ON THE ANGULAR DISTRIBUTION OF NEUTRON FIUX OF T(d,n) REACITON APPARATUS

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T(d,n)反応装置における中性子線束の角分布

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速中性子によるステンレス鋼板の放射化を利用し，T(d,n) 反応中性子発生装置の中性子線束密度の角分布の測定をおこなつた．線源を中心とした4 π方向における角分布の異りは±25%となるが，全方向において照射可能である．しかしながら1群の照射物にたいして均等照射をのぞむときには回転照射をおこなうべきである．回転照射についてその均等度を上記同様の方法で測定をおこなつた結果，回転ケースがまわつているときは静止時の σ 値 7.2 (m= 2.1) にたいして 2.0 (m = 0.6) という均等度を与えた．

Introduction

As neutron sources, many kinds of reactions and reaction apparatuses (Tables 1,2 and 3) have been discovered, produced and improved[1-4]. At the present time, D(d,n) and T(d,n) reactions derived with accelerated deuterons, rather than (α,n) reaction, (γ,n) reaction or other sources, are used in order to obtain dense and monochromatic neutron flux. Neutron produced by fission of U^{235} in the atomic pile is another neutron source.

Among these neuton sources, T(d,n) reaction, which is resonant at 108 kV and has 17.6 MeV of Q value[5], is the best from the standpoint of yield quantity and energy uniformity. This reaction has a uniform differential cross section in 4π directions when

Table 1. Typical (α, n) neutron sources.

Source	Half-lifetime	Neutron energy (Mev) (max.)	Productive power (n/sec/curie)
Ra-Be	1622y	13.08	15×10^6
Po^{210}-Be	138.4d	10.87	2.5×10^6
Po^{210}-B^{10}	138.4d	6.29	0.6×10^6
Ra-B^{10}	1622y	8.58	7×10^6
Po^{210}-F	138.4d	2.8	0.2×10^6

Table 2. Typical (γ, n) neutron sources.

Source	Half-life time	Neutron energy (MeV)	Productive power (n/sec/curie)
Na^{24}-D_2O	14.8h	0.22	27×10^4
Na^{24}-Be	14.8h	0.83	13×10^4
Ra-Be	1622y	0.7 max.	1.3×10^6
Sb^{124}-Be	60d	0.024	19×10^4

Table 3. Typical artificial neutron sources.

Source	Max. cross section (Accelerating voltage) (barn)	Neutron energy (MeV)
${}_1D^2(d,n){}_2He^3$	0.1 (at 2MV)	2.45
${}_1T^3(p,n){}_2He^3$	0.5 (at 3MV)	0.6~ 4
${}_1T^3(d,n){}_2He^4$	5 (at 108KV)	14
${}_4Be^9(\alpha,n){}_6C^{12}$	0.03 (at 3MV)	7.7~10.6
${}_6C^{12}(d,n){}_7N^{13}$	0.05 (at 2MV)	~2.76
${}_6C^{12}(\alpha,n){}_8O^{16}$	0.03 (at 3.4MV)	4.3~ 5.6
${}_3Li^7(p,n){}_4Be^7$	0.6 (at 2.4MV)	0.27~ 1.5

the energy of accelerated deuteron is not very large. Depending on the apparatus of the neutrou source, there is some question whether or not the distribution of the neutron flux is equal in all directions of 4π. It must be considered that the accelerated ion particle beam may be deviated somewhat from the geometric center of the target plate, that by decreasing the beam size the reaction point may be a plane rather than a point, and that the kind of material used for the target prop and frame may introduce a variance.

When animals are irradiated with such a deviated neutron flux, the results obtained will be biased and of no value. It is, therefore, necessary to ascertain the deviation of neutron flux density of each neutron source instrument.

For biological studies, this department is equipped with a 14.1 MeV neutron source generator, T(d,n) raction type, being operated with high voltage of 200 kv†. The angular distribution of the neutron flux density was evaluated by determining the radioactivity of Mn^{56} produced by Fe^{56} (n,p) Mn^{56} reaction in stainless steel plates. In this experiment, the usefulness of the revolving method for uniform irradiation was also studied.

Method

1. *The angular distibution of neutron flux in the direction of* 4π.

Fig. 1 shows the neutron source instrument except the controller and the high voltage transformer. The target and prop made of stainless steel are shown in Fig. 2. Theoretically, the angular distribution of neutrons produced by T(d,n) reaction should be equal in all directions of 4π. Distortion of the flux density, however, may be caused by the deviation of the beam center from the geometric center of the target plate, by the kind of material used as parts near the target, and by the structure of such parts.

The measurement of the angular distribution was attempted on a glass globe having a spherical surface (10 cm radius) and at each measuring point a stainless plate (10mm in diameter, 0.2 mm in thickness and 0.121 ± 0.001 g in weight) was attached. The measured points except those on the side of target prop are indicated with numbers in Fig. 3. The steel plates were attached to the indicated points on the spherical glass and placed perpendicular to the sphere center. Neutron irradiation was continued for 60 minutes to give a total neutron flux of 6.6×10^9 n/cm^2**. The count rate was taken by a G.M.

† Tōshiba Neutron Source NS-H Type.

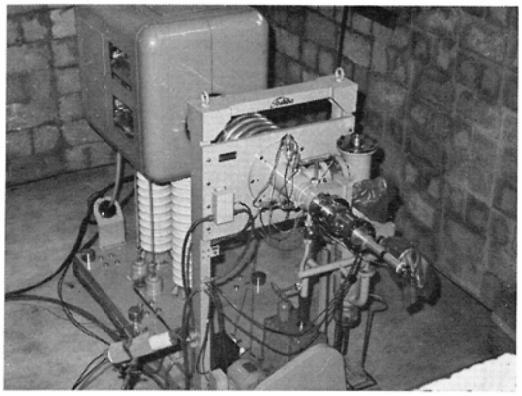
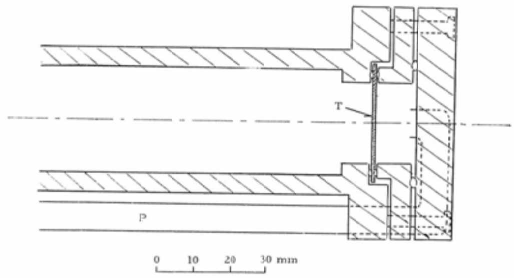
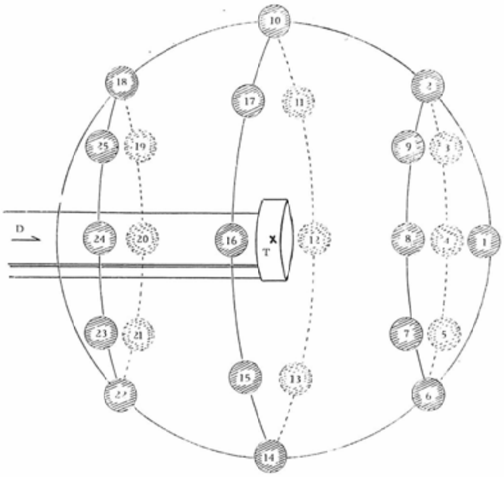


Fig. 1. Fast neutron source generator by T(d,n) reaction.



T: Target plate
P: Cooling water pipe

Fig. 2. The cross-section of the target area of the T(d,n) reaction apparatus.



T: Target (reaction center), D: Deuteron ion beam

Fig. 3. The figure of angular distribution measurement of neutron flux density (the 25 measuring points are shown with numbers).

Table 4. Neutron flux density in directions of 4π.

Number of measuring points	Flux density*	Number of measuring points	Flux density	Number of measuring points	Flux density
2	104	10	113	18	121
3	94	11	119	19	115
4	99	12	107	20	116
5	93	13	93	21	123
6	84	14	84	22	107
7	84	15	73	23	94
8	90	16	88	24	103
9	94	17	105	25	106
				1	91

$\sigma = 13.0$, $m = 2.6$

* These values are relative cpm at the measuring points with 100 as the mean value.

counter†† from the first hour to the seventh hour following irradiation, and then converted back to the time immediately after irradirtion. Table 4 shows the relative values with 100 as the mean value.

2. *The uniformity of neutron flux by revolving irradiation method.*

Fig. 4 shows the apparatus which is designed to revolve the object to be radiated. It consists of a revolving case in which the objects for irradiation are placed and of a propelling unit. This apparatus was aligned so that the target or reaction center would be at center of the revolving case, and the target prop would not contact the revolving case. As shown in Fig. 5 stainless steel plates were attached tc the 12 measuring points on the revolving case and placed perpendicular to the deuteron ion beam.

The center of target plate was accurately bombarded with deuteron ion beam. The distance from the beam center to the measuring points was 13.3 cm. The steel plates were irradiated with neutrons under two conditions; that is when the case was in motion

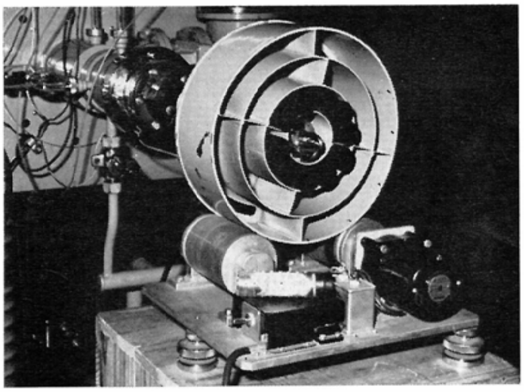
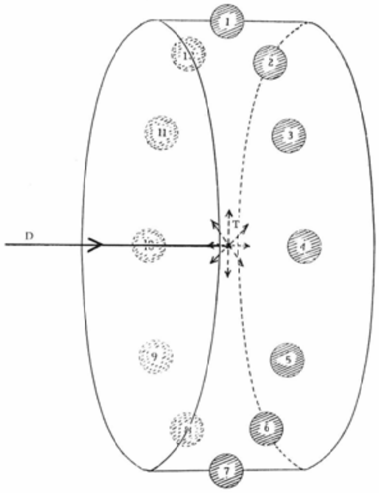


Fig. 4. Revolving irradiation apparatus.



T: Target(reaction center), D: Deuteron ion beam

Fig. 5. Neutron flux density measurement on the revolving case (the 12 measuring points are shown with numbers).

Table 5 The comparison of flux uniformity between case in motion and case not in motion.

Number of measuring points / State of revolving case	1	2	3	4	5	6	7	8	9	10	11	12	σ	m
Stationary	96	90	94	93	99	99	102	113	114	106	97	97	7.2	2.1
In motion	101	97	99	102	103	100	99	103	98	100	97	101	2.0	0.6

The values are relative cpm at the measuring points with 100 as the mean value.

†† Tōshiba G.M. Counter EAG 31102 Type.

** These values were induced by S(n,p)P reaction.

and when the case was stationary. The plates were irradiated for 60 minutes to give total neutron flux of 3.7×10^{9} n/cm^{2}** and the measurement after irradiation was done in the same manner as above. The comparison of the two is shown in Table 5 in which the relative values are shown with 100 as the mean value.

Results and Discussion

By Storer et al.[6] a exposure to the 14.1 MeV neutrons has been made with the Los Alamos Cockcroft-Walton accelerator. The neutron source strength and the total flux have been determined by counting α-particles emitted concurrently with the neutrons in a 1 : 1 ratio. While flux variations have been also determined from measurement of the relative activation of copper foils. But correction was necessary in their copper activation method, because of rapid changing of cross section with small variation in energy.

When deuterons are accelerated with 200 kV, strictly speaking, there are a few percent difference in neutron energy between 0° and 180° in angle to incident beam[7]. Copper and iron have the resonance peak at about 18 MeV[8] and at about 14 MeV[9] in neutron energy, respectively. On the iron activation, therefore, the deviation of relative activation with small variation in neutron energy would be very smaller than that of copper.

In this experiment stainless steel plates which resist rust and consist mostly of iron were used. When the stainless steel is irradiated with fast neutrons, the steel is strongly activated. The decay curve is made up of two linear curves, corresponding to the decay curves of Mn^{56} and V^{52m} induced by Fe^{56} (n,p) Mn^{56} reaction[9-11] and Cr^{52} (n,p)V^{52m} reaction[11-13], respectively. A stainless steel plate was irradiated for 45 minutes to give a total neutron flux of 5.5×10^{10} n/cm^{2}**. The count rate was measured at distance of 8mm from the detector window of the G.M. counter. The radiation decay curve is shown in Fig. 6. In this curve, the steep slope is due to the decay of V^{52m}[10,14-16] with a short-life time. The following flat line shows the decay of Mn^{56}[10,17-21]. The considerably long flat curve of Mn was utilized to estimate the neutron flux distribution. The measurament

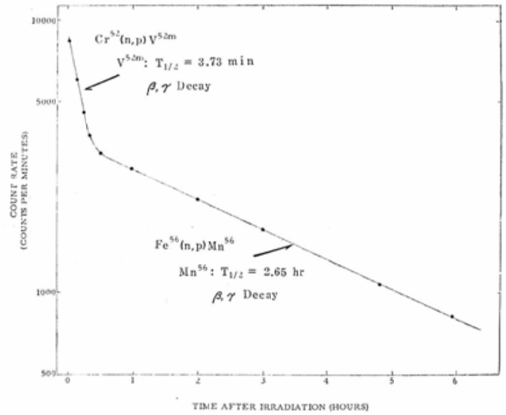


Fig. 6. Decay curve of the activated stainless steel plate.

of cpm of the Mn^{56} decay should be made after that the V^{52m} has completely decayed.

As shown in Table 4, the difference in flux densities on the plane at right angle to the deuteron beam was noted. This difference is considered to be due to the fact that two cooling water pipes are under the target prop and that the deuteron ion beam has deviated from the target center.

Though the difference of doses in the direction of 4π is $\pm 25\%$, this neutron source can be used in all directions for irradiation. To irradiate objects uniformly, the revolving irradiation method in which the objects are irradiated while revolving around the target should be employed. As shown in Table 5 the results of the revolving method were in fact remarkably uniform. It is necessary to employ this method in experiments where it is necessary to irradiate a group of small animals or other materials to a uniform dose of radiation.

Summary

The decay of Mn^{56} in stainless steel plates activated with fast neutron was utilized to measure the angular distribution of neutron flux density of T(d,n) reaction apparatus. The difference of neutron flux angular distribntion was found to be $\pm 25\%$ in the apparatus used.

Though it is possible to irradaite an object in all directions, it is desirable to employ the revolving method to irradiate a group of objects uniformly. In comparing the result when the revolving case was stationary with that when the case was in motion, the deviation values with regard to the uniformity of the irradiated neutron flux were found to be 7.2 (m=2.1) and 2.0 (m=0.6), respectively.

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