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NEUTRON DIAGNOSTIC SYSTEM FOR PARTICLE BEAM FUSION EXPERIMENTS

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Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115
and Livermore, California 94550 for the United States Energy Research
and Development Administration under Contract AT (29-1)-789

Printed June 1977

Sandia Laboratories

SF 2900 Q(7-73)

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SF 1004-DF (3-75)

Printed in the United States of America

Available from
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5285 Port Royal Road
Springfield, VA 22161

Price: Printed Copy ; Microfiche \$3.00

NEUTRON DIAGNOSTIC SYSTEM FOR
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ABSTRACT

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The neutron detection system being developed at Sandia Laboratories to measure the neutron production from particle beam fusion target experiments is presented. This system consists of three major components, namely: (1) time resolving neutron counters, (2) neutron threshold activation detectors, and (3) the total neutron yield monitors. These three components when taken together enable a thorough description of target produced neutrons. In particular, the system is capable of giving an indication of the neutron spectrum produced, the total number of neutrons produced, and the neutron formation time. The system is designed to maintain as high an overall detection efficiency as possible since it is expected that initial pellet implosion experiments will have low thermonuclear neutron yields. A novel feature of the system is the use of gated photomultiplier tubes capable of operating in the presence of the intense bremsstrahlung background characteristic of electron and some ion beam experiments.

*Work supported by U. S. Energy Research and Development under Contract AT(29-1)-789.

I. Introduction

The detection and measurement of neutrons produced in the REB accelerator diode is of primary importance for the determination of the degree of pellet implosion and heating obtained. Two mechanisms for neutron production are known to be possible in experiments involving the implosion of D-T filled pellets with a relativistic electron beam. These two mechanisms give rise to (a) true thermonuclear neutrons produced by pellet implosion and heating, and (b) neutrons produced by ions present and accelerated by the fields existing within the diode of the REB accelerator. In order to correlate the neutron production with compression and heating, it becomes essential that the neutron diagnostic systems be capable of distinguishing between these two sources of neutrons. It is also expected that initial pellet implosion experiments will have low thermonuclear neutron yields. The above properties call for a system which has as high efficiency as possible, is capable of giving a measure of the neutron spectrum produced as well as the total number of neutrons produced, and of particular importance, it should be able to determine the time of formation of the various neutron groups. In addition to these requirements, it must contend with the intense bremsstrahlung pulse produced by the decelerating electrons in the REB diode.¹

In order to obtain the maximum information available, the neutron diagnostic system being developed consists of three separate detection schemes. Each component of the system looks only at a particular aspect of the neutron production, however taken together they give a relatively thorough description of the neutrons being produced. In Section II, we discuss the time-resolving neutron counters under development for pellet

implosion experiments; the nuclear activation system which give a measure of the spectrum of the neutrons being produced is discussed in Section III. Finally in Section IV, we present results on the total neutron yield monitors being developed.

II. Time Resolving Neutron Counters

Time resolving counters are necessary in order to obtain neutron group energies by time-of-flight techniques and also for determining the time of formation for these groups. This latter aspect of the measurements is of particular importance since computer simulations of pellets irradiated with e-beams indicated that, for ablative pusher type pellets, compression and neutron emission occur significantly after the e-beam power pulse.² A system capable of establishing the time for the neutron pulse would then be unambiguous in establishing the thermonuclear character for these neutrons.

In experiments with a REB accelerator, the prompt bremsstrahlung pulse produced by the decelerating electron beam presents the most serious constraint on a time-resolving neutron detector, i.e., a scintillator-photo-multiplier system. With standard circuitry, the x-ray intensity is high enough to saturate the detector to a point beyond recovery until well after the neutron burst is over. The most direct corrective action which can be taken is to add sufficient shielding around the detector to reduce the x-ray flux; however, this option also involves a substantial attenuation of the neutron flux and is thus inconsistent with low-yield measurements. A second option, and the one we have taken is to control the P.M. tube gain so that it is essentially "off" during the x-ray burst and is turned "on" shortly thereafter.

A number of methods have been reported for gating P.M. Tubes.³ Most of them suffer from deficiencies which make them undesirable for the present application; they either have slow "turn-on" times and/or do not have a high enough attenuation ratio between their "on" and "off" state. Nonlinearity, ringing, and spurious pulses have also been encountered with some of these schemes. A gating scheme has been devised which does away with most of these difficulties; it is shown in Figure 1. Here a normal P.M. tube divider chain has been modified to keep the tube at very low gain but capable of switching rapidly to full gain on command by a low level gating signal.⁴

The operation of the circuit shown in this figure can be described as follows: Originally dynodes 3 and 7 are tied to dynodes 4 and 8 through 10 megohm resistors as shown. Electron multiplication in the tube is thus stopped at two places down the chain without seriously disturbing the electron optics near the focus electrode. The chain is heavily bypassed to prevent unwanted dynode potential changes during gating and to allow high linear currents while the tube is "on." Gating is accomplished through the SCRs⁵ and associated circuitry. The SCR anode circuits provide high forward current during gating for fast risetimes, rapidly establishes junction resistances at low stable values and maintains them for a sufficiently long time after the gate pulse. Gating action is initiated by a 10-25 volt positive pulse fed to the SCRs causing dynodes 3 and 7 to return to their normal potentials in the divider chain. After several hundred microseconds the SCR's stop conducting the system reverts back to its "off" state.

The bremsstrahlung pulse is sufficiently strong to result in possible ionization of residual gas within the P.M. tube and/or to produce photoelectrons

FIGURE 1

Schematic of the Gated Photomultiplier Tube Divider Chain

direct interaction with the dynode structure. Both of these can lead to spurious pulses at the anode and have been observed elsewhere in the past.⁶ The use of a gating circuit at two points along the chain was an attempt at circumventing this problem. In some instances it was found that the bremsstrahlung radiation was so intense that, despite the gating used, several inches of lead shielding was still required. The gating does allow, however, for a substantially reduced shielding requirement while preventing x-ray saturation of the detector and thus minimizes such undesirable effects as scattering and attenuation of neutrons by the shielding.

A neutron detector was assembled by coupling a 12.7 cm long by 12.7 cm diameter plastic scintillator⁷ to an RCA-4522 P.M. tube using the gated divider chain described above. The time response for this detector was established by using a low level light pulse from an L.E.D. The shape of the light pulse from the L.E.D. is shown in Fig. 2(a). The detector output obtained when the gating signal is arranged so that only the tail end of the light pulse can be observed, is shown in Fig. 2(b). The first pulse seen here is the inverted gating pulse and the second is the detector output. By removing all instrumental delays it was determined that the delay between application of the gate signal and the beginning of detector "turn-on" was 16 nanoseconds. The risetime of the output pulse observed here represents a combined risetime of the P.M. tube and the gating circuit. This risetime was found to be 11 nanoseconds. In the experiments to be performed these times define a gating time window and hence a minimum distance from the source since the gating should not begin until after the x-ray burst yet should be "full-on" prior to the arrival of the neutrons at the detector. Another important characteristic of the gated

(a) $2 \mu\text{sec/div}$ 50 mV/div
SQUARE LIGHT PULSE
FROM L.E.D. SOURCE

(b) 20 ns/div 50 mV/div
DETECTOR RISE TIME

(c) 10 ns/div 50 mV/div
GATING SYSTEM JITTER

(d) 20 ns/div 0.2 V/div
DETECTOR RESPONSE TO
 $\text{Co}^{60} \gamma$ AFTER GATING

FIGURE 2

Response of the Gated Detector to a Pulsed L.E.D. Light Source and to a $\text{Co}^{60} \gamma$ -ray. In (b) the first pulse is the inverted gate pulse and the second one is the detector output. Here the gate timing is such that only the trailing edge of the light pulse is being observed.

detector is the time jitter between application of the gate signal and the detector turn-on. The results of six consecutive shots are shown in Fig. 2(c). Here the gating signal is used to trigger the oscilloscope and the output from the detector is displayed. It can be seen that the time jitter for the system is extremely low since all six shots appear as a single trace. The jitter is less than the width of the trace at a horizontal sweep of 10 ns per division. This characteristic is important because it determines how close to the tail end of the x-ray pulse the detector can be gated on. Fig. 2(d) shows the overall detector response to a single ^{60}Co γ -ray arriving at the detector shortly after it had been gated on. Using the pulsed L.E.D. light source it was also determined that the gated detector achieved the same gain level in its "on" state as that obtained when using an ungated divider chain.

Two of these gated scintillator-photomultiplier neutron detectors were employed to look at the neutrons produced by ions present and accelerated in the Hydra REB accelerator.⁸ The nominal machine parameters used for this series of measurements were 500 kV, 110 kA, 120 ns electron beam pulse. The time-of-flight (TOF) detectors were placed 7 and 14 meters from the accelerator diode and at angles of 42° and 32° to the diode axis. The detectors were gated "on" immediately after the bremsstrahlung pulse.

The neutrons to be detected were produced via the $d(d,n)^3\text{He}$ ($Q = 3.3$ Mev) and $^7\text{Li}(d,n)^8\text{Be}$ ($Q = 15.0$ Mev) reactions. Deuterons from a deuterated polyethylene film on the anode were accelerated across the diode and interacted with target materials consisting of LiCl and/or TiD_2 at the cathode. Figure 3 shows results obtained for four different shots. When no neutron producing material was present in the accelerator diode no signal was

apparent from either of the two TOF detectors. This is shown in Fig. 3(a). As can be seen from Fig. 3(b), a yield of 2×10^9 neutrons was large enough to cause saturation problems in the detector. These problems disappear as the total flux was reduced to 6×10^8 and then to 4×10^8 . In Fig. 3(d) both $d(d,n)^3\text{He}$ and $^7\text{Li}(d,n)^8\text{Be}$ neutrons are present. These can be identified as two resolved pulses in both detectors.

The timing information obtained from shots were both neutron groups are produced is displayed in Fig. 4. Here the time of arrival of the neutrons at the detector is plotted versus the distance of the detectors to the source. All instrumental delays have been removed. Each data point is an average from 2 shots and the size of the squares is representative of the error bars. The arrow indicates the time at which the diode current begins to rise in the accelerator. The slope of the solid lines shown were determined given the geometrical position of the detectors and calculating the difference in the arrival time of the neutron groups at the two detectors assuming that the incident deuterons on target have an energy of 500 keV. Lines with these slopes were then drawn through the data to give a "best fit." The points at which these lines cross the time axis give the time of emission for the neutrons. The dashed lines were obtained following a similar procedure but assuming an incident deuteron energy of 0.0 keV. Basically this is what would result if the reaction was initiated by thermal ions. While either of the two lines can be said to give a reasonable good fit to the higher energy neutron data, it is apparent that the $d + d$ neutron group data cannot be fit if one assumes that the reaction was initiated by thermal ions. The error bar shown along the time axis is an estimate of the uncertainty in the neutron

(a)

400 ns/div 4.0 V/div NO d OR Li IN DIODE 400 ns/div 4.0 V/div

NEUTRON
YIELD
 2×10^9

(b)

400 ns/div 4.0 V/div d SOURCE/Li⁷ TARGET 400 ns/div 4.0 V/div

NEUTRON
YIELD
 6×10^8

(c)

400 ns/div 4.0 V/div d SOURCE/d TARGET 400 ns/div 4.0 V/div

NEUTRON
YIELD
 4×10^8

(d)

400 ns/div 4.0 V/div d SOURCE/d - Li⁷ TARGET 400 ns/div 4.0 V/div

FIGURE 3

Detector Response for Several Hydra Experiments. The figures on the left correspond to detector 1 and those on the right to detector 2. The sharp positive pulse at the beginning of the traces is a timing fiducial. All sweeps are at 400 ns/div and 4.0 volts/div.

FIGURE 4

Arrival Time of a Neutron Group at the Detector Plotted Versus the Distance of the Detector to the Source. All instrumental time delays have been removed. The arrow indicates the beginning of the e-beam current in the REB diode. The solid lines were obtained assuming 500 keV incident deuterium ions; the dashed lines result assuming thermal ions.

formation time due to data reduction uncertainties introduced in the analysis. It can be seen in this figure that the formation time deduced from the solid lines for the two neutron groups are the same within the experimental accuracy. It should also be pointed out that the time of formation deduced from these measurements is in very good agreement with independent Faraday cup measurements of ion current at the cathode.⁹

As a further improvement to the TOF system, we have designed and are presently building two high pressure helium gas scintillators.¹ Although these scintillators will have a somewhat lower neutron counting efficiency compared to the plastic scintillators now used (a few percent efficiency for fast neutrons), their γ -ray sensitivity will be substantially lower. This should allow us to reduce the amount of lead shielding used, and also to get closer to the tail end of the bremsstrahlung pulse. A number of different high current P.M. tubes, both gated and ungated are also being investigated. These specially selected tubes may be less sensitive to saturation than those presently employed.

III. Neutron Activation System

Scintillation detectors are capable of precisely determining the time history of target produced neutrons in REB fusion experiments. But the use of such detectors to determine the neutron energy spectrum is questionable. The reason for the difficulty is threefold: (1) the neutrons are produced in a single short pulse and therefore cannot be counted as single individual pulses, (2) the response of a scintillation detector to a monoenergetic source of neutrons is such that the output pulses range from zero to some maximum value depending on the angular distributions of the detected recoil protons, and (3) the required use of several inches of lead shielding make it difficult to determine the exact efficiency of the neutron counter.

Consequently, the conventional methods of scaling or using pulse height analysis of a detector's output cannot reliably be used to infer the neutron energy distribution.

For these reasons, we have decided to develop a threshold neutron activation system.¹⁰ In this method, a number of different materials are exposed to a neutron flux. The resulting neutron induced radioactivities are then determined. These activities when combined with a knowledge of the energy dependence of the cross sections of each material irradiated gives the total number of neutrons produced above a given neutron energy threshold. The method offers a number of advantages:

1. Controlled sensitivity over a wide range. Through the choice of materials with different cross sections, it is possible to make measurements down to fluxes as low as 10^4 neutrons/cm² and up to fluxes greater than 10^{14} neutrons/cm².
2. Small size. The detectors may be thin foils or small pellets. This will allow samples to be placed inside the diode of the REB accelerator so that they will intercept the maximum possible neutron flux.
3. Activity measurements are made after irradiation, thus electrical noise induced by the REB accelerator does not affect the counting system.
4. Selection of desired energy thresholds. The cross section for the production of the given activity varies with neutron energy for different sample materials. Therefore, it is possible to select, within limits, materials appropriate for various neutron energy groups.

In addition, the information obtained with the activation system will complement the TOF system in its area of greatest weakness, that is, in determining the total number of neutrons present in a given neutron group. The above considerations make activation systems look quite attractive. Before proceeding several relationships need to be introduced in order to gain a better understanding of threshold activation systems and their designs.

For irradiation times short with respect to the decay times, the initial induced activity in the i th sample nuclei is given by

$$D_i^0 = n_i \lambda_i \int_0^{\infty} \sigma_i(E) \phi(E) dE, \quad (1)$$

where

n_i = the number of target nuclei in the sample available for the reaction to produce the radioactive nuclide i .

λ_i = the decay constant for the activated nuclide i .

$\sigma_i(E)$ = the energy dependent cross section for the reaction producing the activated nuclide.

$\phi(E)$ = the neutron energy spectrum

The amount of initial induced activity D_i^0 left after a delay time t measured from the end of the irradiation is given by

$$D_i(t) = D_i^0 e^{-\lambda_i t}. \quad (2)$$

The total number of disintegrations in a time interval t is given by

$$\text{Total Disintegrations} = n_i (1 - e^{-\lambda_i t}) \int_0^{\infty} \sigma_i(E) \phi(E) dE \quad (3)$$

after a time t

As an aid in helping to understand how these parameters interact in realistic cases, Table I lists several threshold reactions which are useful for fast neutron detection. Included in the table are the half-lives of the radioactive product nuclides, the approximate threshold energy for each reaction, the reaction cross sections at 14 MeV, and the decay mode(s) of the activated nuclides. In addition column six lists the total numbers of disintegrations expected for each product nuclide in one half-life. These numbers were calculated from Equation (5) assuming a 14 MeV isotropic source of 10^7 total yield neutrons that is located 5 cm away from a sample of 1 cm³ volume. From the table it can be seen that at low neutron yields it is advantageous to have product nuclides that have short half-lives (large decay constants), large reaction cross sections, and reasonably large samples.

TABLE I

Some Common Neutron Threshold Activation Reactions

Reaction	$T_{1/2}$ (sec)	Threshold Energy (MeV)	σ (14 MeV, millibarns)	Decay Mode	Disintegrations in one Half-Life
$O^{16}(n,p)N^{16}$	7.1	9.62	41	β^-, γ	43
$Mg^{24}(n,p)Na^{24}$	5.4×10^3	4.73	210	β^-, γ	113
$Al^{27}(n,p)Mg^{27}$	567.6	1.8	78	β^-, γ	75
$P^{31}(n,\alpha)Al^{28}$	138.0	4-5	119	β^-, γ	67
$Cl^{37}(n,\alpha)P^{34}$	12.4	1.4	120	β^-, γ	12
$Ni^{58}(n,2n)Ni_i^{57}$	1.3×10^5	12.0	21	β^+, γ	31
$Cu^{63}(n,2n)Cu^{62}$	585.6	10.65	480	β^+, γ	446
$Pr^{141}(n,2n)Pr^{140}$	204	9.5	1800	β^+, γ	719

In most of our experiments we will have from five to ten different materials present in the activation samples with activation threshold energies ranging from 1-14 MeV. It would thus be possible to obtain the total number of neutrons produced with energies that fall in a number of given energy regions determined by the activation samples, and which cover the entire energy region of interest.

From the above considerations, it is clear that the essential experimental problem involved in performing neutron activations are the irradiation of the sample and the subsequent identification and measurement of the induced activities D_i^0 . To irradiate the sample, we are developing a high speed pneumatic sample transfer system which will place the sample to be irradiated to within a few centimeters of the target inside the diode of the REB

accelerators. After irradiation the system will automatically, and at high speed, transfer the sample out of the diode and to our counting equipment. The high speed is a necessary feature in order to measure short half-life nuclides.

To measure the induced activities D_1^0 we have designed a counting system which is capable of performing conventional β and γ ray spectroscopy with NaI detectors and a multichannel analyser. But in addition, our system will have the capability of performing such functions as $\beta - \gamma$ coincidence measurements, sum coincidence measurements, Compton suppression spectroscopy, and $\gamma - \gamma$ coincidence measurements. These additional capabilities are necessary to reduce the background in low yield measurements. Figure 5 shows a block diagram of the conventional β and γ spectroscopy portion of our system. As an example of the additional flexibility in the system, Figure 6 shows a block diagram of a subsystem configured to measure the coincidence of the two 0.511 MeV gamma rays from positron annihilations.

FIGURE 6

A portion of the neutron threshold activation system configured to measure the coincidence of the two 0.511 MeV gamma rays from positron annihilation.

IV. Total Neutron Yield Counters

The standard detector used for measuring total yields from a neutron burst is the silver activation counter.¹³ This type counter is employed in most, if not all, laser fusion pellet experiments. It consists of four geiger tubes surrounded by silver foils imbedded in a polyethylene moderator. The beta decay of the silver nuclei activated by the neutrons is measured. The count obtained in a one minute interval immediately following the burst gives a measure of the total number of neutrons produced in the burst. One of the principal disadvantages of this type detector is its sensitivity to radiation sources other than neutrons; this then gives rise to a natural background counting rate of ~ 200 counts/minute which is undesirable for monitoring low yield fluxes.

Because of the background countrate problems encountered with the silver activation counters, we are presently developing a new total yield neutron monitor based on a ^6Li glass scintillator.¹⁴ A diagram of this monitor is shown in Fig. 7. The neutrons incident onto the counter are thermalized by the polyethylene placed in front of the scintillator. These thermalized neutrons then interact with the scintillator via the

$^6\text{Li} + n \rightarrow ^3\text{H} + ^4\text{He} + 4.7 \text{ MeV}$ reaction. The entire energy available is converted into recoil energy of the ^3H and alpha particles. This recoil energy is converted into light output by the scintillator which in turn is viewed by the photomultiplier. Since the neutron-scintillator interaction is a direct one, and does not involve an activation process, the necessary time interval required for counting is the characteristic slowing down time for the neutrons, e.g., a few hundred microseconds.

FIGURE 7

Total Yield Monitor

One detector has been assembled using a 2 mm thick, 5 cm diameter ^6Li glass scintillator¹⁵ and a gated photomultiplier similar in design to the one used for the TOF counters. The photomultiplier tube is gated "on" 5 microseconds after the bremsstrahlung pulse. The associated fast electronics used to count the photomultiplier output pulses is gated "on" together with the photomultiplier and remains "on" for a predetermined time period. This counting time is determined by a specially designed gate and delay generator and can range from 1 microsecond to several milliseconds. Because of the short counting time required, and the inherent low γ -ray sensitivity of the scintillator itself, the background counting rate for this detector should be negligible.

Preliminary efficiency measurements for this counter have been made using a calibrated pulsed laboratory neutron source. The detector has also been used to look at neutrons produced by ions accelerated in the diode of the Hydra REB accelerator. The measurements we have made show that, for our application, this concept for a total yield monitor is superior to the silver counters. Not only is the background count rate insignificant, but the sensitivity is as good or better than that of the silver counters; furthermore these counters are substantially smaller than the silver counters allowing for better spatial resolution.

A number of counters similar to the one described here are being constructed, including two with 12.7 cm diameter scintillators. These counters will replace all silver activation counters presently used. A complete set of measurements are planned to thoroughly characterize the performance of these detectors.

ACKNOWLEDGMENTS

The authors would like to thank G. W. Kuswa, J. F. Powell and A. J. Toepfer for their valuable comments and suggestions on this manuscript. We also thank F. C. Young for bringing the Lithium-6 glass counters to our attention.

REFERENCES

1. J. J. Ramirez, "On the Detection of Neutrons from REB Accelerators," Sandia Laboratories Report, RS 5245/017, August 1976.
2. M. J. Clauser, private communication.
3. K. B. Keller, Rev. Sci. Instr. 35, 1360 (1964); G. Charpak, Nucl. Instr. Methods 51, 175 (1967); D. Ben Zeev, et al., Nucl. Instr. Methods 114, 513 (1974).
4. J. J. Ramirez and L. W. Kruse, Rev. Sci. Instr., 47, 832 (1976).
5. Unitrode Corporation, Watertown, MA 02172.
6. See G. P. Lamaze, et al., Nucl. Instr. Methods 123, 403 (1975); also Refs. 1-4 therein.
7. Nuclear Enterprises, Inc., San Carlos, CA.
8. T. H. Martin, IEEE Trans. Nucl. Sci. NS-20, 289 (1973).
9. D. W. Swain, L. P. Mix, L. W. Kruse, and J. W. Poukey, J. Appl. Phys. 48, 1118 (1977).
10. William J. Price, Nuclear Radiation Detection (McGraw-Hill, New York, 1964).
11. Paul Kruger, Principles of Activation Analysis (Wiley-Interscience, New York, 1971).
12. J. A. Halbleib, C. L. Greer, and J. V. Walker, "Neutron Spectroscopy by Foil Activation in Radiation Effects Studies," Sandia Laboratories Report, SC-R-67-1157, July 1967; C. R. Greer, J. A. Halbleib, and J. V. Walker, "A Technique for Unfolding Neutron Spectra from Activation Measurements," Sandia Laboratories Report, SC-RR-67-746, December 1967.
13. R. J. Lanter and D. E. Bannerman, Los Alamos Scientific Laboratory Report, LA-3498-MS, July 1966.

References (Continued)

14. D. Kedem and D. Kedem, Nucl. Instr. Methods 97, 267 (1971).
15. Nuclear Enterprises Scintillator NE-912.

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