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**The Neutron Diagnostic
Experiment for Alcator C-Mod**

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The Neutron Diagnostic Experiment for Alcator C-Mod.

Abstract

The neutron production rate on Alcator C-Mod is expected to peak at 1×10^{16} n/s for the highest performance experimental pulses. Measurement of the total fusion yield is important for both assessing the experiment and for evaluation of radiological data. The neutron detectors must therefore be capable of accurate measurement over a wide operating regime (10^{11} – 10^{16} n/s from the source). This can be achieved with a series of fission detectors (U^{235} and U^{238}), capable of operating in both a pulsed and current mode. Computer calculations optimizing the the placement of these detectors and also the moderator design are detailed. Calibration of this system will be achieved using a Cf^{252} source which will be moved on a track continuously around the major axis. It will also be placed discretely at a number of locations in the torus. MCNP calculations will complement the calibration data. Details of the experimental setup and calibration scheme will be presented.

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I. Introduction

The neutron diagnostic system for Alcator C-Mod must be capable of measuring the total fusion yield over the full range of deuterium operation. The anticipated neutron source rate will vary from 1×10^{11} neutrons/s at $T_i = 1\text{keV}$ and $\hat{n}_e = 1 \times 10^{20}\text{m}^{-3}$ to 1×10^{16} neutrons/s for $T_i = 6.5\text{keV}$ at $\hat{n}_e = 1 \times 10^{21}\text{m}^{-3}$ [1,2]. This system must yield accurate and reliable measurements of the total neutron production both for plasma diagnostics and for the project health physics. The experimental layout, design calculations and calibration plans are detailed below.

II. Experimental Layout.

The epithermal neutron detection system will consist of 4 U^{235} fission detectors (Reuter Stokes Model RS-C3-2510-114). The choice of fission detectors allows excellent discrimination against counts arising from γ ray interaction in the ionization chamber [3]. This particular model can be operated in a pulse counting or current detection mode to provide wide dynamic range for the global neutron measurements.

The detectors will be located in the vicinity of Alcator C-Mod as shown in Fig. 1. Detectors 1, 2, and 3 will be placed inside the igloo structure which surrounds the experiment in order to minimize the variation in detector sensitivity which occurs when the location of nearby structures is changed. The placement of the detectors 1, 2 and 3 allows us to compensate for problems arising from changes in the position or shape of the plasma, as well as providing redundancy to the system so that changes in sensitivity can be more readily noted. A U^{238} detector (sensitive only to neutrons of energy greater than 1 MeV) will also be obtained from Reuter Stokes and sited with one of the U^{235} detectors inside the igloo.

The moderator assembly which will be used will consist of a 10 cm thick lead cylinder (8 cm inner diameter and 28 cm outer diameter) surrounded by a 10 cm thick polyethylene cylinder. As shown in Fig. 2, the assembly is 91 cm tall and is covered in thin Cadmium sheeting. The lead significantly decreases the γ flux reaching the detector.

III. Calculations

The surface efficiency of several neutron detector-moderator configurations was determined using the technique detailed by Ku [5] in which the adjoint function for the detector

arrangement is calculated. The determination of the adjoint current was done with the ANISN program [6] using the macroscopic cross section for U^{235} as the source function. The surface efficiency (normalized to 1 at 14 MeV) of the detector-moderator combination shown in Fig. 2 is plotted in Fig. 3. This calculation assumes that the incident flux is isotropic, which will be a good assumption for the detector locations in the Alcator C-Mod experiment. The detector response decreases with decreasing neutron energy, which will decrease the detector sensitivity to changes in large structures in neighborhood of the detector site.

The MCNP code [4] was used to calculate the expected neutron and γ flux at the detector locations shown in Fig. 1. The source used was 99% D-D fusion neutrons and 1% D-T (14 MeV) neutrons distributed uniformly in a 10 cm torus located at the vacuum chamber center. The calculation was repeated using a Cf^{252} ring source (the calibration of the system will require use of Cf^{252}) located at the midplane at the vacuum chamber center in order to investigate the difference in detector response arising from the deviation in energy distributions of the Cf^{252} spectrum and the mixed D-D and D-T fusion spectra. The expected flux versus energy at the location of detector 2 from the two sources is shown in Fig. 4. The overall efficiency, calculated by integrating the product of the surface efficiency with the calculation of the neutron flux at the detector over energy, was $3.90 \times 10^{-9} \pm 5.3\%$ per source neutron for the Cf^{252} ring source and $3.69 \times 10^{-9} \pm 5.1\%$ per source neutron for the plasma source.

The efficiencies calculated at the other detector sites are tabulated in Table I. The calculation has limited validity for the detector located above Alcator C-Mod but inside the igloo structure. It is necessary to imbed this detector in the top of the igloo plug which then provides additional moderating material around the detector. The surface efficiency calculation would not be correct in this case.

MCNP calculations have also been made of the detector sensitivity to the Cf^{252} spectrum when the source is located at discrete points on the midplane. The total efficiency for detectors 2 and 3 is plotted as a function of toroidal angle in Fig. 5. As can be seen from the plot, detector 2 is most responsive when the source is located in the port lying directly above it. Detector 3, however, shows little deviation in sensitivity with source position.

IV. Calibration

The U^{235} detectors will be absolutely calibrated in situ using a Cf^{252} source which will be continuously revolved toroidally around the interior of the vacuum chamber to simulate a plasma ring source. Since a total calibration error of $\leq 10\%$ is desirable, at least 10^4 counts would be required on each detector to reduce the statistical error to the 1% level. Using the numerically calculated sensitivity described above (3.9×10^{-9}), the neutron counts would have to be integrated for about 7 hours, assuming that a source strength of 10^8 n/s could be obtained. A ring source could be approximated by simply placing the source at many discrete locations around the torus rather than continuously rotating it. However, in order to achieve the desired accuracy, measurements at a prohibitively large number of toroidal angles would have to be performed. The mechanism for revolving the Cf^{252} will use a motorized carriage moving on a track or a monorail hung from the ceiling of the vacuum vessel with the source suspended from a basket below it. This will minimize the scattering effects from the hardware. It is very important that the angular velocity around the tokamak be constant, so use of a synchronous motor with gear drive is desirable. In addition, actual measurements of the toroidal angle as a function of time will provide verification of the uniformity. To account for the spatially extended nature of the plasma, the ring source calibration will be repeated at several different heights and major radii. Because of the large amounts of time and effort required to perform this calibration procedure, it will only be carried out infrequently. Therefore, in order to measure any drifts of the detector sensitivities over days and weeks, each detector assembly will have a small container fixed to it in which a particular neutron source can be quickly and reproducibly placed from time to time, allowing relative variations in sensitivities to be easily determined.

The U^{238} detector will be cross calibrated with the U^{235} detectors during high neutron rate plasma pulses.

V. Conclusion and Future Work

The selection of fission detectors for the Alcator C-Mod neutron detection experiment will enable measurement of the neutron flux over the entire range of expected Deuterium operating parameters. The choice of Cf^{252} for calibration of the system will provide the

best available calibration.

The computer analysis has demonstrated that the moderator design and siting of the detectors is sufficient to provide the necessary measurements. Further work is required, however, to establish the anticipated errors arising from variation in the plasma size, content and position.

References

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- [6] Sapyta, J.J., Newlon, K.M., Hassan, N.M., "User's Manual for B & W's Version of ANISN," Report NPGD-TM-128, Babcock and Wilcox Power Generation Division, Nuclear Power Generation Department, Lynchburg, VA, Dec 1971.

Figure Captions

Figure 1. Location of epithermal neutron detectors for Alcator C-Mod. The U^{238} fast neutron detector will be placed near detector 2. Detector 4 will be used for health physics as well as diagnostics.

Figure 2. Moderator design for epithermal neutron detectors. Ten cm polyethylene covers 10 cm lead surrounding the detector. The structure is covered in Cadmium sheet.

Figure 3. ANISN adjoint calculation of the detector surface response function for the moderator-detector combination shown in Fig. 2.

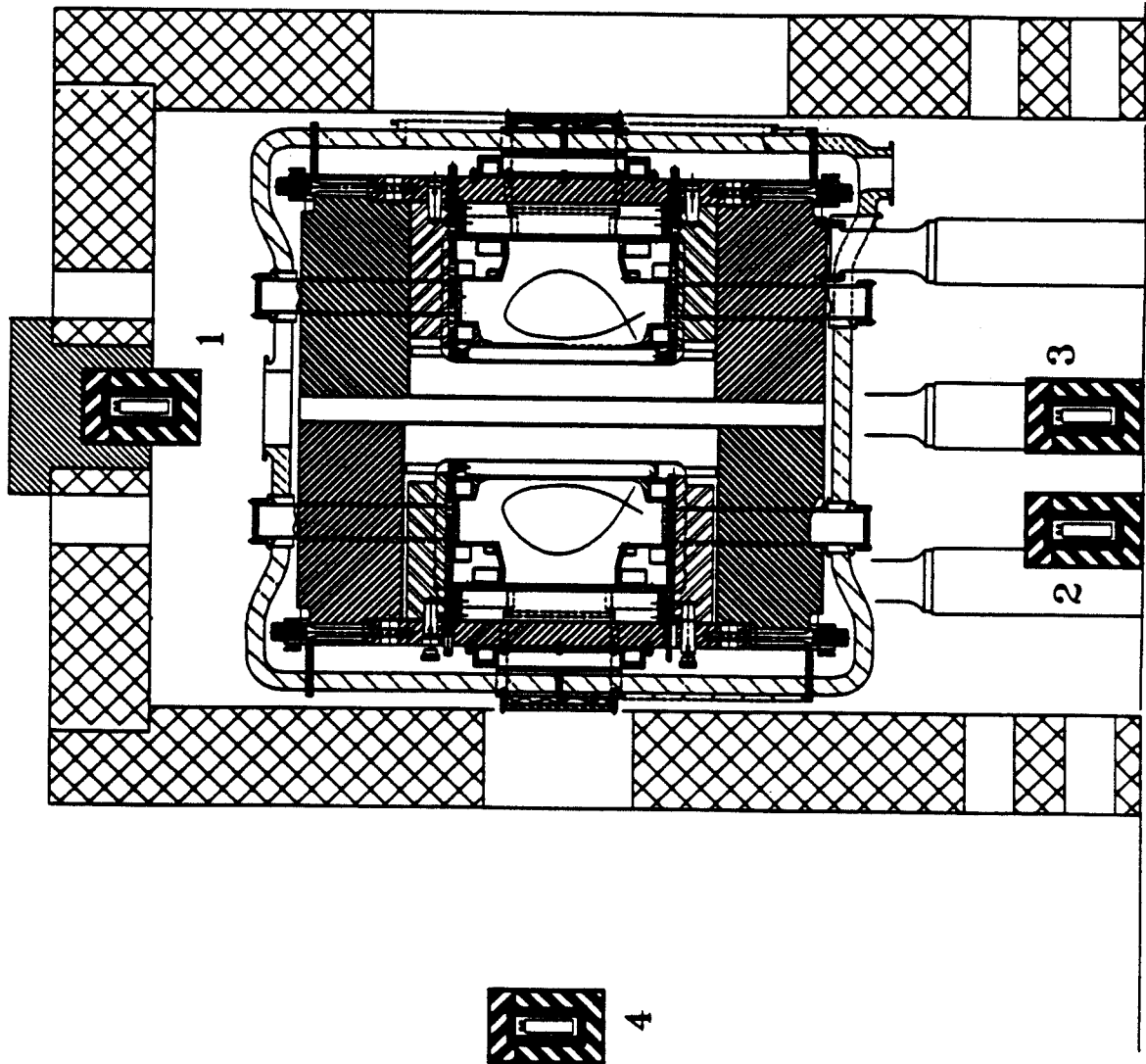
Figure 4. MCNP calculation of the neutron flux as a function of energy at detector site 2 for a mixed D-D and D-T fusion source compared to that from a Cf^{252} ring source located at the vacuum chamber midplane.

Figure 5. Total efficiency as a function of Cf^{252} point source location for detector sites 2 and 3.

Table I. Neutron Detector Efficiency

Location	Total Flux n/cm ² /s	Neutron Efficiency Counts/Source	% Error*
Inside Igloo			
Under Port (2)	8.5×10^{-7}	3.69×10^{-9}	5.1
Under Center (3)	8.5×10^{-7}	3.21×10^{-9}	6.2
Above Tokamak			
At Igloo (1)			
1.8 m from plasma	5.3×10^{-7}	2.33×10^{-9}	14.0
Outside Igloo			
Midplane at port (4)			
4.4 m from plasma	7.5×10^{-8}	2.91×10^{-10}	7.8

* From MCNP statistics alone.



Neutron Detector Locations

Figure 1

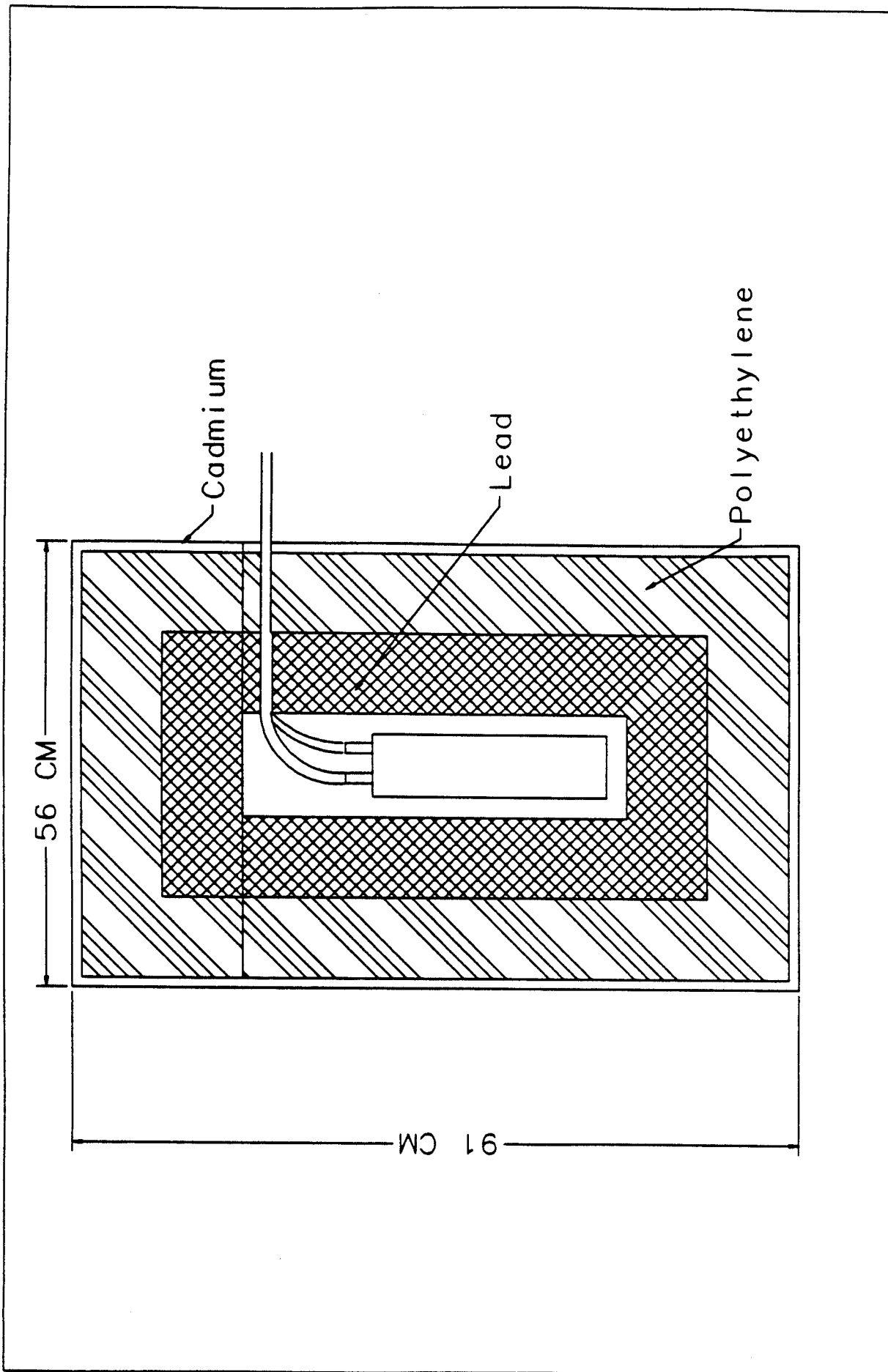


Figure 2

Neutron Importance

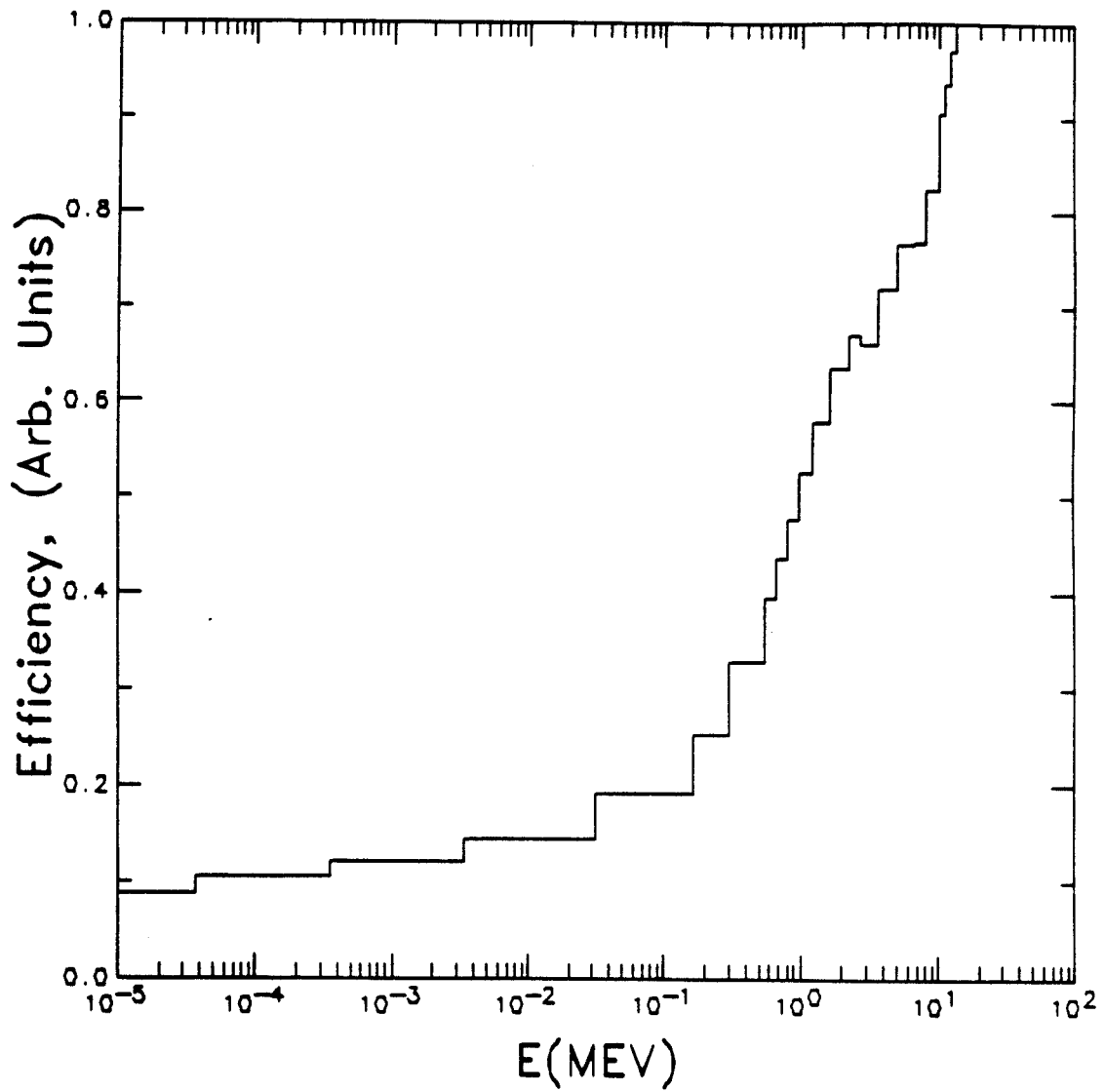


Figure 3

Neutron Flux

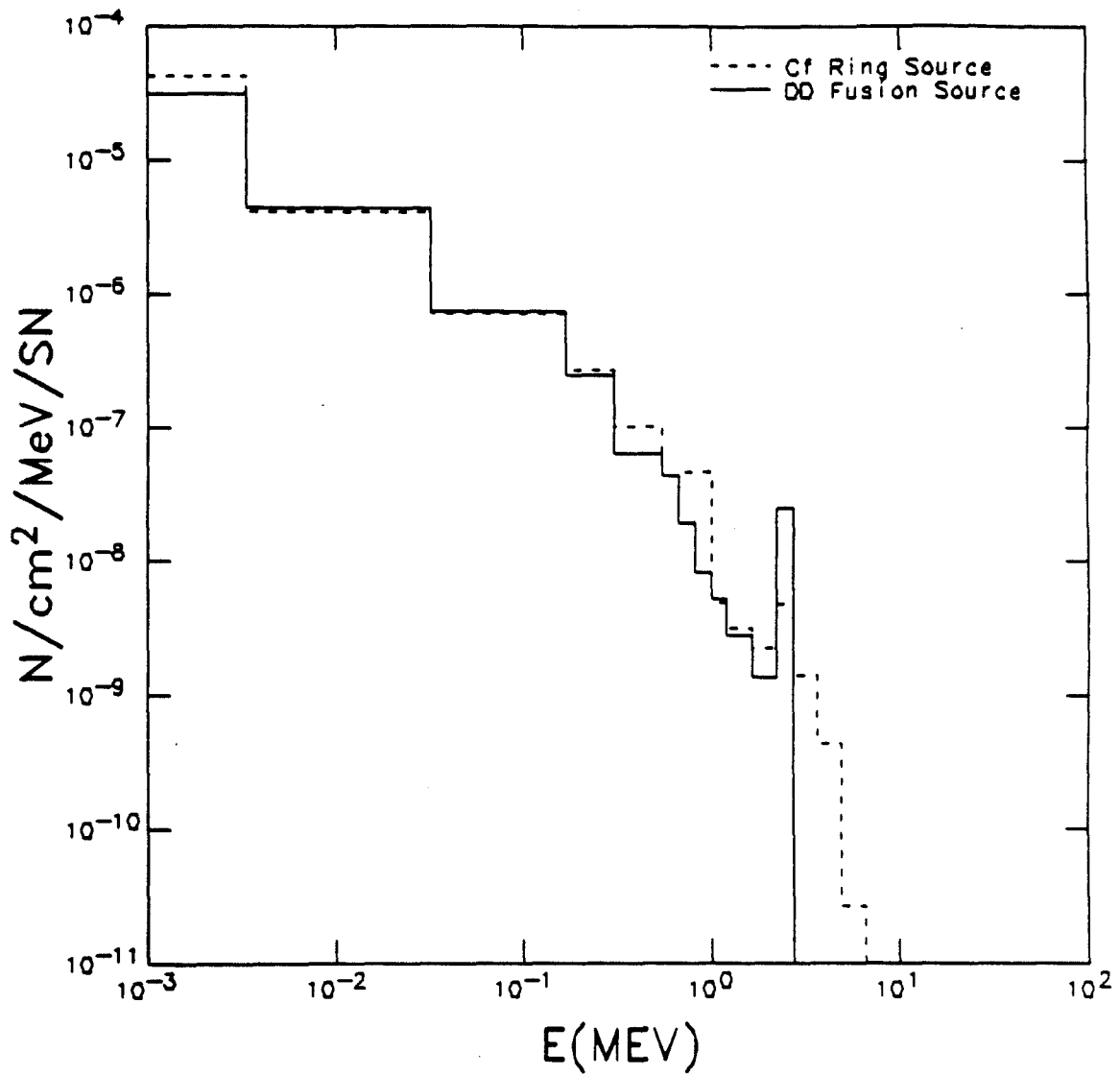


Figure 4

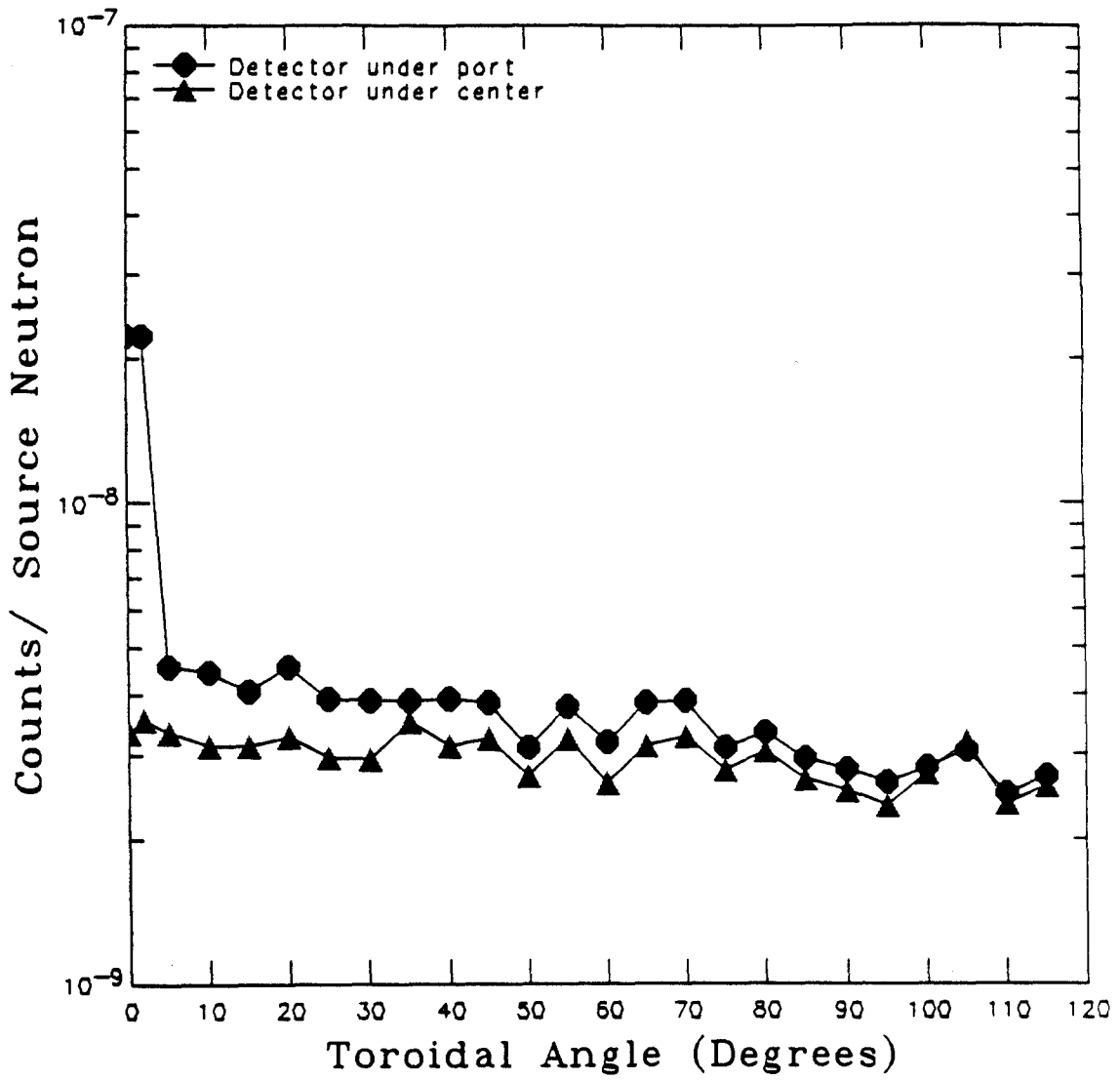


Figure 5