UCRL- 87588
PREPRINT

CONF-821011--12

MASTER

PASSIVE NEUTRON-MULTIPLICATION MEASUREMENTS

A. S. Zolnay
C. S. Barnett
H. P. Spracklen

This paper was prepared for submission to
the Institute of Electrical and Electronics Engineers
1982 Nuclear Science Symposium,
October 20-22, 1982, Washington, D.C.

October 14, 1982

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

A. S. Zolnay, C. S. Barnett, and H.P. Spracklen
Lawrence Livermore National Laboratory
P. O. Box 808
Livermore, CA 94550

UCRL--87588

DE83 001620

Abstract

We have developed an instrument to measure neutron multiplication by statistical analysis of the timing of neutrons emitted from fissionable material. This instrument is capable of repeated analysis of the same recorded data with selected algorithms, graphical displays showing statistical properties of the data, and preservation of raw data on disk for future comparisons. In our measurements we have made a comparison of the covariance to mean and Feynman variance to mean analysis algorithms to show that the covariance avoids a bias term and measures directly the effect due to the presence of neutron chains. A spherical assembly of enriched uranium shells and acrylic resin reflector/moderator components used for the measurements is described. Preliminary experimental results of the Feynman variance to mean measurements show the expected correlation with assembly multiplication.

Introduction

The measurement of neutron multiplication is based on the statistical analysis of the timing of neutrons emitted from an assembly containing fissionable materials. The cause-effect relationship of neutrons emitted in a chain of fission events results in a correlation of neutrons which can be determined through a statistical analysis.

Fission chains are sustained longer and the degree of neutron correlation increases as the system approaches criticality. Fissionable material species and quantity, presence of moderator and reflector materials, and the geometric parameters of the system all influence system multiplication. Thus, it is appropriate to view multiplication as a system performance or figure of merit for sustaining a neutron population.

Knowledge of the criticality status or multiplication of a system is important from a safety standpoint as well as for experimental verification of calculations. Our research is directed toward the development of an instrument we can use to optimize analysis algorithms to specific multiplying assemblies of interest.

This paper describes the electronic instrument developed for neutron multiplication measurements. The capability to repeatedly analyze recorded data allows us to compare the effectiveness of different analysis algorithms. Specifically, we chose to investigate the covariance to mean and Feynman variance to mean ratio algorithms. A well-characterized enriched uranium assembly with simple spherical geometry was chosen for our initial measurements. Preliminary experimental results are presented.

* This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

Electronics Description

The instrument for multiplication measurements consists of 16 independent detector channels, electronics for recording neutron events with the appropriate timing and detector tags, and computing capacity for applying various algorithms for data analysis.

The unique capabilities of the instrument include the ability to repeatedly analyze the same recorded data with selected algorithms, and to optimize algorithm parameters. Graphical displays showing the statistical properties of the data can be made. Finally, the preservation of raw data on disk allows future comparisons of neutron noise properties of changing systems or similar systems. A block diagram of the instrument is shown in Fig. 1. A brief description of the important components will be made in the approximate order of data flow through the instrument.

The detectors consist of 16 helium-3 filled tubes of approximately 2-in. diam and 36-in. length in two banks of 8 backed by polyethylene. Each of the 16 tubes has its own preamplifier-discriminator and amplifier mounted right on the tube assembly. The 16 independent detector channels provide improved signal-to-noise ratio over the large capacitance parallel combination. Deadtime is considerably reduced because all the other detectors are active while a particular one is registering a neutron event. Finally, the 16 channels are not detector specific, that is, some of the channels can be replaced with gamma detectors for investigating gamma-gamma and gamma-neutron coincidences.

The input circuitry is provided with optical coupling between the preamplifier module and the formatter card to ensure proper matching and reduce noise pickup. A synchronizing circuit on each input line allows random input signals to be synchronized with the next 1- μ s clock pulse from the system clock.

The formatter card performs the function of taking the logic signals from the amplifiers and processing them so they are available to a direct memory access (DMA) card in the LSI-11/23 microcomputer. This card has the following multiple functions:

- Input matching.
- Synchronization with system clock.
- Providing a time tag for each event.
- Logging each event by tube number.
- Handling burst rates.
- Sending time tagged data for memory storage.
- Providing periodic format reference bytes in the data stream.

The system clock consists of a 16-MHz crystal source, a divide by 16 precounter to output 1-MHz pulses, and a 16-bit binary synchronous scaler to output time information. The scaler will count 65 536 1- μ s time intervals before restarting. The system clock provides the following functions:

- Input synchronizing pulses.
- Pulse to latch the tube and time data.

- Scaler overflow code signals.
- Sequences the tube, time, and code signals to the first-in first-out (FIFO) device.
- Provides the FIFO input strobe signals.

The random input of the data stream requires that events spaced close together be temporarily stored in a buffer until the computer is ready to accept the data in memory. The FIFO device performs this function with a temporary storage capacity of 32 events.

The flow of information is from pre-amp/discriminator/driver via optical coupling to one of 16 pulse-to-system-clock synchronizers. The time resolution of the system is determined by the 1- μ s clock. One or more pulses occurring during each clock time are latched into a 16-bit register with each bit assigned to a particular detector. The same clock latches a 16-bit counter in a register which is used as a time tag for the data bits. Every 65 536 μ s, when the time counter overflows, a gate is enabled to the bus and a unique word pair is recorded to enable the computer to keep track of system time. The data and time words are sequentially placed on the bus and loaded into a FIFO memory. The FIFO can store up to 32 events which allows burst events to be counted as the computer can accept them. The data are then fed to a direct memory access (DMA) card in the computer which deposits the data in memory. When a full block of memory is recorded, a dump to disk takes place. This operation will repeat either until enough data are taken to satisfy the particular experiment or until the disk is full. Storage of data to a Winchester disk takes place automatically. If a permanent record is required for future reference, the data can be transferred to floppy disks.

A keyboard is provided for user input to the system. Results of data analysis are displayed on a monitor screen or printed out on a printer-plotter.

Covariance to Mean and Feynman Variance to Mean Ratio Comparison

A space and energy averaged model is assumed for the derivation of the Feynman variance to mean expression and the covariance to mean ratio. This model assumes:

1. That a neutron is characterized by existence or nonexistence; no other descriptors enter.
2. There are no delayed neutrons.
3. The assembly is subcritical.
4. That spontaneous fission and nonfission extraneous sources are present.
5. That assembly and extraneous sources have been in place long enough for transients to die away.

Let:

S = neutron emission rate of the nonfission source.

S_F = mean fission rate of the spontaneous fission source.

μ = number of neutrons emitted in a spontaneous fission (a random variable).

ν = number of neutrons emitted by a neutron-induced fission in fuel (a random variable).

$\frac{n}{\tau_C}$ = mean rate of disappearance of neutrons from the assembly by nonfission capture or nondetected leakage when the neutron population is n .

$\frac{n}{\tau_F}$ = mean fission rate in the fuel when the neutron population in the assembly is n .

$\frac{n}{\tau_D}$ = mean neutron detection rate when the neutron population in the assembly is n .

We define $1/\tau$ by the following expression:

$$\frac{1}{\tau} = \frac{1}{\tau_C} + \frac{1}{\tau_D} - \frac{\langle \nu \rangle - 1}{\tau_F}$$

where $\langle \rangle$ represents "expectation"

$$f(t/\tau) = \begin{cases} 0 & \text{if } t/\tau = 0 \\ 1 - \frac{1 - e^{-t/\tau}}{t/\tau} & \text{if } t/\tau > 0 \end{cases}$$

$M(t)$ = number of counts accumulated in the detector by time t . $M(t)$ is a random variable for each t .

Then, it can be shown, (for example, by methods sketched in Ref. 1) that

$$\frac{V[M(t)]}{M(t)} = 1 + \frac{1}{(\tau_D/\tau)} \times \left[\frac{\langle \nu(\nu - 1) \rangle}{\tau_F/\tau} + \frac{\langle \mu(\mu - 1) \rangle}{\langle \mu \rangle + (S/S_F)} \right] f(t/\tau), \quad (1)$$

where V represents "variance."

For the case in which the extraneous source is pure nonfission ($S_F = 0$), Eq. (1) becomes

$$\frac{V[M(t)]}{M(t)} = 1 + \frac{\langle \nu(\nu - 1) \rangle}{(\tau_D/\tau)(\tau_F/\tau)} f(t/\tau) \quad (2)$$

Equation (2) was first derived by Feynman et al.² in 1944. Function f is often called the Feynman function.

Suppose we have two detectors whose efficiencies are characterized by times t_1 and t_2 . Let $M_1(t)$ and $M_2(t)$ be the accumulated counts. Then, it can be shown that

$$\frac{\text{Cov}[M_1(t), M_2(t)]}{\langle M_1(t) \rangle^{1/2} \langle M_2(t) \rangle^{1/2}} = \frac{1}{(\tau_1/\tau)^{1/2} (\tau_2/\tau)^{1/2}} \times \left[\frac{\langle \nu(\nu - 1) \rangle}{\tau_F/\tau} + \frac{\langle \mu(\mu - 1) \rangle}{\langle \mu \rangle + S/S_F} \right] f(t/\tau), \quad (3)$$

where Cov represents covariance.

Notice that the Poissonian relative variance term of unity representing uncorrelated events in Eq. (1) does not appear in Eq. (3). The unit value is itself subject to error that can be large enough to mask the correlated excess term of interest. Thus, the use of two detectors with the covariance algorithm of Eq. (3) avoids the bias term and measures directly the effect due to the presence of neutrons chains. This enables the experiment to be performed even with low detection efficiency.³

Assembly Measured

The assembly used for neutron multiplication measurements consists of an inner spherical moderator shell, 93.2% enriched uranium shells, and outer acrylic resin reflector shells. This assembly was chosen for our initial experiments because the neutron multiplication properties of this simple geometry are well-known from previous experiments and calculations. The multiplication of this assembly can be varied by choices of moderator thickness, mass of fissile material, and reflector thickness. A drawing of the assembly is shown in Fig. 2.

The acrylic resin moderator shells with varying wall thickness fit within the smallest set of uranium shells. The inner void is filled with foam with a hole to locate a neutron source at the center of the assembly.

The fissionable material consists of eight enriched (93.2%) uranium hemispherical shells that can be nested together to build up a solid layer of uranium. Fully assembled they form a 15.9-cm-diam sphere with a central void of 11.8-cm diam. Different combinations of shells allow the assembly mass to be varied from 2313 g to a total of 22 638 g. Identical shells of depleted uranium are also available for studies with constant uranium mass and variable enriched uranium component.

Acrylic resin reflectors fit snugly around the largest uranium shell to provide 2, 5, and 10 cm of reflector. Ten centimeters of acrylic resin provide nearly equivalent infinite reflector for this assembly.

The maximum apparent neutron multiplication (based on neutrons leaking from the system) of the assembly is just over 10. The apparent multiplication, experimentally determined by count rate measurements for the bare and reflected case is shown in Fig. 3. The effective multiplication constant of the assembly in its optimum configuration (with full moderation and reflection) is calculated to be 0.95.

Experimental Results

The assembly described in the previous section with full moderation and reflection was used for our measurements. We first measured apparent multiplication using the count rate ratio method with a nominal 10^4 n/s PuBe neutron source. The nonmultiplying case had four depleted uranium shells. Each of the depleted uranium shells was replaced with enriched uranium, starting with the inner shell and working outward. The variance to mean ratios obtained are tabulated in Table 1 for a 400- μ s sampling interval, along with apparent multiplication from the count rate ratio method.

Table 1. Variance to mean ratio at 400- μ s sampling interval.

Enriched uranium weight (kg)	Apparent multiplication ⁻¹	Variance to mean ratio
5.49	0.576	1.052
11.67	0.383	1.150
16.31	0.265	1.311
22.64	0.132	2.037

The variance to mean ratio increased as the sampling interval ranged from 100 to 1600 μ s. A saturation value beyond 1600 μ s is anticipated in future experiments. Table 2 shows the variance to

mean ratio as a function of sampling interval for the nonmultiplying case (all four shells depleted uranium) and the maximum multiplication case (all four shells enriched uranium).

Table 2. Variance to mean ratio at various sampling intervals.

Sampling interval (μ s)	All shells depleted uranium (nonmultiplying)	All shells enriched uranium (22.64 kg)
100	1.002	1.280
200	1.003	1.554
400	1.004	2.037
800	1.008	2.722
1600	1.011	3.372

We also checked count rate dependence using the nonmultiplying assembly with two PuBe sources of approximately 10^4 n/s and 10^6 n/s. We found less than 0.02 deviation from the expected 1.00 variance to mean ratio for the sampling intervals in Table 2.

Conclusions

Our preliminary results show the expected correlation of Feynman variance to mean ratio with the assembly multiplication. Upon completion of programming of the covariance to mean ratio algorithm, we will experimentally determine the advantages of this method. The capability to explore various analysis algorithms and to repeatedly analyze the same recorded data provides a valuable research tool for neutron multiplication measurements. As we changed the program parameters to analyze the recorded data, we found that not having to contend with the logistics of setting up and repeating experiments was a welcome advantage of this instrument.

Acknowledgments

The authors wish to thank Mechanical Engineering Research Program personnel for their support by selecting and administering this project, and Sandra Robinson for her programming support.

We also express our appreciation to E. J. Dowdy and members of Q-2 group at the Los Alamos National Laboratory for helpful discussions regarding neutron multiplication measurements.

References

1. J. Lewins, Nuclear Reactor Kinetics and Control (Pergamon Press, 1978), p. 160.
2. R. Feynman, F. de Hoffmann, and R. Serber, "Dispersion of the Neutron Emission in ^{235}U Fission," J. Nuclear Energy **3**, 64-69 (1956).
3. N. Pocilio, Reactor-Noise Analysis in the Time Domain, U.S. Atomic Energy Commission, TID-24512 (1969), p. 55.

Fig. 1. Passive neutron multiplication measurements.

Fig. 2. Drawing of assembly with source, moderator, uranium shells, and reflector. Top hemispheres are sectioned to show detail.

Fig. 3. Effect of uranium mass and reflection on multiplication.

DISCLAIMER

This document was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DO NOT MICROFILM
COVER

Technical Information Department • Lawrence Livermore Laboratory
University of California • Livermore, California 94550

DO NOT MICROFILM
COVER

DO NOT MICROFILM
COVER