THE USE OF A SMALL ACCELERATOR AS A SOURCE OF 14-MeV NEUTRONS FOR SHIELDING STUDIES*

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Summary

It is important in calculating complex shields such as those proposed for the fusion reactors to ascertain that the neutron cross-section data sets used in the calculations are as accurate as possible and that the calculational methods used to transport the neutrons are as reliable as practical. To assure that both these criteria are met, a project at the Oak Ridge National Laboratory (ORNL) is being conducted in which a small accelerator is used to provide 14-MeV neutrons via the $T(d,n)^4He$ reaction and an NE-213 detector is used to measure the neutron and gamma-ray pulse-height spectra of the radiations transported through and/or created in very thick laminated shields of stainless steel (type 304) and borated polyethylene. To produce the neutron flux required, the targets are made by depositing about 4 mg/cm^2 of TiT onto a 1.27-cm circular area of a 0.254-cm thick copper disk. The NE-213 detector is operated in standard, state-of-the-art electronic circuits. A surface-barrier alpha counter and a small NE-213 detector are located permanently at a distance of about 150 cm from the target to monitor the reaction rate in the target. The pulse-height data are unfolded to produce energy spectra by using the computer program FERD.[2] These results are then compared almost immediately with spectra[3] obtained using two-dimensional radiation transport methods incorporating 53-neutron, 21-gamma-ray energy-group cross section data derived from the VITAMIN-C data set (ENDF/B).[4] Laminated stainless-steel and borated polyethylene shields having thicknesses up to 412 g/cm^2 have been measured.

The Facility

The facility, designed and built for conducting the measurements described here, is located in Bldg. 6025 at ORNL. Since this is primarily an office complex, it was necessary to provide shielding to meet all Health Physics requirements in addition to that needed to reduce the backgrounds produced by neutron scattering and/or capture in the room. Fig. 1 shows a cut-away drawing of the facility as configured for attenuation measurements. The components are shown in place in the figure. A minimum of one meter of concrete shielding surrounds each configuration in all directions except the foward direction. To reduce the return of neutrons from the wall behind the detector, iron slabs were placed between the detector and the wall. This, in effect, simulated making the measurements with the detector located within the experimental shield.

The accelerator target (see below) is located in a cylindrical can of iron with a 7.5-cm wall thickness. This can serves to modify the nominal 14-MeV neutron source spectrum to more nearly represent the softer spectrum from the reactor. In addition, the source can with its backup shield of lithiated paraffin in the accelerator drift-tube port, reduces the number of neutrons reflected from the back wall of the room. As designed and built, the facility allows making statistically good measurements with experimental shields as thick as 412 g/cm^2 in only 3 to 4 hours counting time.

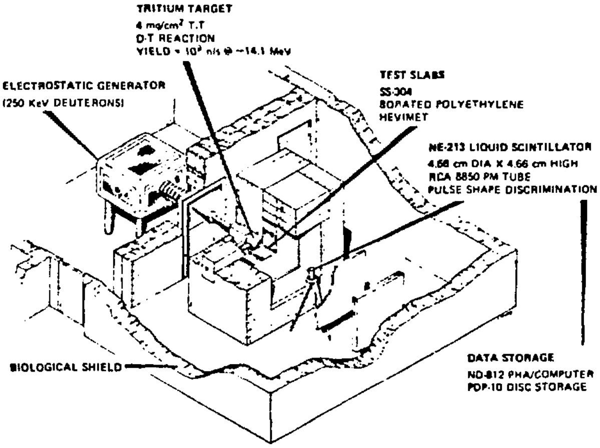

Figure 1. Artist rendition of the Experimental Facility.

Target Calibration

For the deuteron energies used in this work (E < 300 keV) the $T(d,n)^4He$ reaction is essentially isotropic in the center-of-mass system. Therefore, counting the alpha particles emitted into a known solid angle gives an accurate determination of the neutron source strength. The only calibration constant necessary is the solid angle transformation factor (lab to center-of-mass) for the reaction angle at which the alpha particles are observed. This transformation factor is dependent on the deuteron energy and is calculated using the $T(d,n)^4He$ cross section as a function of energy, the stopping power of the target (TiT), and the relative molecular fractions of the incident beam.

The initial test of the technique was carried out using a very low mass target holder in which the alpha particles were detected by a surface-barrier detector at an angle of 165° and a distance of about 30 cm. The detector was protected from scattered deuterons by a foil of aluminized mylar with a thickness of 3.8×10^{-4} cm. Pulse height distributions observed in the detector showed a very clean peak, well isolated from noise and free of background. The source strength determined by the alpha particle detector was compared with a simultaneous measurement of the neutrons at 0° (Fig. 2) using a calibrated[5] NE-213 detector (with suitable calculation of the 0° neutron-solid-angle transformation factor). Agreement was within 3% which is within the uncertainties of 5% on neutron detector efficiency and 3% on alpha particle calibration factor (due mainly to possible variations in the molecular fractions of the incident deuteron beam).

The same low-mass holder was installed in the target position in the concrete containment shield to calibrate an NE-213 neutron monitor located at 0°. The production target holder was then installed. This target holder used the same alpha-particle detector package relocated to 90° and at a distance of 150 cm. The source strength determined by this assembly was then compared to that determined by the calibrated neutron monitor and found to agree within 1%. The solid angle transformation factor at 90° is very nearly equal to unity and is essentially independent of deuteron energy and therefore independent of the relative molecular fractions in the deuteron beam.

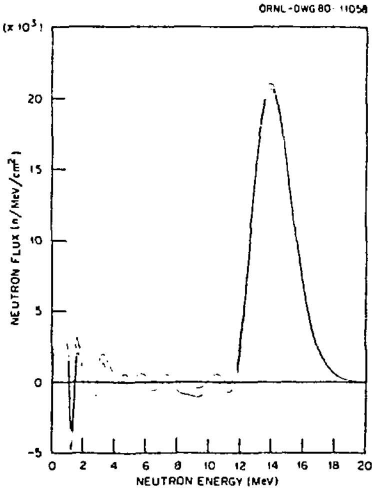

Figure 2. The unfolded response of the NE-213 detector to 14-MeV neutrons with the target in the low-mass holder.

Detector and Electronics

The primary neutron/gamma-ray detector used in this work was made at ORNL and consisted of 66.1 g of NE-213 scintillation liquid contained in a cylindrical cup made of aluminum (4.32×10^{-2} cm wall thickness) and coated on the inside with titanium dioxide reflector paint. The detector was mounted on an 8850 photomultiplier tube which was used with state-of-the-art, pulse-shape discrimination circuitry to distinguish between neutrons and gamma rays. The photomultiplier tube base and the preamplifier were also designed and built at ORNL. Indicative of the response of the detector to both neutrons and gamma rays are the data shown in Fig. 2 and Fig. 3 respectively.

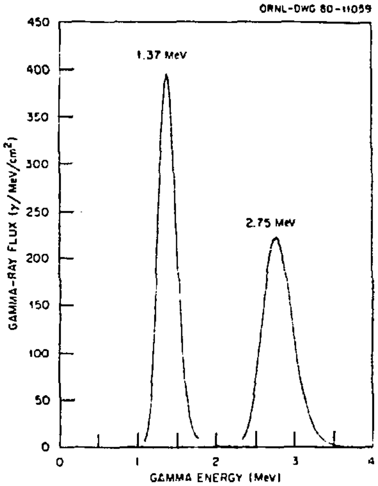

Figure 3. The unfolded response of the NE-213 detector to gamma rays from a small Na^{24} source.

Attenuation Measurements

Figure 4 shows the data taken with the shield configurations given in Table 1. The solid lines indicate the confidence band for the unfolded results and the points show the results of the calculations for comparison.[5] The calculations are smoothed with an energy-dependent Gaussian distribution comparable to the actual resolution of the NE-213 detector. The data are compared for neutrons above about 850 keV and for gamma rays above 750 keV. The low-energy neutron response is governed by the dynamic range and linearity of the detector system and although a lower energy gamma-ray threshold is possible, it was not attempted for these measurements.

Table 1

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COMPOSITION AND THICKNESS OF STAINLESS STEEL 304 AND BORATED POLYETHYLENE SLABS

CONFIGURATION	COMPOSITION						TOTAL SLAB THICKNESS (cm)
	SS-304[a]	SS-304	BP[b]	SS-304	BP	SS 304	
	SLAB THICKNESS (cm)						
1	0						0
2	15.24						15.24
3	30.48						30.48
4	30.48	5.08	5.08				40.64
5	30.48	5.08	5.08	5.08			45.72
6	30.48	5.08	5.08	5.08	5.08		50.80
7	30.48	5.08	5.08	5.08	5.08	5.08	55.88

[a] STAINLESS STEEL TYPE 304
[b] BORATED POLYETHYLENE

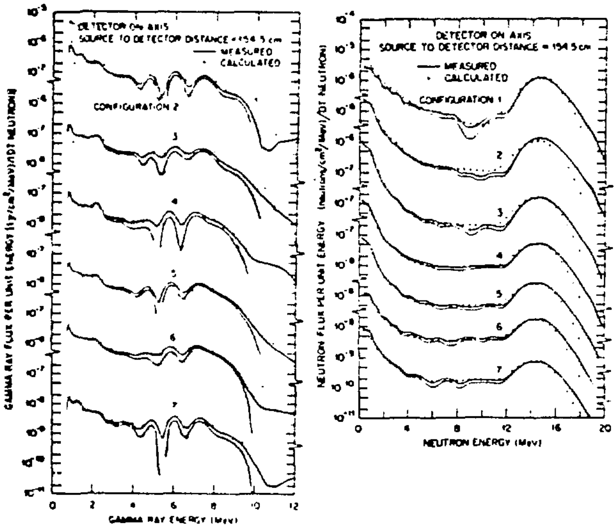

Figure 4. The gamma-ray and neutron data measured with the detector on the axis of symmetry showing the effects of attenuation by varous thicknesses of stainless steel and borated polyethylene.

Streaming Measurements

The facility may be reconfigured to measure the streaming of neutrons and gamma rays through ducts. In this case, a duct of a given length and diameter is placed in the containment shield and surrounded by concrete to eliminate any voids. One such duct consisting of a 60.96-cm extension of the target can described above has been measured and the results are shown in Fig. 5. Again, the solid lines show the confidence band for the unfolded data and the points show the calculated results.[6] The calculated results for the detector off the axis of symmetry show an inconsistancy with the measured data. This is tentatively attributed to the inability of the P_3 Legendre expansion used in the calculations to approximate the neutron scattering angular distribution. (The data shown here have the single-scattered contributions subtracted.) Further investigations of this discrepancy are underway at ORNL using higher order expansions and Monte Carlo techniques.[6]

Conclusions

A small facility at the Oak Ridge National Laboratory has produced neutron and gamma-ray data with sufficiently good statistics to allow a direct comparison with radiation transport calculations based on group cross-section data derived from the VITAMIN-C data set. A close working association with the group performing the calculations provides an almost immediate comparison of the calculations and the experimental data. This has resulted in a significant improvement in the quality of both methods for evaluating the effectiveness of the proposed fusion-reactor shield.

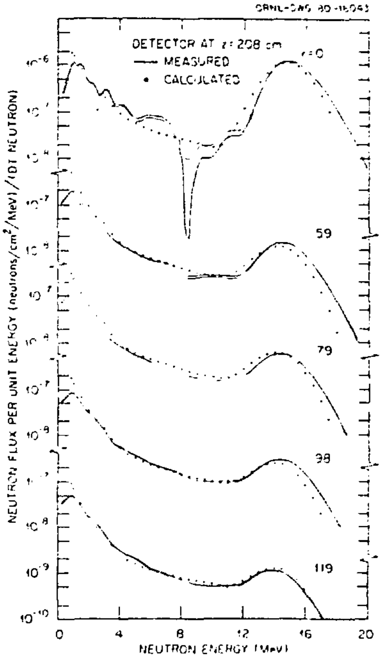

Figure 5. The neutron data measured to show the effects of the radiations streaming through a duct. The data show the effects of moving the detector off the axis of symmetry. The contributions from single scatterings have been subtracted from the calculated neutron data (see text).

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