T (d,n) REACTION NEUTRON GENERATOR FOR BIOLOGICAL STUDIES

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生物学的研究のための T (d,n) 反応中性子発生装置

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1961年にT (d,n) 反応中性子発生装置を設置し，以来この装置を用いて中性子の生物学的作用の研究を行つて来た．この装置で我々は10^{10}n/sec以上の中性子束を発生させることができた．このときの中性子は，ターゲットを中心とした4π方向に対してほとんど均等な線束密度の分布をするので，4πの全空間を実験のために使用することができる．小動物照射に際しては，回転照射法を用いることにより，4～8 rad/min の線量率で致死線量の照射を行うことができた．しかしターゲットの消耗がはげしく，致死線量前後の線量率を発生させると約1時間の照射でその出力は半減した．又，ターゲット個々の出力の差が大きい．生物学的研究の目的では，1枚のターゲットからは総量10^{13}～14^{14}個の中性子を取り出すことはできたが，10^{13}個以上を取り出したあとの線量率は一般に3×10^9n/sec 以下の出力しか得られなかった．

Introduction

In X-ray irradiation or gamma-ray irradiation the ionizing particles are electrons, and in fast neutron irradiation on biological subjects the ionizing particles are mainly recoil protons. If there are some differences between the biological reactions caused by X- or gamma-irradiation and by neutron irradiation, it can be presumed that the differences are caused by the difference in the type of ionizing particles. To emphasize that these differences in reactions are not caused by the difference of dosage but are caused by the difference in the type of energy transfer to biological object, the transmitted radiation doses of both must be determined exactly.

The absorption doses of fast neutrons generated by T (d,n) reaction can be estimated easily on mammal, because such neutron has a monochromatic energy of 14.1 MeV and the reaction is not accompanied by gamma-ray.

Our department procured a neutron generator of T (d,n) reaction type for biological studies in March, 1961[1]. The authors are studying the biological actions of neutron by means of this apparatus. In this paper the performance of this apparatus will be outlined.

Mechanism of the apparatus and the capabilities

Nuclear reaction[2]

When the target of tritium-3 nucleus(^3_1T) are bombarded by acce lerated deuteron, T (d,n) reaction is produced to yield a helium nucleus and a neutron, and releases nuclear energy (Q) of 17.6 MeV, as shown in the following nuclear reaction formula.

$$^3_1T + ^2_1d \longrightarrow ^4_2He + ^1_0n + Q$$

In this reaction, the neutron obtains 14.1 MeV, while the helium nucleus gets the blance of Q. This nuclear reaction resonates at 108 keV of deuteron energy, and the maximum value of the cross section is 5 barns (5×10^{-24} cm^2). When the deuteron energy is 200 kV or less the differential cross section is almost uniform in all 4π directions. Therefore, the distribution of neutron flux in 4π directions is equal, and we can utilize at the same time all 4π spaces around the target for biological studies.

Composition and operation of the apparatus

This apparatus is composed of a controller desk, a high-tension generator, an ion source unit, an accelerating tube and a vacuum system.

The high-tension generator is Cockcroft-Walton type with a two stage selenium rectifier. The 100 kV to 200 kV positve potential, generated by this high-tension generator, is connected to an ion source unit by a high tension cable. This potential is fed into ten accelerating poles.

On the other hand, the deuteron gas ($^2D_2$) produced by electrolysis of heavy water diffuses into the ion source tube through the heated palladium foil. In the ion source tube D_2 gas is ionized by high frequency of 16~19 megacycles (R-F ion source[3]), and the ionized particles or deuterons are pushed into the accelerating tube through the canal by 2~4 kV positive potential probe, and they are accelerated while passing through the 50 cm tube. In the early phase of the acceleration, the deuteron beam is squeesed as desired by an electric field lens. The accelerated deuteron particles run through the guide pipe of about 1 meter length, and bombard the tritium target which is mounted at the end of the guide pipe.

The heating current of palladium foil is regulated at the surface of the ion source unit panel before giving it a high potential, but the probe potential, the lens potential and the accelerating potential are remote controlled at the controller desk on this side of the shielded wall.

Target

The target tritium is purchased from Harwell (United Kingdom). Tritium (^3_1T) is a radioactive isotope, emitting beta ray with the maximum energy of 18 keV and having a half-life of 12.4 years. The following description is given of the target in the catalogue. Titanium is evaporated approximately 200 $\mu g/cm^2$ in thickness onto the copper disc 2.85 cm in diameter and 0.025 cm in thickness, and tritium gas $^3T_2$ of around 6 curies is absorbed in the titanium layer (6 curie thin type). In 1962 the cost is about ¥60,000 per disc in Japan.

The life of the target greatly differs with the bombarding technique employed. According to the catalogue one disc can yield 10^{15} neutrons, but as flux densities smaller than 10^9 n/sec are not suitable for our biological experiments, the disc was replaced after a yield of $10^{13}\sim10^{14}$ n. If the apparatus is run at a smaller current of deuteron beam, the decrease in yield is not very great over a long period. If the target is bombarded with a large current to obtain a dense yield of neutron flux, the target emaciates rapidly. There is about 50% in variation between the yield of each disc at the initial bombardment.

Figure 1 shows three examples of reduction curve of yield of the target used for

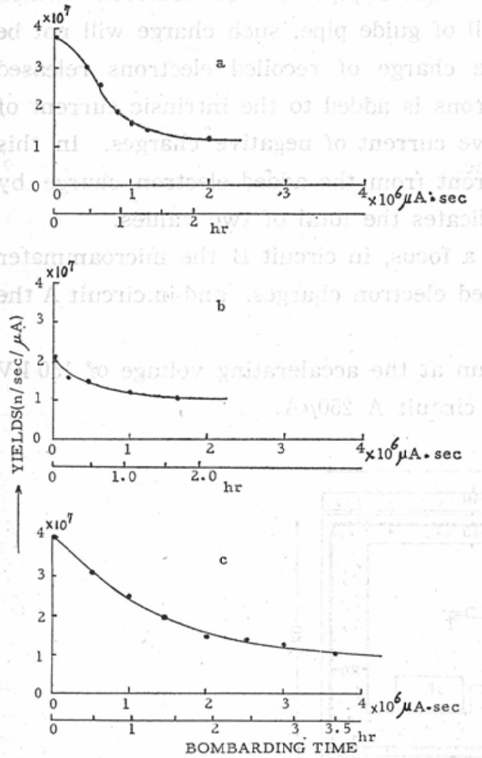

Fig. 1 Reduction curves of neutron yield of ^{3}H-Ti thin target
Accelerating voltage of deuteron: 150 kV
Deuteron beam: (a) 200∼280μA, (b) 250 μA, (c) 275 μA

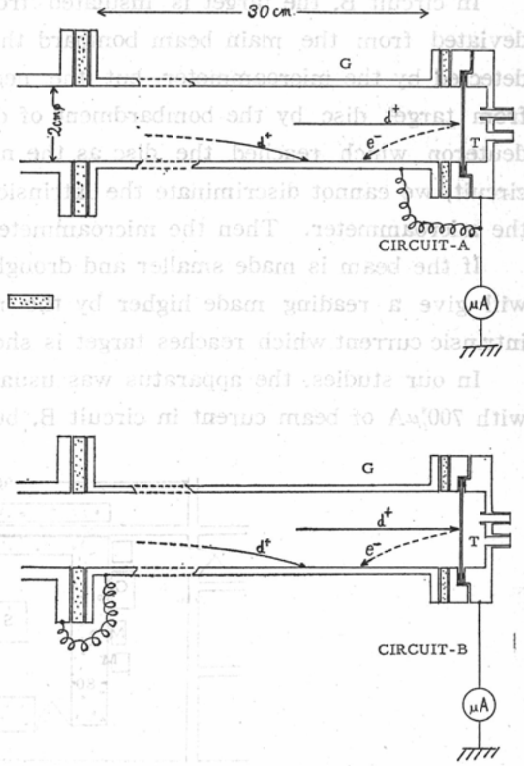

Fig. 2 Circuits to detect the deuteron current
(A): Target T is insulated from the earth and connected with ammeter (μA)
(B): Target is insulated from guide pipe (G)

the irradiation of experimental animals. In these examples the running voltage was 150 kV, and the beam current was from 200 μA to 300 μA. In each bombardment, neutron flux of from 5×10^9 n/sec to 2×10^{10} n/sec was obtained at first, but after an hour of operation the flux decreased to one-half of the initial value. The reduction in yield was there after slight and therefore we could continuously irradiate with $1\sim2\times10^7$ n/sec/cm^2 a group of ten mice placed 5 cm from the target. These flux densities correspond to about $4\sim8$ rad/min of absorption doses in these mice.

Deuteron beam

The current of the deuteron beam is measured by means of circuit A or B of Fig. 2. In circuit A, guide pipe G is insulated from earth and it together with the target unit is connected to the microammeter. Therefore, if the recoiled elctrons released from the target disc by the bombardment of deuteron are captured by the guide pipe, the negative current will not register on the microammeter. However, the positive charge of deuterons which bombarded the inner wall of the guide pipe is added on to the intrinsic current of the deuterons which bombarded the disc.

In circuit B, the target is insulated from the guide pipe G. If deuterons which deviated from the main beam bombard the wall of guide pipe, such charge will not be detected by the microammeter, but the negative charge of recoiled electrons released from target disc by the bombardment of deuterons is added to the intrinsic current of deuteron which reached the disc as the negative current of negative charges. In this circuit, we cannot discriminate the intrinsic current from the added electron charge by the microammeter. Then the microammeter indicates the total of two values.

If the beam is made smaller and drought to a focus, in circuit B the microammater will give a reading made higher by the recoiled electron charges, and in circuit A the intrinsic current which reaches target is shown.

In our studies, the apparatus was usually run at the accalerating voltage of 150 kV with 700 μA of beam curent in circuit B, but in circuit A 250μA.

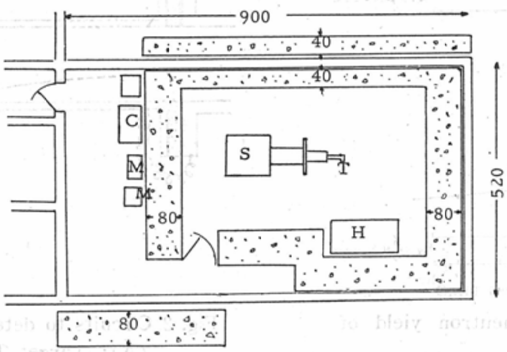

Fig. 3 Schematic diagram of concreate shielding of neutron room

T: Target, H: High-tension generater
S: Ion source unit, C: Controller desk
M: Flux monitor and flux measuring equipment

Shielding construction

This apparatus should be mainly shielded against 14.1 MeV fast neutrons, but the shielding against slow neutrons, gamma-rays caused by (n,γ) reactions, and ionizing radiations emitted from activated isotopes must be given the same consideration.

Our neutron source room is shielded by a concreate wall of 80 cm thickness, and the relaxation length of 14 MeV neutron was estimated to be 11 cm in concreate by reference[1)4)5)]. The floor plan of the room with the shielding walls is shown in Fig. 3.

Summary

In this paper, some of the capabilities of T(d,n) reaction apparatus used in our department for neutron irradiation in biological studies are described.

This apparatus can produce more than 10^{10} n/sec of flux of 14.1 MeV monochromatic energy, but in our biological experiments the ^{3}H-Ti thin target emaciated rapidly under the accelerating voltage of 150 kV and the deuteron current of from 200 μA to 300 μA.

We were able to irradiate continuously groups of mice by $1\sim2\times10^7$ n/sec/cm^2 of flux density (about $4\sim8$ rad/min) at a distance of 5 cm from the target.

References

1) Nishibori, K., et al.: The neutron source generator, Toshiba Review, 16, 1167, (1961). —2) Marion, J.B. and J.L. Fowler: Fast neutron physics, Interscience Monographs and Texts in Physics and Astronomy, Vol. 4, Interscience Pub. Inc., New York, (1960). —3) Ryu, N., et al.: High frequency ion source, Memoirs of the Faculty of Science, Kyusyu Univ., Ser. B, 1, 186, (1955). —4) Jaeger, T.: Abschwächung schneller Neutronenstrahlung durch Beton in Abhängigkeit von seinen Wässerstoffgehalt, Die Bautechnik, 10, 405, (1958). —5) Glasstone, S.: Principles of Neutron Reactor Engineering, D. Van Nostrand, (1955).