Fyzikálny časopis 20 (1970), No. 2

ON THE POSSIBILITY OF DETERMINATION OF THE TRITIUM DISTRIBUTION IN TITANIUM-TRITIUM TARGETS

PAVEL OBLOŽINSKÝ, IGOR RIBANSKÝ, Bratislava

The spectroscopy of α-particles, resulting from the T(d, n) He^4 reaction is suggested as a method for determining the tritium distribution in a titanium layer target in the 14 MeV neutron generation. Experimental possibilities are discussed.

INTRODUCTION

The T(d, n) He^4 reaction is commonly used in the generation of 14 MeV neutrons. Tritium atoms, absorbed in the titanium (zirconium) layer of the target, are bombarded by a deuteron beam from the accelerator. The cross section of this reaction is equal to its maximum value (approximately 5 barns) at about a 130 keV energy of deuterons [1]. As a consequence of both non-uniform tritium loading in the layer and energy loss of deuterons in the target this reaction does not take place in the region of maximum concentration of tritium with incident deuteron energy $E_d \sim 130$ keV. This fact influences both total yield and energy distribution of neutrons. The non-uniform tritium loading in the titanium layer has been investigated by measuring the total neutron yield at different deuteron energies as well as for the different target positions with respect to the deuteron beam axis [2]. Fig. 1 gives the distribution in one target thus determined.

The spectroscopy of α-particles resulting from the T(d, n)He^4 reaction could be utilized for the determination of tritium distribution in a titanium

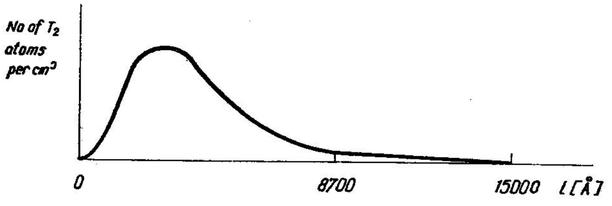

Fig. 1. Tritium distribution inside the titanium-tritium target.

layer target. The basic cosiderations concerning to this method are the subject of this paper.

DESCRIPTION OF THE METHOD

Let us consider deuterons striking the target surface at the angle Θ_1, and the part dl of the target layer in the depth l. We will investigate α-particles emerging from the target at the angle Θ_2, i. e., with respect to the deuteron beam axis at the angle $\Theta = \Theta_1 + \Theta_2$ (Fig. 2). The energy $E_\alpha^{(0)}$ of α-particles generated in the layer dl depends, in general, on both Θ and the energy of the interacting deuterons $E_d(l)$. It is possible to choose Θ so that the energy $E_\alpha^{(0)}$ will not depend on the depth l($\Theta = 87°$, $E_\alpha^{(0)} = 3529 \pm 3$ keV if the incident deuteron energy is 150 keV [1]).

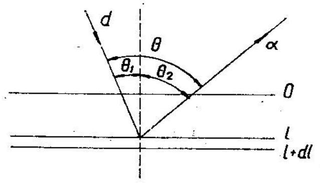

Fig. 2.

After leaving the target, the α-particles have the energy

$$E_\alpha(l) = E_\alpha^{(0)} - \int_0^{l/\cos\Theta_2} \left|\frac{d\varepsilon_\alpha}{dx}\right| dx, \qquad (1)$$

where $d\varepsilon_\alpha/dx$ is the rate of the energy loss of α-particles in the target material. The latter can be expressed according to the Bragg rule [2]

$$\frac{d\varepsilon_\alpha}{dx} = \frac{48}{48 + 3C(l)}\left(\frac{d\varepsilon_\alpha}{dx}\right)_{\mathrm{Ti}} + \frac{3C(l)}{48 + 3C(l)}\left(\frac{d\varepsilon_\alpha}{dx}\right)_{\mathrm{T}}, \qquad (2)$$

where $\left(\frac{d\varepsilon_\alpha}{dx}\right)_{\mathrm{Ti}}$ and $\left(\frac{d\varepsilon_\alpha}{dx}\right)_{\mathrm{T}}$ are the rates the energy loss of α-particles in titanium and tritium, respectively; $C(l)$ is the loading ratio of tritium in titanium in the depth l, i. e., the number of tritium atoms absorbed by one titanium atom in the depth l.

It is clear from equation (1) that there is an unabmiguous relation between the energy of α-particles and the depth l, with $\Theta = 87°$.

It is assumed in the following considerations that:

1) The deuteron flux Φ_d does not depend on the depth l
2) The deuteron flux Φ_d contains a negligible portion of D_2^+ ions
3) The multiple scattering of deuterons in the target material has only a very small influence on the energy $E_\alpha^{(0)}$
4) The titanium density ϱ_{Ti} is independent from the loading ratio $C(l)$, i. e., the expansion of the titanium lattice is negligible.

Let us consider again the part dl of the layer in the depth l. The number of α-particles arising in this part and emitted within the solid angle $\Delta\Omega$ at the angle Θ_2 is

$$\Phi_d \Delta\Omega \sigma(E_d(l))\, n(l)\, dl = N_\alpha(E_\alpha(l))\, dE_\alpha(l), \qquad (3)$$

where $\sigma(E_d(l))$ is the differential cross section for the T(d, n)He^4 reaction, $E_d(l)$ is the deuteron energy in the depth l and $N_\alpha(E_\alpha(l))$ is the number of α-particles with the energy E_α in the depth l; the deuteron energy $E_d(l)$ is given by

$$E_d(l) = E_d^{(0)} - \int_0^{l/\cos\Theta_1} \left|\frac{d\varepsilon_d}{dx}\right| dx, \qquad (4)$$

where $E_d^{(0)}$ is the incident deuteron energy, $d\varepsilon_d/dx$ has the same meaning as in Eqs. (1) and (2); $n(l)$ is the number of tritium atoms in the unit volume. According to the assumption 4):

$$n(l) = \frac{\varrho_{\mathrm{Ti}} N}{A_{\mathrm{Ti}}} C(l), \qquad (5)$$

where A_{Ti} is the atomic weight of titanium and N is Avogadro's number. The relation (3) can be rewritten in the following form

$$N_\alpha(E_\alpha(l)) = \Phi_d \Delta\Omega \frac{\sigma(E_d(l))}{\dfrac{dE_\alpha(l)}{dl}} n(l). \qquad (6)$$

As it follows from Eq. (1) $dE_\alpha(l)/dl$ equals the specific energy loss given by equation (2).

Both the cross section $\sigma(E_d)$ [1] and the specific energy loss of deuterons [2] as well as of the α-particles [3] are known functions. The quantities E_α, $N_\alpha(E_\alpha)$ can be obtained by means of α-spectroscopy. Substitution of (2), (4) and (5) into (1) and (6) gives thus the system of two equations for which the numerical solution with respect to $C(l)$, depending on l, describes the distribution of tritium in the titanium-tritium target.

DISCUSSION

The experimental determination of the tritium distribution $C(l)$ in the target by this method depends on the validity of the assumptions mentioned above.

1. If one assumes the deuteron current to be 10^{-6}A and the total neutron yield 10^8 neutrons/4π sec (the usual parameters of neutron generators), the decrease of the deuteron beam due to the T(d, n)He^4 reaction is 10^{-5}. The other decreasing effects can also be neglected.
2. The neutron generators with the high-frequency discharge as a deuteron source give the deuteron beam containing ~ 10 % od D_2^+-ions [4]. The influence of this portion of D_2^+ can be neglected if we take into account that molecular deuterons interact with half their energy when the cross section sinks rapidly and that they lose their energy in front of the target layers, where $C(l)$ is low, very quickly. The D_2^+ portion can be completely eliminated by use of the magnetic separation.
3. The influence of the multiple scattering of deuterons on the energy $E_n^{(0)}$ of neutrons emitted at the angle $\Theta = 98°$ was investigated in paper [7]. The calculated half-width of the corresponding energy spread for a thick target at $E_d^{(0)} = 150$ keV is equal to the value of ~ 100 keV while the kinematic spread of the energy of neutrons is only ~ 30 keV. The experimental results obtained in paper [7] give a value which is little lower than the theoretical one. The kinematic spread of the α-particle energy at the angle $\Theta = 87°$ is ~ 6 keV [1]. One can thus expect that for such a class of α-particles the energy spread due to the multiple scattering of deuterons is considerably less than that for $E_n^{(0)}$ at 98°.
4. The loading ratio C for Ti lies within the range 0.2—2.3 [5]. The consequence of this fact is the deformation of the titanium lattice, i. e., ϱ_{Ti} depends on C. The characteristic value of this deformation is the expansion of the lattice by about 15 % for $C = 1.5$ [2].

The proper choice of the time interval Δt and the geometry are very important experimental requirements. The value of Δt is limited by the requirement that $C(l)$ has to be constant during the measurement and that the α-particles count rate be sufficiently high. On the other hand the geometry must verify the assumption $E_\alpha^{(0)} \approx$ const.

If one considers the parameters of the neutron generators mentioned above one can assume $\Delta t = 10^2$ sec being the interval in which the quantity $C(l)$ changes very little [6]. It can be shown from kinematics that within the angle interval of 0.5° around $\Theta = 87°$ the assumption $E_\alpha^{(0)} \approx$ const. holds good. According to the simple calculation under the condition defined above, one can expect the area of the α-spectrum of the order of 10^5.

Experimental preparations for the verification of the described method are in progress.

ACKNOWLEDGEMENTS

The authors are indebted to Ing. Š. Bederka, CSc. and RNDr. J. Pivarč for helpful discussions. They also wish to thank Ing. F. Severa for the correction of the manuscript.

REFERENCES

[1] Oria M., Sorriaux A., Rapport CEA-R2779, Saclay 1965.
[2] Gunnersen E. M., James G., Nucl. Instr. Meth. *8* (1960), 173.
[3] Marion J. B., Young F. C., *Nuclear Reaction Analysis*. North Holland, Amsterdam 1968.
[4] Табович М. Д., *Плаземные источники понов*. Киев 1964.
[5] Saker, Wood, S. E. R. L., Baldock. Techn. Mem. No. 413 (1958).
[6] Marion J. B., Fowler B. L., *Fast Neutron Physics I*. New York 1960.
[7] Breunlich W. H., Acta Phys. Austr. *23* (1966), 224.

Received June 2^d, 1969

Fyzikálny ústav SAV,
Bratislava