Title
The Energy Spectrum of the Delayed Neutrons from O17

Permalink
https://escholarship.org/uc/item/8sq585sz

Author
Hayward, Evans

Publication Date
1948-10-19
TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks.
For a personal retention copy, call Tech. Info. Division, Ext. 5545
DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal 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 its 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, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.
Each person who received this document must sign the cover sheet in the space below.

<table>
<thead>
<tr>
<th>Route to</th>
<th>Noted by</th>
<th>Date</th>
<th>Route to</th>
<th>Noted by</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R.K. Wahlenig</td>
<td>11/145</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
THE ENERGY SPECTRUM OF THE DELAYED NEUTRONS FROM \(^{17}\)O

Evans Hayward

October 19, 1948

Berkeley, California
STANDARD DISTRIBUTION: Series A

Argonne National Laboratory 1-8
Armed Forces Special Weapons Project 9
Atomic Energy Commission 10-11
Battelle Memorial Institute 12
Brookhaven National Laboratories 13-20
Carbide & Carbon Chemicals Corporation (K-25 Area) 21-24
Carbide & Carbon Chemicals Corporation (Y-12 Area) 25-28
Columbia University (Dunning) 29
General Electric Company 30-33
Hanford Directed Operations 34-38
Iowa State College 39
Los Alamos 40-42
Monsanto Chemical Company, Dayton 43-44
National Bureau of Standards 45-46
Naval Radiological Defense Laboratory 47
NEPA 48
New York Directed Operations 49-50
Oak Ridge National Laboratory 51-55
Patent Advisor, Washington 59
Technical Information Division, ORDO 60-74
UCLA Medical Research Laboratory (Warren) 75
University of California, Radiation Laboratory Information Division 76-78
Chemistry Department 79
University of Rochester 80-81
Chicago Office of Directed Operations 82

DECLASSIFICATION PROCEDURE:

Declassification Officer 83-86
Publication Officer 87
Patent Department 88-89
Area Manager 90
E. O. Lawrence 91
Information Division 92

INFORMATION DIVISION
Radiation Laboratory
Univ. of California
Berkeley, California
THE ENERGY SPECTRUM OF THE DELAYED NEUTRONS FROM $^{17}$O

Evans Hayward

October 19, 1948

When bombarded with high energy deuterons, the elements just above oxygen in the periodic table have been found to yield delayed neutrons analogous to those found in fission products. The delayed neutrons are emitted with a period that corresponds to a 4.14 second half-life. The nucleus responsible for this period has been identified by Alvarez to be $^{17}$N which $\beta$-decays to give an excited state of $^{17}$O, which in turn emits a neutron and becomes $^{16}$O.

Alvarez has some preliminary data which indicate that the neutrons emitted do not all have the same energy. The object of this investigation was to determine the neutron energy spectrum from the ranges of the knock-on protons in a hydrogen-filled cloud chamber. The target was a LiF crystal (1/2" x 1/2" x 1/4") which was clamped to a spool and blown back and forth between the cyclotron and the cloud chamber through a pneumatic tube. The spool was stopped at a position in the tube such that the target was three feet outside of the concrete shielding and six feet from the cloud chamber. (See Fig. 1) The target was bombarded by the circulating 195 Mev deuteron beam of the cyclotron for thirty seconds and then blown out to the cloud chamber which was expanded manually a few seconds after the target came to rest. The cloud chamber clearing field was not turned off until the time of the expansion so that those ions that were formed before the target stopped moving...
were swept out before the vapor could condense on them. The cyclotron was turned off after the bombardment, and since the target spent about ten seconds moving out to the cloud chamber, we may be certain that those events that occurred in the chamber were due to the target.

The neutron energy is related to the energy of its knock-on proton by the equation $E_n = \frac{E_p}{\cos^2 \theta}$, where $\theta$ is the scatter angle. The proton range and the angle that the proton makes with the direction of the incident neutron have been measured by reprojection. The range-energy curve (Fig. 2) for the chamber pressure, which was 129.4 cm of H$_2$ saturated with a 2:1 alcohol-water mixture, has been calculated by A. A. Garren.

A region in the cloud chamber was chosen for selecting the tracks such that all those that started within this region would also end in the illuminated region. All tracks having scatter angles larger than 30° were excluded in order to minimize the error which is introduced by including recoils from neutrons that have scattered first from the walls of the chamber before producing a knock-on proton in the gas. If all scatter angles are included, the neutron energy distribution contains a few neutrons with energies as high as 10 Mev but these all arise from protons with large scatter angles and hence are due to neutrons that did not come directly from the target. In the early stages of the experiment a small number of tracks, large scatter angles included, were measured. Out of twenty protons with scatter angles greater than 30°, only two gave exorbitant neutron energies. From this we estimate that about 10% of the neutrons included had undergone scattering previous to producing the recoil in the gas.

The ranges of all the protons produced by neutrons having energies greater than 0.5 Mev have been measured. The proton ranges were measured to 1 mm. This gives an error in the neutron energy small compared to that caused by the errors in measuring the angles. Tracks of all ages have been included. The
energies of the neutrons corresponding to new tracks have been corrected for
the fact that they were formed after the expansion. More weight should be
attached to the new tracks than to the old, since their scatter angles can be
measured to $\pm 1^0$ whereas the old tracks were measured to only $\pm 3^0$. The errors
in the neutron energies have been estimated to be $\pm 6\%$ for diffuse tracks and
$\pm 2\%$ for sharp ones.

One factor that made the determination of the scatter angles difficult was
the multiple scattering of the protons by the gas. This is unimportant in the
case of the sharp tracks because they are so easy to measure, and since the neutron
distributions obtained from either kinds of tracks are essentially the same
(Fig. 3), we conclude that there are no large errors in the energy distribution
owing to multiple scattering.

One of the checks made in the experiment was to calculate the number of
neutrons scattered per unit solid angle in the center of mass system for three
groups of tracks. This number should be a constant independent of the angle.
The results, which agree well within the standard deviations, are 305 $\pm$ 42,
276 $\pm$ 23, and 270 $\pm$ 19. The standard deviations are based on the number of tracks.

The energy distributions of the 391 recoil protons and of the neutrons
producing them, both before and after correction for the variation of the scattering
cross-section with energy, are given in Figures 4, 5, and 6. Figure 7 shows
the energy distributions that are obtained when the scatter angles are limited
to those smaller than $20^0$ and $10^0$. The errors from measurement are smaller for
small angles but, of course, the statistics are bad. It should be pointed out
that there are proton recoils with energies as great as 1.7 Mev so that even
if the direction of the incident neutron is unknown, it must in these cases have
at least 1.7 Mev. Experimental error cannot account for the large spread in
energy and this experiment leads one to the conclusion that this neutron can have any energy between .6 and 1.7 Mev, 1 Mev being its most probable energy.
DELAYED NEUTRON RUN.

190 MEV DEUTERON BEAM

LITHIUM FLUORIDE TARGET \( \frac{1}{2} \times 1 \times 1 \frac{1}{4} \)

THIN FOIL

\( \frac{3}{32} \) BRASS WINDOW

CYCLOTRON

COMPRESSED AIR LINE FOR SENDING TARGET BACK TO CYCLOTRON FOR BOMBARDMENT

72"

GLASS WALL

CLOUD CHAMBER

CAMERAS

FIG. 1
RANGE OF PROTONS IN HYDROGEN GAS, ALCOHOL AND WATER VAPOR AT A 2:1 RATIO BY VOLUME (OF THE LIQUID), AT 129.4 cm Hg AND 20° C

FIG. 2
FIG. 5.
CLASSIFICATION CASE OF THE DIST
OF THE DECLASS COMMITTEE