UCRL 924
Cy. 2

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

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

BERKELEY, CALIFORNIA

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.

UNCLASSIFIED

UCRL-924
Unclassified Distribution

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

Contract No. W-7405-eng-48

A SEARCH FOR EXCITED STATES OF Be^7 USING THE Li^6 TECHNIQUE

George R. Keepin, Jr.

September 10, 1950

Berkeley, California

INSTALLATION	Number of Copies
Argonne National Laboratory	8
Armed Forces Special Weapons Project	1
Atomic Energy Commission - Washington	2
Battelle Memorial Institute	1
Brush Beryllium Company	1
Brookhaven National Laboratory	4
Bureau of Medicine and Surgery	1
Bureau of Ships	1
Carbide and Carbon Chemicals Division (K-25 Plant)	4
Carbide and Carbon Chemicals Division (Y-12 Plant)	4
Chicago Operations Office	1
Columbia University (J. R. Dunning)	1
Columbia University (G. Failla)	1
Dow Chemical Company	1
H. K. Ferguson Company	1
General Electric Company, Richland	3
Harshaw Chemical Corporation	1
Idaho Operations Office	1
Iowa State College	2
Kansas City Operations Branch	1
Kellex Corporation	2
Knolls Atomic Power Laboratory	4
Los Alamos Scientific Laboratory	3
Mallinckrodt Chemical Works	1
Massachusetts Institute of Technology (A. Gaudin)	1
Massachusetts Institute of Technology (A. R. Kaufmann)	1
Mound Laboratory	3
National Advisory Committee for Aeronautics	1
National Bureau of Standards	3
Naval Medical Research Institute	1
Naval Radiological Defense Laboratory	2
New Brunswick Laboratory	1
New York Operations Office	3
North American Aviation, Inc.	1
Oak Ridge National Laboratory	8
Patent Branch - Washington	1
Rand Corporation	1
Sandia Corporation	2
Santa Fe Operations Office	2
Sylvania Electric Products, Inc.	1
Technical Information Division (Oak Ridge)	15
Armament Division, Deputy for Research and Development (Capt. Glenn Davis)	1
Assistant for Atomic Energy, Deputy Chief of Staff (Col. Robert E. Greer)	1
Chief of Documents and Disseminations Branch (Col. J. E. Mallory)	1
USAF Assistant for Research Director of Research and Development, Deputy Chief of Staff (Col. B. G. Holzman)	1

INSTALLATION	Number of Copies
Electronic Systems Division (Mr. E. C. Trafton)	1
Chief of Scientific Advisors (Dr. Theodore von Karman)	1
USAF, Eglin Air Force Base (Major A. C. Field)	1
USAF, Kirtland Air Force Base (Col. Marcus F. Cooper)	1
USAF, Maxwell Air Force Base (Col. F. N. Moyers)	1
USAF, NEPA Office	2
USAF, Offutt Air Force Base (Col. H. R. Sullivan, Jr.)	1
USAF Surgeon General, Medical Research Division (Col. A.P. Gagge)	1
USAF, Wright-Patterson Air Force Base (Rodney Nudenberg)	1
U. S. Army, Atomic Energy Branch (Lt. Col. A. W. Betts)	1
U. S. Army, Army Field Forces (Captain James Kerr)	1
U. S. Army, Commanding General, Chemical Corps Technical Command (Col. John A. MacLaughlin thru Mrs. Georgia S. Benjamin)	1
U. S. Army, Chief of Ordnance (Lt. Col. A. R. Del Campo)	1
U. S. Army, Commanding Officer, Watertown Arsenal ((Col. Carroll H. Deitrick)	1
U. S. Army, Director of Operations Research (Dr. Ellis Johnson)	1
U. S. Army, Office of Engineers (Allen O'Leary)	1
U. S. Army, Office of the Chief Signal Officer (Curtis T. Clayton thru Maj. George C. Hunt)	1
U. S. Army, Office of the Surgeon General (Col. W. S. Stone)	1
U. S. Geological Survey (T. B. Nolan)	2
U. S. Public Health Service	1
University of California at Los Angeles	1
University of California Radiation Laboratory	5
University of Rochester	2
University of Washington	1
Western Reserve University	2
Westinghouse Electric Company	4
R. F. Bacher (California Institute of Technology)	1
Cornell University	1
Total	140

Information Division
Radiation Laboratory
Univ. of California
Berkeley, California

A SEARCH FOR EXCITED STATES OF Be^7 USING THE Li^6 TECHNIQUE

George R. Keepin, Jr.

September 10, 1950

ABSTRACT

At least one excited state in Be^7 is well established at 429 ± 15 Kev. The Li^6 technique of neutron energy measurement has been used to measure $Li^7(p,n)Be^7$ spectra in an extended seach for additional levels of Be^7. Spectra were obtained at angles 10, 30, and 90 degrees to the proton beam for each of three bombarding proton energies, E_p = 3.00, 3.60 and 4.35 Mev. Although some of the data suggest an additional level in Be^7 intermediate between the known level and the ground state, no single group was considered sufficiently resolved or sufficiently intense to be so identified with certainty. From nine measured spectra comprising approximately 10,000 disintegrations, a mean value of 433 ± 26 Kev for the level excitation energy in Be^7 is obtained.

A SEARCH FOR EXCITED STATES OF Be^7 USING THE Li^6 TECHNIQUE

George R. Keepin, Jr.

September 10, 1950

I INTRODUCTION

The mirror nuclei, Li^7 and Be^7, are with the singular exception of He^4, the lightest stable nuclei in which bound excited states are known to exist; thus through the excited level structure of these nuclei one may study the general problems of nuclear structure in their simplest form.

In addition to the well established 480 Kev level in Li^7 there has been reason[1] to expect other excited states in Li^7 though none has been found. Recently Inglis'[2] careful work has shown that for excitation energies up to 2.5 Mev no further states above the 480 Kev level appear with as much as 5 percent of the ground state intensity. In Be^7 the mirrored counterpart of this single level in Li^7 is now well established at 429 ± 15 Kev by two independent methods.[3] However, Grosskreutz and Mather,[4] using a cyclotron beam of analyzed 5.1 Mev protons and examining the neutron spectrum from $Li(p,n)Be^7$, reported two additional levels in Be^7 at 205 ± 70 Kev and 745 ± 70 Kev. Subsequently, others[5] using similar techniques have not found evidence for such levels. The improved neutron energy resolution (particularly for $E_n < 2$ Mev)

---

[1] S. Hanna and D. Inglis, Phys. Rev. 75, 1767 (1949)

[2] D. Inglis, Phys. Rev. 78, 104 (1950)

[3] Brown, Chao, Fowler and Lauritsen, Phys. Rev. 78, 88 (1950), and Lauritsen and Thomas, ibid.

[4] J. Grosskreutz and K. Mather, Phys. Rev. 77, 580 (1950)

[5] V. Johnson, M. Laubenstein and H. Richards, Phys. Rev. 77, 413 (1950); G. Freier, L. Rosen and T. Stratton, Phys. Rev. 79, 721 (1950); B. Hammermesh and V. Hummel, Phys. Rev. 78, 73 (1950)

afforded by the Li^6 technique[6] has been used to measure $Li^7(p,n)Be^7$ neutron spectra in an extended search for any additional levels in Be^7. The suggestion[4] that there may be an effective high energy threshold for excitation of these additional levels led us to extend the range of bombarding proton energies to nearly 0.5 Mev above the maximum Van de Graaff beam energy employed by previous workers.

II EXPERIMENTAL METHOD AND RESULTS

The proton beam from the Berkeley electrostatic generator was deflected through a stationary 90° analyzing magnet just forward of the linear accelerator entrance valve. The beam was required to traverse a double slit system giving energy definition of the protons to better than ± 20 Kev at the three bombarding energies used, i.e., E_p = 3.00, 3.60 and 4.35 Mev. The target was made by evaporation of pure metallic lithium onto a 3/32 inch thick copper backing disc and transferred to the target chamber while in an atmosphere of argon. The chamber was then connected to the Van de Graaff vacuum system and evacuated. Target thickness (< 30 Kev) was determined by difference weighings in a small airtight glass container. Satisfactory target cooling without rotation was accomplished by directing an air stream on copper fins protruding from the copper target backing. A liquid air trap was located just ahead of the target to condense out any oil-vapors present in the vacuum line. A ruled quartz disc immediately in front of the target allowed accurate beam focussing on the target. Li^6 loaded plates in light-tight cadmium containers were mounted tangentially to the neutron direction at angles η = 0°, 30° and 90° to the proton beam giving neutron collimation to better than ± 5°. In order to obtain

---

[6] G. Keepin, Jr. and J. H. Roberts, Phys. Rev. 76, 154 (1949) and Rev. Sci. Inst. 21, 163 (1950); G. Keepin, Jr., AECU-563 (LAMS-924) (1949); A. J. F. Siegert and G. Keepin, Jr., LAMS-937 (1950)

optimum exposure (order of one disintegration per field of view) the proton beam was monitored by proton collection on the insulated target with a conventional current integrator to measure the charge. Calibration of integrator counting rate vs. proton current was linear over the range of beam current variation so the total count gave integrated exposure to better than 10 percent which was sufficient for our purpose. The entire experimental setup with respect to the Van de Graaff and linear accelerator is shown in Fig. 1. Fig. 2 shows the target assembly and collimating arm in greater detail.

Exposed plates were given natural fading for about two weeks, processed,[7] and then examined using 90X oil-immersion objectives and 8X oculars fitted with AO #1407 reticules. The sum of alpha and triton ranges ($R_\alpha + R_T \equiv \sum R$) was measured to the nearest reticule unit (0.7 μ) which corresponds to nearly 25 Kev in neutron energy. An eyepiece giniometer gave the laboratory angle ϕ, between neutron and triton to the nearest degree. An acceptable disintegration was required to have δ, the depth difference between beginning and end of an event, less than 10 μ in the shrunk emulsion and to have $-20^\circ \leq \phi \leq 20^\circ$. Further details of selection criteria and data analysis using the Li^6 technique for collimated and/or isotropic neutrons are given in references 6 and 7.

Two separate runs were made at each proton energy; good agreement between runs was obtained at the same angle and energy. Figs. 3 through 11 show the composite data at each proton energy and angle of observation. Irrevelant statistical fluctuations were reduced by plotting the number of disintegrations per two RU* intervals at each RU. An arrow indicates theoretical ground state energies as calculated from E_p, η, and the $Li^7(p,n)Be^7$ Q-value = - 1.63 Mev.

---

[7] G. Keepin, Jr., UCRL-790 (1950)

* One LRU = 0.60 μ; one SRU = 0.70 μ .

From the data the (weighted) mean energy for each resolved neutron group is obtained and the corresponding Q values and excitation levels of Be^7 then calculated. The results as tabulated in Table I give 433 ± 26 Kev as an overall mean value for the excited state in Be^7. Though some of the data do suggest a level intermediate between the known level and the ground state, no single group corresponding to such a level was considered sufficiently resolved to be so identified with certainty.

E_p (Mev)	Mean Neutron Energy (Mev)			(-) Q Value (Mev)			Mean Be^7 Excitation (Kev)
	0°	30°	90°	0°	30°	90°	
3.00	1.29±.04	1.27±.09	0.69±.07	1.66±.04	1.60±.09	1.78±.07	438±47
	0.83±.06	0.78±.06	———	2.08±.06	2.06±.06	———	
3.60	1.91±.10	1.74±.09	0.99±.09	1.65±.10	1.72±.09	1.67±.09	433±46
	1.43±.06	1.31±.09	0.60±.10	2.10±.06	2.13±.09	2.11±.10	
4.35	2.57±.07	2.46±.07	1.75±.05	1.75±.07	1.72±.07	1.73±.05	430±34
	2.14±.06	2.11±.06	1.34±.09	2.16±.06	2.14±.06	2.19±.09	

TABLE I

III DISCUSSION

The spectra of Figs. 3 through 11 have been corrected for energy dependence of the geometrical selection criteria[6] but not for Li^6 capture cross section since little is known of the latter at these relatively high energies; in the Li^6 calibration work[7] there was some evidence for a broad resonance centered near 2 Mev and probable 1/E flatness elsewhere. Applying this tentative cross section correction, no neutron group corresponding to a level in Be^7 other

than the known level has been observed with more than 15 percent the intensity of the ground state group. Though one anticipates a fairly smooth variation of σ with energy, in limited regions where the cross section is changing rapidly (e.g., near 2 Mev), clearly there has been slight shifting and appreciable spreading of the peaks which in turn contribute appreciably to the error in excitation level determination. The remote possibility of either Li^6 cross section variation or inelastically scattered neutrons being responsible for separate neutron groups may be ruled out by their consistency in energy (at various bombarding energies and angles of observation) with a definite level assignment in Be^7. More accurate comparison of relative peak intensities and widths must await a precision measurement of the $Li^6(n,\alpha)H^3$ cross section in the present energy range; such a measurement, using both counter and plate detection, is now in progress.

We now consider possible sources of error in some detail. Beam energy regulation and target thickness have already been discussed in Part I. As a target material we chose metallic lithium rather than any lithium compound to eliminate extraneous neutron groups from p,n reactions in the negative radical. A mass spectrographic analysis of the Li sample indicated only traces (0.01-0.1 percent) of Al and Ca and weak presence (0.1-1 percent) of Na. Conceivable p,n reactions in or near the target are: (1) $Na^{23}(p,n)Mg^{23}$-4.5 Mev from Na impurity in the target; this is energetically impossible for $E_p \leq 4.5$ Mev; (2) $C^{13}(p,n)N^{13}$-3 Mev from pump oils; low abundance of the mass 13 isotope (1.1 percent), together with the use of an oil-vapor trap forward of the target insures negligible p,n contribution from this source; (3) Cu^{63} and Cu^{65} p,n reactions from the copper backing plate; again negligible p,n neutrons are obtained due to the combination of a high Coulomb barrier for protons on

Cu ($\sim$5 Mev), the short range of 4 Mev protons in Cu (<1 mil) and the low Cu (p,n) cross section at these proton energies. Thus there should be essentially no extraneous neutron groups from p,n reactions in or near the target.

To consider feasible n,p reactions within the emulsion (constituting a background from which one must readily distinguish Li^6 disintegrations) we have: (1) recoil protons, easily distinguished from alpha-triton pairs by both length and grain density variation along the track; (2) $Li^6(n,p)He^6$-2.9 Mev, discriminated from alpha-triton pairs by their shorter length, i.e., shorter than a Li^6 thermal neutron disintegration; (3) $N^{14}(n,\alpha)B^{11}$+0.28 Mev and $N^{14}(n,p)C^{14}$+0.63 Mev; both of these rare events are clearly distinguished by track length and grain density variation; (4) n,p reactions from AgBr present in the emulsion, which may be ruled out on the basis of low relative AgBr concentration and low cross section due to high Coulomb barrier seen by the emerging proton. Thus the dangers of all extraneous n,p reactions, very real in the recoil proton method, are almost nil with the Li^6 technique.

Li^6 monitor plates mounted in the vicinity of the target assembly indicated a background of less than one percent for neutrons of all energies.

I thank Professors L. W. Alvarez and E. Segrè for their advice and interest in this work and Mr. F. C. Gilbert for his assistance in plate exposure and measurement. I am indebted to the linear accelerator crew for their cooperation, and to the Atomic Energy Commission for the fellowship which has sponsored this work.

Information Division
scb/9-27-50

KEY TO FIGURES 1 AND 2

Figure 1

A - Collimating arm and target assembly

B - Linear accelerator entrance valve

C - 90° analyzing magnet

D - External steering magnet

E - Van de Graaff exit valve

F - Integrator scaler-counter rack

Figure 2

A - Plate holder with Cd boxes in place

B - Target cooling fin

C - Liquid air oil-vapor trap

D - Manual control on target quartz-focussing-disc

E - Window to target quartz-focussing-disc

F - Vacuum valve isolating target chamber (during time of transfer)

G - Target pumpout valve

H - Sylphon for adjustment of target-slit position

I - Beam integrating circuit

J - Window to magnet quartz-focussing-disc

K - Analyzing magnet exit-slit

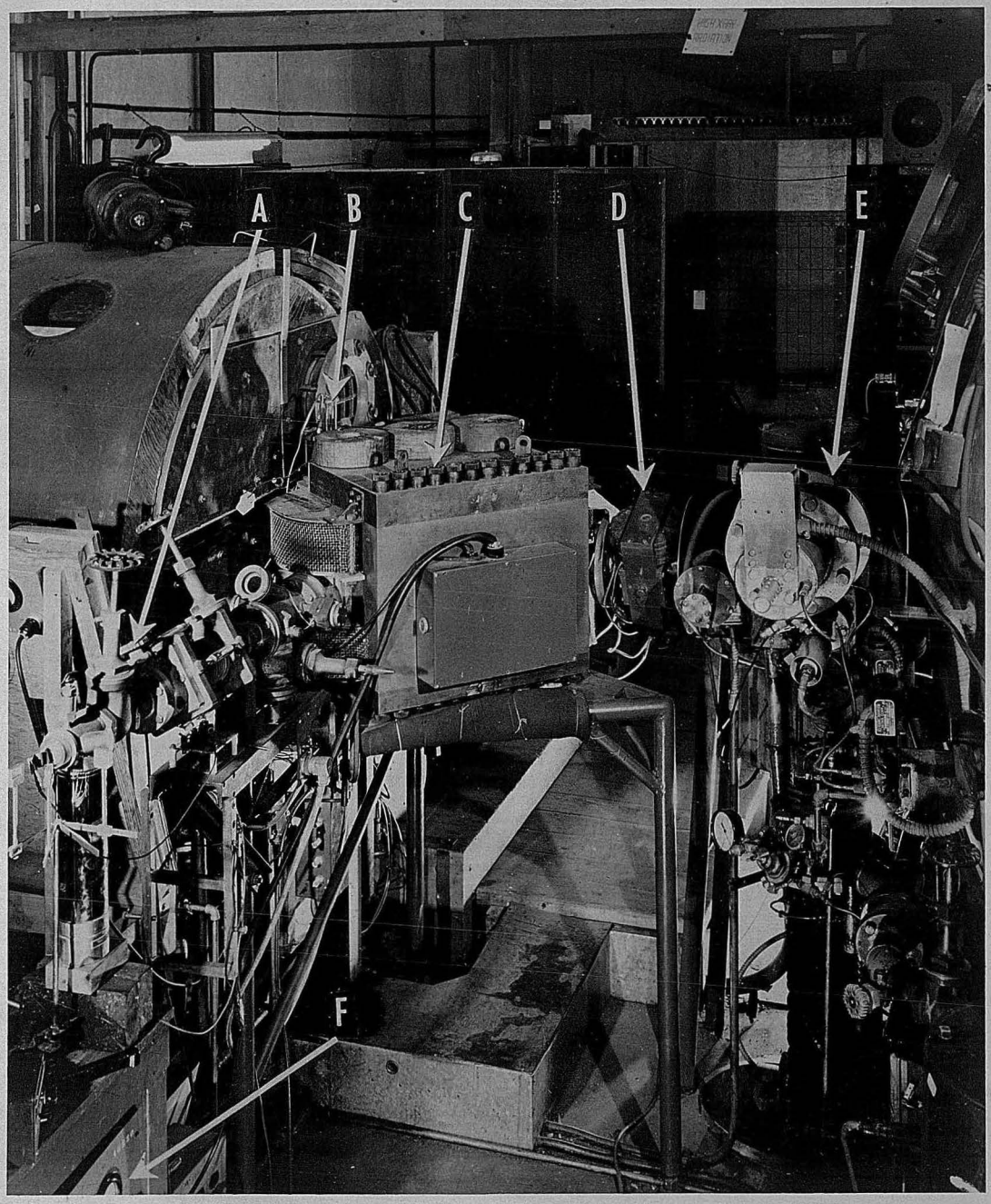


FIG. 1

OZ.959
KODAK—SAFETY 308

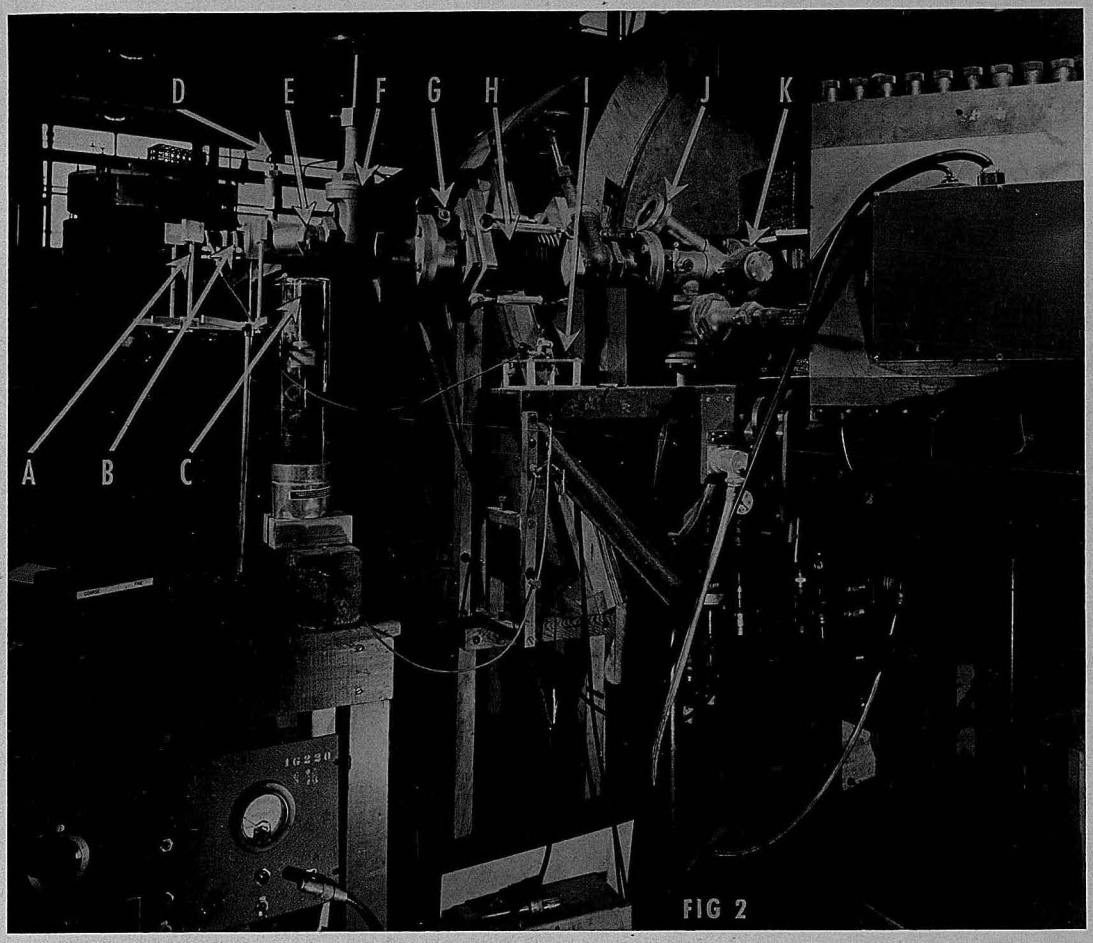
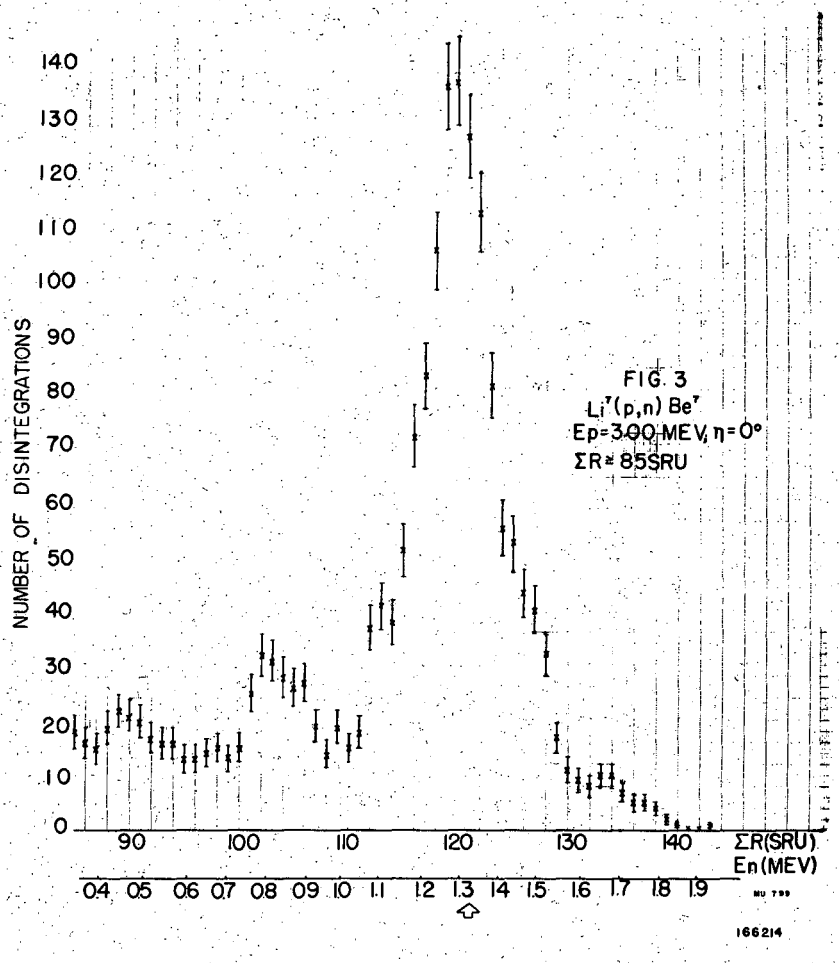


FIG. 2

OZ. 960


NUMBER OF DISINTEGRATIONS
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
90
100
110
120
130
140
ΣR(SRU)
En(MEV)
0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9
FIG. 3
Li⁷(p,n) Be⁷
Ep=3.00 MEV, η=0°
ΣR≈85SRU
166214

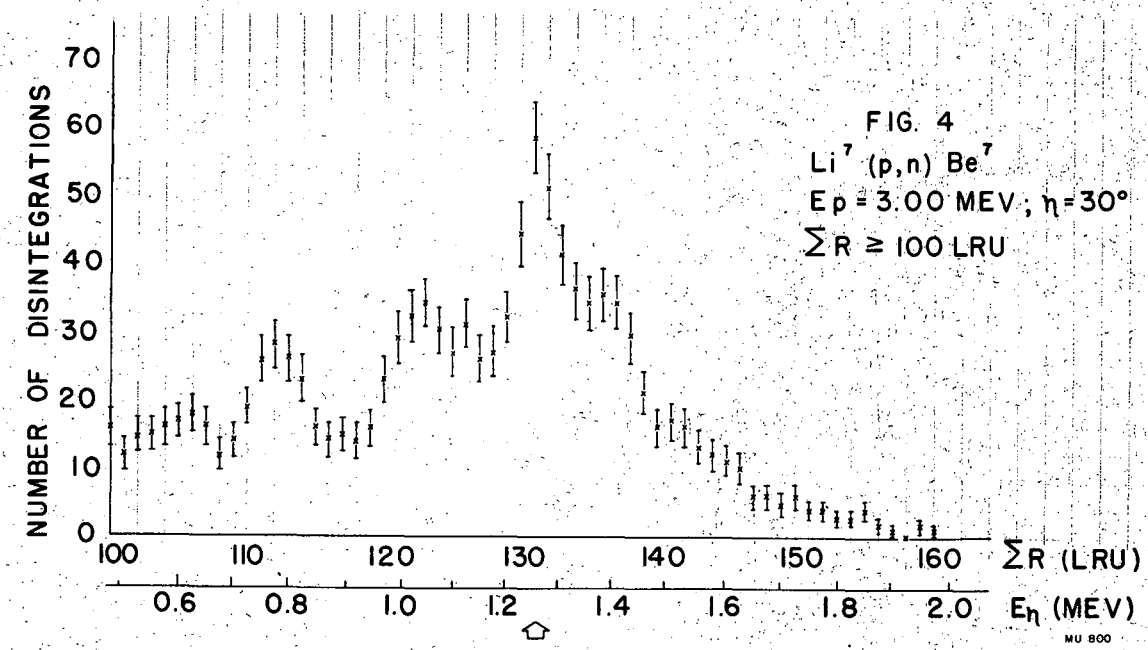


FIG. 4
Li^7 (p,n) Be^7
Ep = 3.00 MEV ; η = 30°
ΣR ≥ 100 LRU

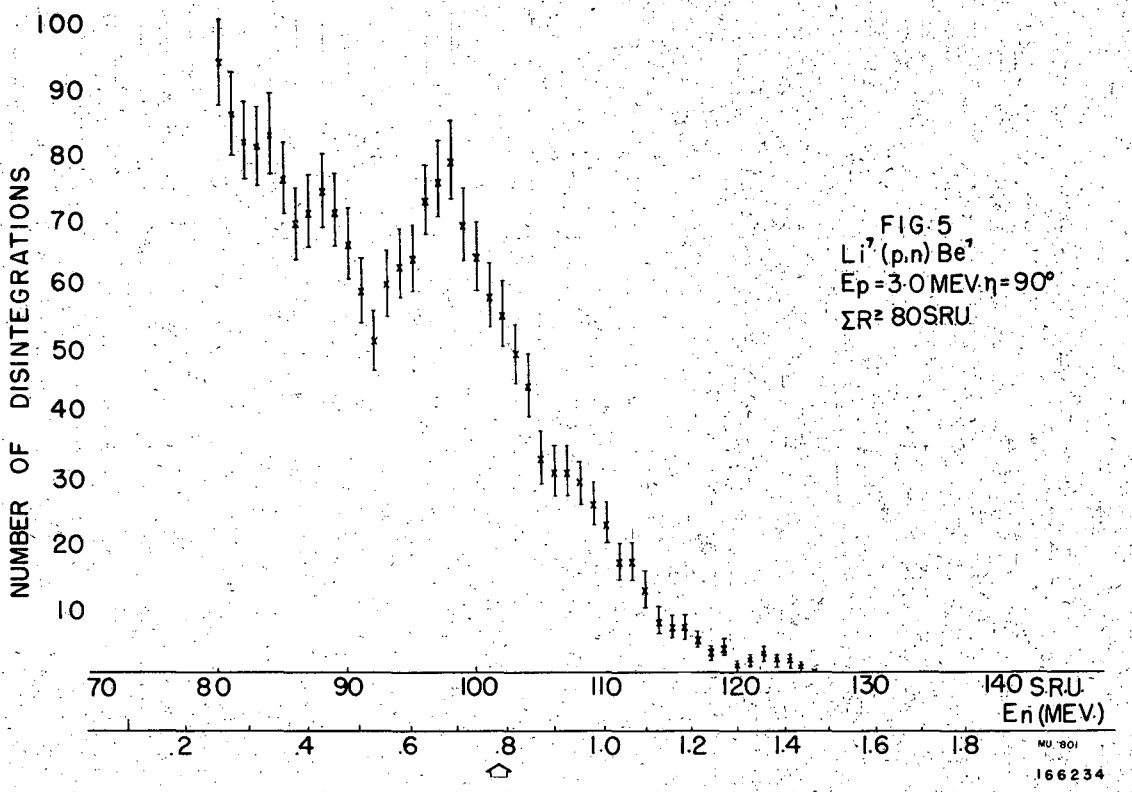


FIG. 5
Li^7 (p,n) Be^7
Ep = 3.0 MEV η = 90°
ΣR = 80 SRU

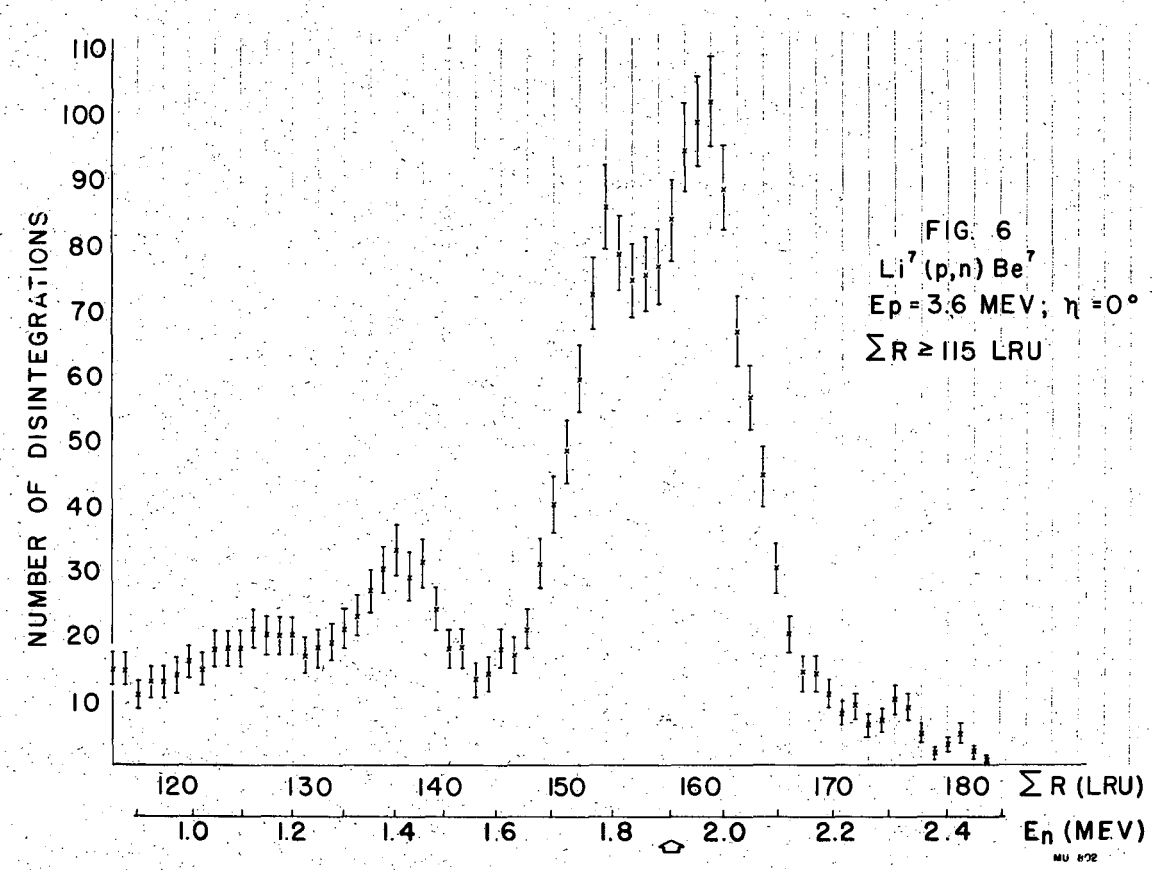


FIG. 6
$Li^7(p,n)Be^7$
Ep = 3.6 MEV; η = 0°
$\Sigma R \geq 115$ LRU

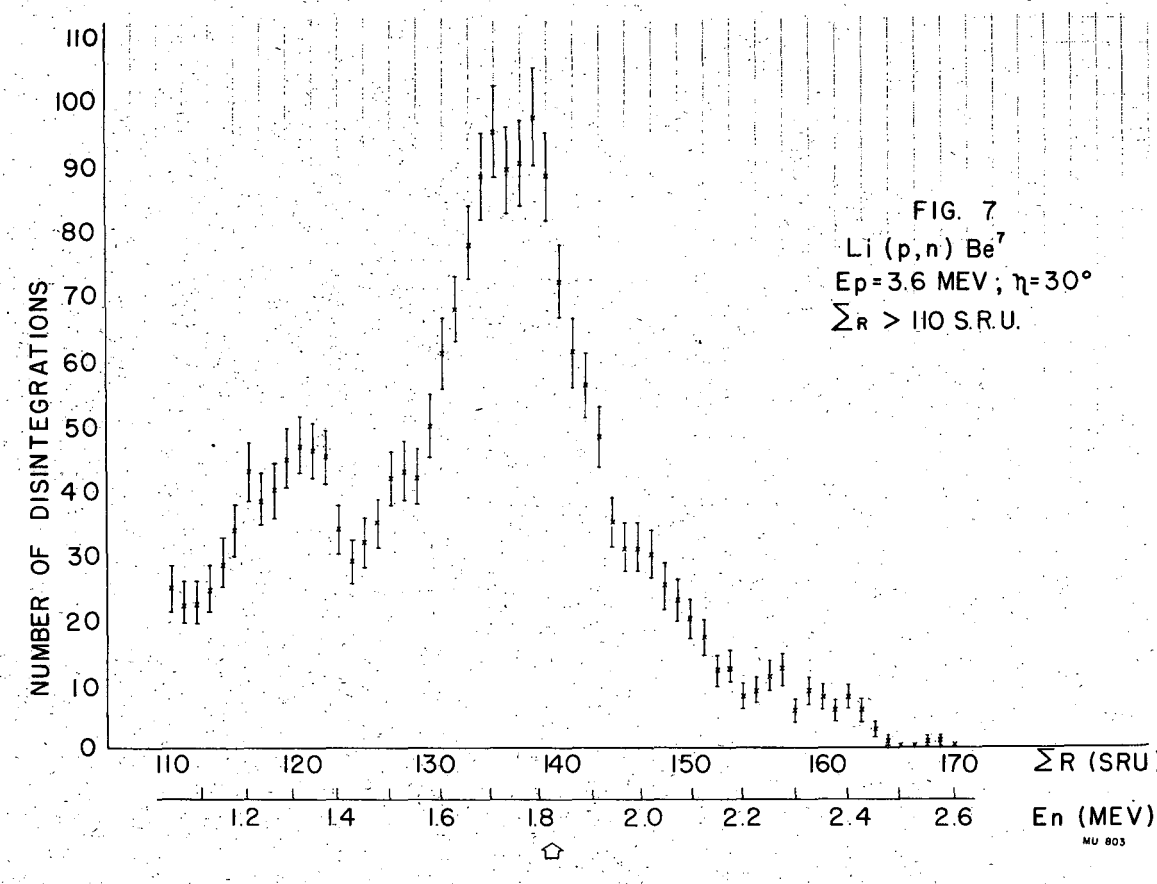


FIG. 7
$Li(p,n)Be^7$
Ep = 3.6 MEV; η = 30°
$\Sigma_R > 110$ S.R.U.

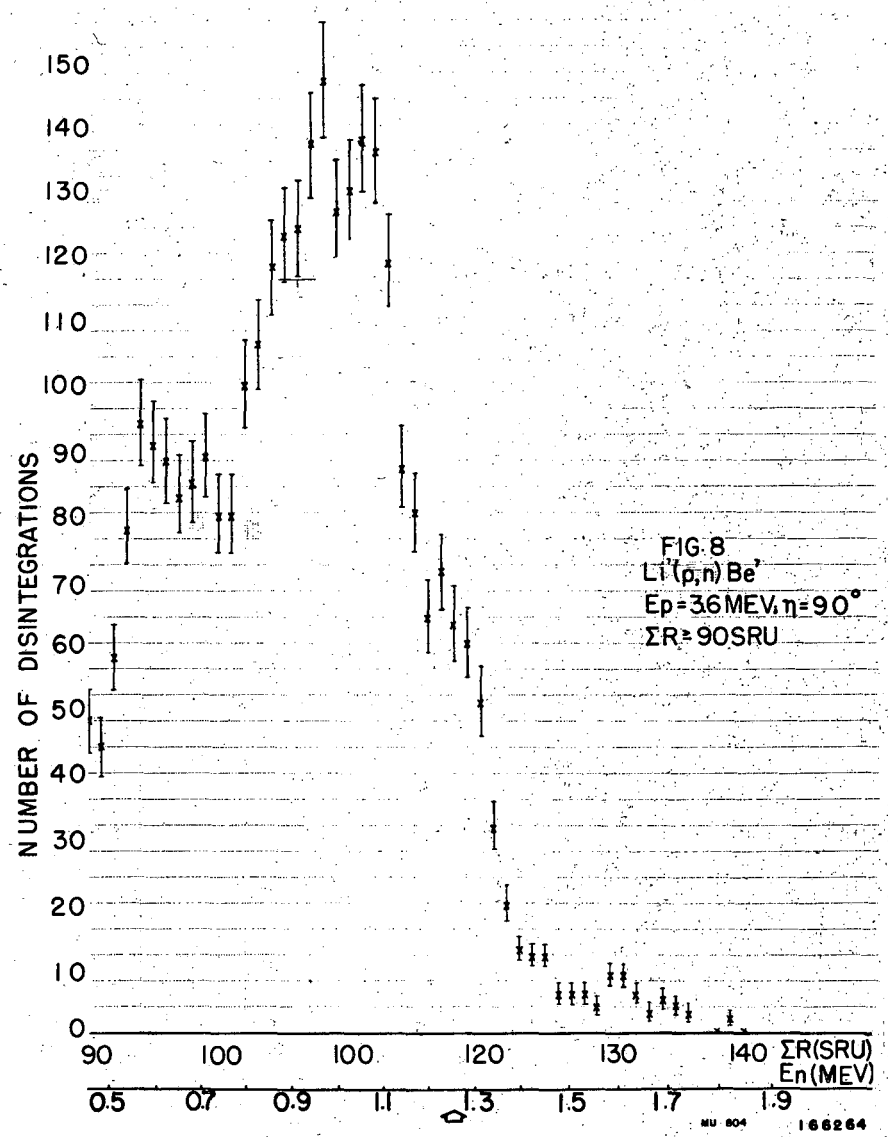


FIG. 8
$Li^7(p,n)Be^7$
$E_p = 3.6$ MEV, $\eta = 90°$
$\Sigma R = 90$ SRU

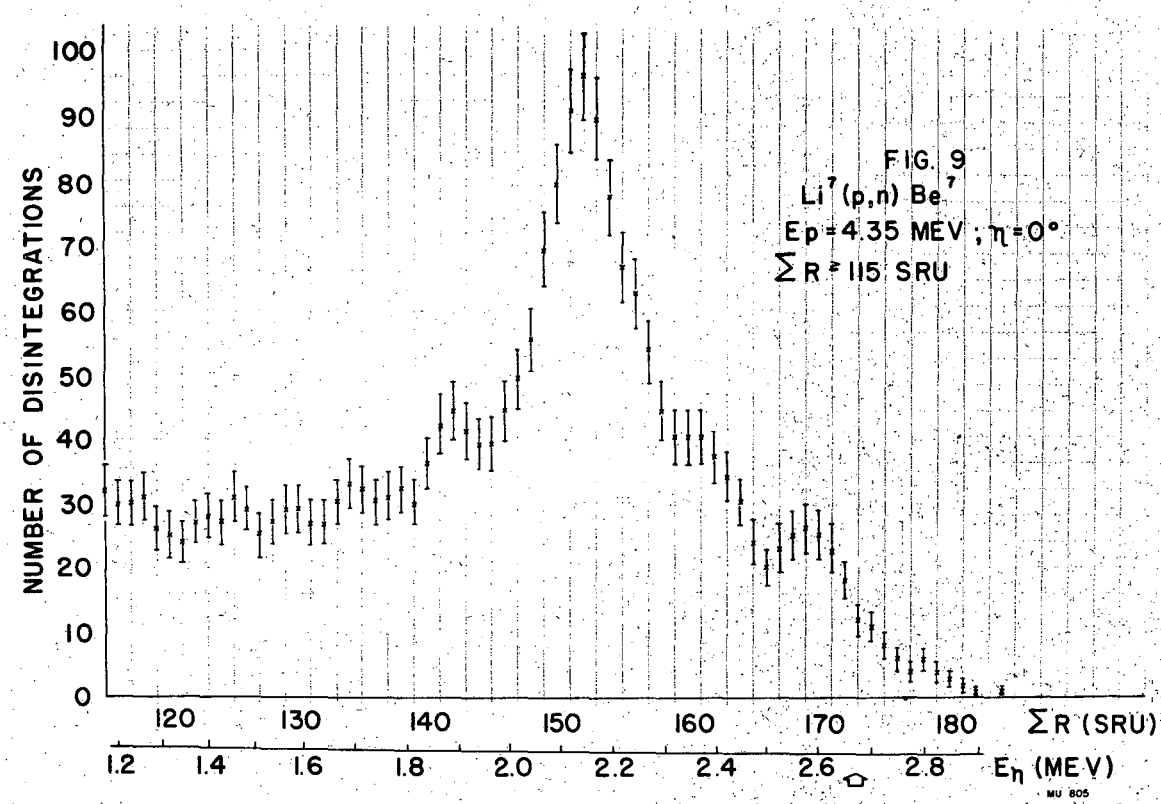
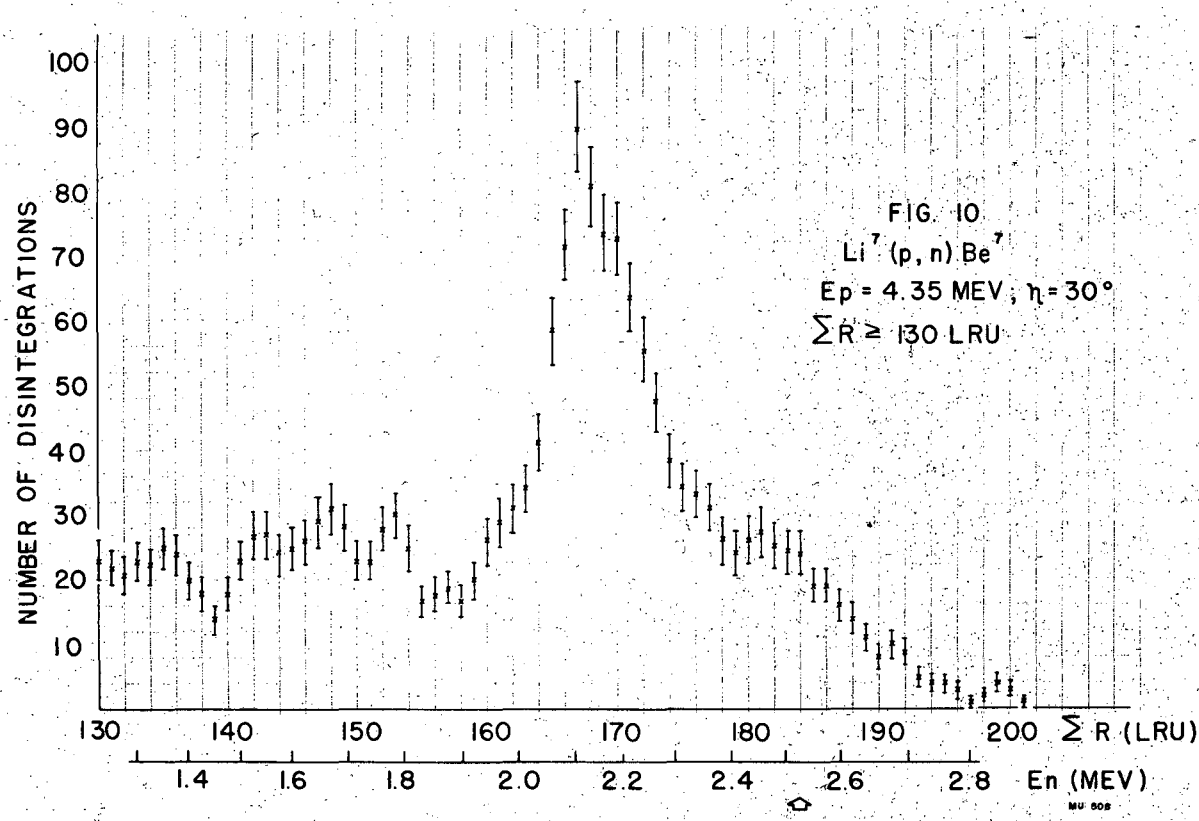
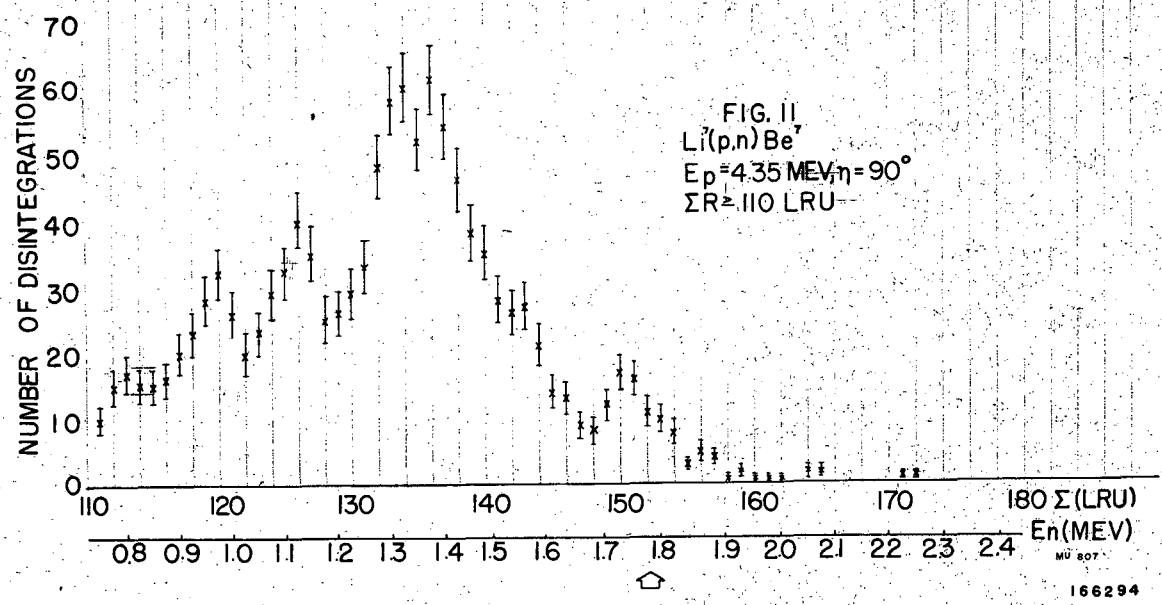


FIG. 9
Li7(p,n) Be7
Ep = 4.35 MEV ; η = 0°
ΣR = 115 SRU
NUMBER OF DISINTEGRATIONS
0
10
20
30
40
50
60
70
80
90
100
120
130
140
150
160
170
180
ΣR (SRU)
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
Eη (MEV)
MU 805


NUMBER OF DISINTEGRATIONS
100
90
80
70
60
50
40
30
20
10
FIG. 10
Li7 (p, n) Be7
Ep = 4.35 MEV ; η = 30°
ΣR ≥ 130 LRU
130
140
150
160
170
180
190
200
Σ R (LRU)
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
En (MEV)
MU 808


NUMBER OF DISINTEGRATIONS
70
60
50
40
30
20
10
0
FIG. 11
Li7(p,n) Be7
Ep=4.35 MEV, η=90°
ΣR≥110 LRU
110
120
130
140
150
160
170
180 Σ(LRU)
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
En(MEV)
MU 807
166294