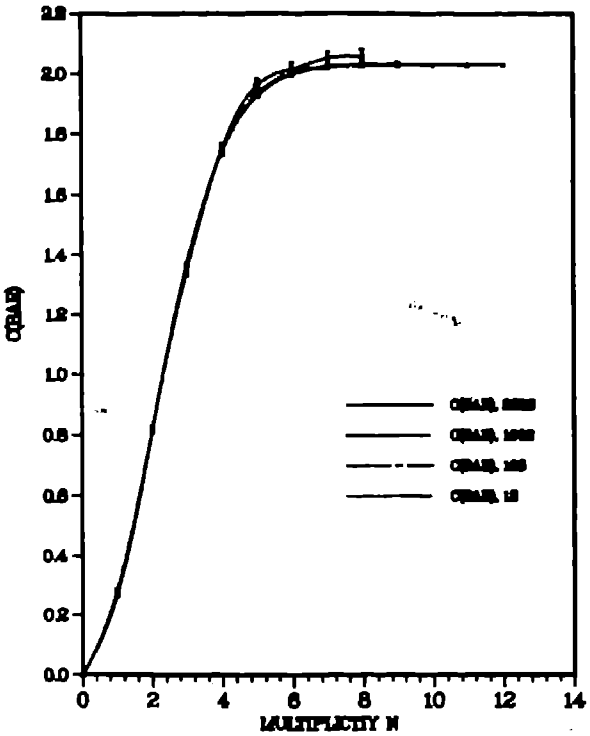

Figure 3: test graph

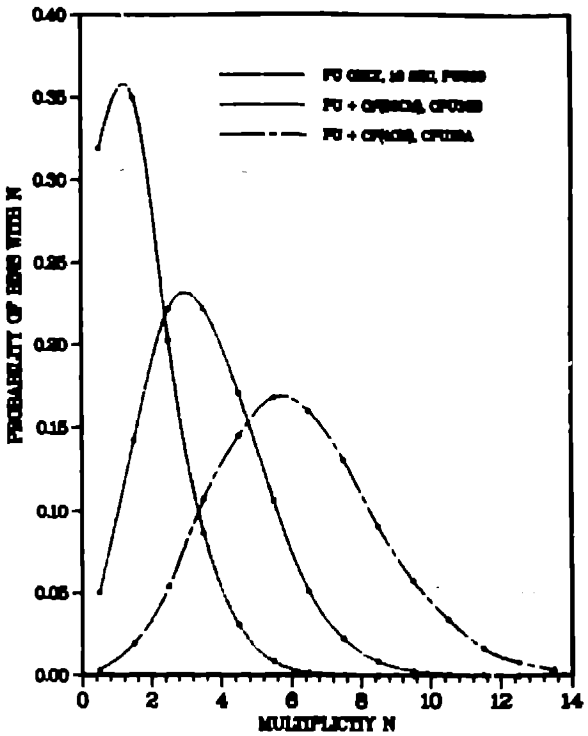

Figure 4: test graph

other two cases. This behavior, if confirmed by the measurements, clearly suggests that the multiplication for externally driven systems such as this cannot be related to the keff of the fissile material alone.

Summary

The results presented here indicate that the described computational technique can predict cf, within the accuracy of the measurements, the multiplicity histogram needed for the Feynman variance-to-mean method of determining subcritical multiplication. It is the opinion of the authors that the calculations will also accurately replicate the behavior of multiplying systems such as masses of plutonium and enriched uranium. The feasibility of such calculations will aid in assaying quantities of fissile material in unknown systems such as those encountered in SNM safeguards, arms-control verification, and imports of foreign-generated SNM.

Acknowledgements

References

[1] E.J. Dowdy, G.E. Hansen, and A.A. Robba, "The Feynman Variance-to-Mean Method", Workshop on Subcritical Reactivity Measurements, August 26-29, 1986, Albuquerque, NM.

[2] A.A. Robba, E.J. Dowdy, and H.F. Atwater, "Neutron Multiplication Measurements using Moments of the Neutron Counting Distribution", *Nucl. Instr. and Meth.*, 215, 473-479 (1983).

[3] "MCNP-A General Monte Carlo N-Particle Transport Code - Version 4A", Los Alamos National Laboratory report LA-12625-M, November 1993.

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memorandum

TO: E. D. Aragon Jr., ESA-WE, MS C936
DATE: June 14, 1995
FROM: Guy P. Estes and W. M. Taylor, XTM
MAIL STOP/TELEPHONE: B226/7-4041
SYMBOL: XTM:yy-nn(U)
SUBJECT: XXX

Table I

	moments (fsd*)				
time(sec)	c1(bar)	c2(bar)	c3(bar)	c4(bar)	multiplication
1	2.0610(.0224)	6.2565(.1227)	23.1720(.0026)	99.3225	1.34
2	2.0514(.0158)	6.2036(.0858)	22.8151(.0013)	97.3751	1.54
10	2.0342(.0070)	6.1210(.0378)	22.3625(.0002)	94.5880	1.36
100	2.0316(.0022)	6.1129(.0120)	22.3668(.0000)	94.9098	1.25
250	2.0335(.0014)	6.1177(.0076)	22.3949(.0000)	95.1871	1.35

GPE:xxx

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