PROBLEMS OF THE ACT REACTOR (THE P11B REACTION)

V.I. Volosov

BINP SB RAS, Novosibirsk

Publications [1, 2] considered a project of aneutronic reactor (the P11B reaction) based on the asymmetric centrifugal trap (ACT), the energy of protons and alpha particles leaving the reactor subjected to direct transformation to electrical energy.

These works considered a project of such a reactor under some simplifying assumptions. The most significant of them is that of the scheme of the intermediate Be nucleus decay into 2 alpha particles through the ground state, which determined the energy spectrum of these particles. However, there are two channels of decay of this nucleus in this reaction, i.e., through the ground state of Be and through its excited state, see Fig.1. It can be seen from calculation in [3,4] that the probability that the reaction goes through the excited state is two orders higher than the ground state variant.

It significantly changes the shape of the energy spectrum of alpha particles and makes it necessary to somehow change the scheme of their energy recovery in this project, the scheme of realization of the main process (the P11B reaction) remaining unchanged.

I. TWO CHANNELS OF DECAY OF C12* NUCLEUS IN THE P11B REACTION

Works [3,4] present schemes of decay of C12* nucleus both through the excited and ground state of the intermediate Be8 nucleus and the energy spectrum of alpha particles in these processes, see Fig.2 and Fig.3 The same problem is considered in a number of experimental works ([5,6]).

The main difference of the fusion reactor described in [1] from a reactor in which an actual alpha spectrum is considered (see [3,4]) is that both channels of beryllium decay have to be taken into account in the latter case.

II. EXTRACTION OF “COLD” ALPHA PARTICLES FROM THE ACT

The presence and accumulation of “cold” alpha particles in any magnetic trap is dangerous for the P11B reaction. Alpha particles with energy higher than the energy of the barrier that confines both the plasma and alpha particles in the trap are assumed to go to the energy recovery system rather fast, i.e. within the time of flight of alpha particles along the ACT system. Alpha particles with energy lower than the energy of this barrier can be confined in the trap, being reflected from magnetic plugs, for a rather long time.

If the time of confinement of “cold” alpha particles in the magnetic trap is one order or more higher than the time of their origination, the stationary mode is associated with origination and accumulation of the so-called “ash” of cold alpha particles. Energy losses due to the bremsstrahlung of electrons associated with this ash exceed the energy yield of the nuclear reaction [7].

Unlike a conventional magnetic trap, the ACT system allows removing the alpha “ash” in the radial direction in the central area of the trap (not through a magnetic plug) due to the particularities of motion of heavy ions in this system.

Let us consider the area of “small” energies of alpha particles at W_α < 1.0 - 1.5 MeV (compare with Fig. 9 in [1]).

The velocity of azimuthal drift in a radial electric field, the centrifugal force taken into account, equals:

$$V_\varphi = V_E(1+\rho_{LE}/R) \qquad (1)$$

where $\rho_{LE} = mV_Ec/ZeH$ is the Larmor radius of an ion with the speed V_E, $V_E = c(E/H)$, R is the radial size of the rotating plasma (distance to the axis of the system) [8].

Clearly, this velocity is different for different particles of different masses and charges. This difference and “friction” between particles of one sort with particles of another type causes drift in the direction perpendicular to the azimuthal drift, i.e., in the radial direction. Heavier ions are drifting in the direction of the centrifugal force; lighter ones are drifting in the opposite direction.

The plasma under consideration contains 2 sorts of ions. Those are protons and boron ions, but the velocity of the radial drift of alpha particles V_{drr} is determined substantially by interaction with boron ions (due to Z^2).

Let us calculate this velocity for a pair of an alpha particle and boron ion. The Larmor radii of an alpha particle and boron ion with velocities equal to the azimuthal drift velocity V_E are $\rho_{LE\alpha} = 4m_pV_Ec/2eH$ (alpha); $\rho_{LEB} = 11m_pV_Ec/5eH$ (boron ion).

Correspondingly, the difference azimuthal drift velocity equals:

$$\Delta V_{\varphi} = V_E(\rho_{LEB}/R - \rho_{LE\alpha}/R)$$
$$\equiv \Delta\rho_{LE} V_E/R = 0.2V_E(\rho_{L\alpha}/R) = 0.2V_E(2\rho_{Lp}/R) \qquad (2)$$

$V_{drr} = \Delta V_{\varphi}/(\tau_s \cdot \omega_c)$; τ_s is the characteristic time of momenta transfer between boron ions and alpha particles (see [9]), ω_c is the cyclotron frequency for particles under consideration (alpha particles in this case).

We will use the plasma parameters presented in [1]. The plasma radius is 200 cm (because of optimization). The density is n=10^{13}cm^{-3}, E=300kVcm^{-3}, H=3.0T.

Here, in accordance with (2),

$$\Delta V_{\varphi} = 0.2V_E(2\rho_{LEp}/R) = 2.70\ 10^{-3}\ V_E. \qquad (3)$$

The characteristic times of momenta transfer between an alpha particle and boron ions give the values τ_1 and τ_s calculated subject to the energy (temperature) of these particles. In the first approximation, the temperatures of electrons, cold protons, boron ions and cold alpha particles, which got cold on electrons, are equal to one another, $W_e = W_\alpha = 55\text{keV}$ [1].

Under this condition, τ_1 = 0.026 s.

For the ACT parameters,

τ_s = 0.73 τ_1 = 0.73 (2.65 10-2 s) = 0.019 s. The radial drift velocity is

$$V_{drr} = \Delta V_{\varphi}/(\tau_s \cdot \omega_c) \cong 1.041 \quad \text{cm/s} . \qquad (4)$$

Thus the time of escape of alpha particles from the plasma at interaction only with boron ions is

$$\tau_{esc} = \Delta r\ /V_{drr} = 28.5 \text{ s}. \qquad (5)$$

Here Δr =30 cm is the radial size of plasma in [1].

A similar drift takes place in the ACT system at interaction of alpha particles and protons.

The additional velocity of the radial drift of alpha particles on protons is about several percents of the radial drift of alpha particles on boron ions.

The total velocity of radial drift at interaction of alpha particles both with boron ions and with protons equals the difference of the drift velocities.

The characteristic time of origination of an alpha particle (to be more precise, of 3 alpha particles) is about 66 s for each proton injected into the ACT system [1].

It follows from the above estimates that in the scheme of ACT reactor presented in [1] there is no accumulation of cold alpha particles or that their density does not exceed the plasma density.

Recuperation of the energy of "cold" alpha particles and boron ions leaving the ACT across magnetic force lines

The energy taken off by alpha particles in the laboratory system of coordinates is rather high even for "cold" alpha particles. It equals the sum of two energies: the energy of rotation of the alpha particle mass center relative to the ACT axis $W_\alpha = m_\alpha V_E^2/2$ and that of alpha particle motion in a rotating system of coordinates, which includes the Larmor rotation $W_{\alpha L}$ and longitudinal motion $W_{\alpha II}$.

$$W_\alpha \approx \quad 2.7\text{MeV}+0.6\text{MeV}+0.3\text{MeV} \qquad (6)$$

A significant decrease in these losses can be realized through varying the radial distribution of the radial electric field in the ACT. If the field intensity is made a few times (2-5) lower within an interval of 2-3 Larmor radii from the side wall (for alpha particles it is the inner liner of the ACT), the energy of rotation of the centre of mass of the alpha particles will decrease 4-25 times, and the energy removed by the alpha particles from the trap will lessen by a corresponding factor.

III. RECUPERATOR OF THE ENERGY OF ALPHA PARRTICLES ESCAPING ALONG THE MAGNETIC FIELD

The main channel for extraction of alpha particles from the ACT system was described in [1,2]. The difference of the modified scheme of recuperation is associated with a significantly wider energy spectrum of alpha particles. However the general scheme of recuperation stays the same. Because of the reflection from the alpha barrier, all alpha particles are extracted through the alpha plug. A particular feature of the alpha recuperator is the deceleration system for the longitudinal component of the alpha particle velocity, which can take off part of the longitudinal energy (roughly estimated to be 0.5 to 1.0 MeV). This system makes it possible to recuperate a significant part of the longitudinal energy of alpha particles and lower the longitudinal velocity of particles in the recuperator and thus its longitudinal dimension.

The transversal component of the alpha particle velocity after deceleration is recuperated in the segmented recuperator by the scheme described in [1] and [10]. Two conditions have be fulfilled here: the alpha particle has to make one complete turn in the magnetic field while passing through one stage of the segmented recuperator (the time τ_{II})in order to touch the potential electrode at the point where the kinetic energy of the particle is minimum. This condition can be presented in the following form:

$$\tau_{II} = L_{II}/V_{II} \geq 2\pi/\omega_c \; ; \qquad (7)$$

here V_{II} is the longitudinal velocity; L_{II} is the longitudinal dimension of the recuperator stage; ω_c is the cyclotron frequency of the alpha particle.

As compared with the scheme in [1], this condition makes it necessary to increase the longitudinal dimension (length) of the recuperator to 150 – 250 meters, see Fig.4.

The second condition is linked with the alpha particle spectrum. In this case, it is much wider than the spectrum under consideration in [1]. The alpha particle energy recuperation takes place due to the summing of two velocities: the centrifugal rotation velocity V_C ($V_C \approx V_E$, see(1)) and the velocity of the Larmor motion – motion along the Larmor orbit.

According to [8] the energy losses are

$$\Delta W_{loss} \approx m(V_{Cm} - V_{Lm})^2/2 \approx \left(\sqrt{W_{Cm}} - \sqrt{W_{Lv}}\right)^2; \qquad (8)$$

here V_{Cm} is the velocity and W_{Cm} is the energy of the centrifugal motion; V_{Lm} is the velocity and W_{Cm} is the energy of the Larmor motion in the recuperation area (the index m means that we consider particle motion in the magnetic plug). Provided that the parameter ΔW_α - the alpha particle spectrum broadening - is small as compared with $W_{Em} \equiv W_{Cm}$, we have

$$\Delta W_{loss} \approx W_{Em}(\Delta W_\alpha / 2W_{Em})^2; \qquad (9)$$

Therefore, for the half width of the alpha particle spectrum $\Delta W_\alpha \approx 0.5W_E$ the losses are about 5 to 10 per cent. It follows from the above estimates that the system for recuperation of alpha particle energy allows returning as much as 80% of alpha particle energy to the energy system in the form of electrical energy.

The author expresses his deep gratitude to S.V. Putvinsky and Dan Barnes for statement of the problem and discussion of results and to V.F. Dmitriev for the presented amended data on the nuclear reaction.

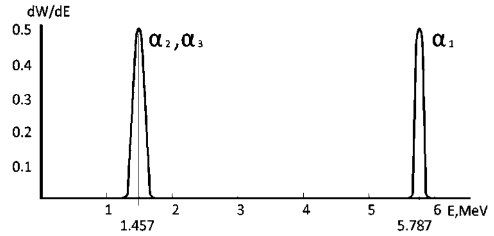

Fig.2.Alpha energy spectrum in reaction through the ground state of 8Be nuclei

REFERENCES

1. Volosov V.I. Nucl. Fusion 46(2006)820-828
2. Volosov V.I. VANT. Ser. TC. Issue.1 2008 31-40(in Russian)
3. Putvinskij S.V. Private communication (Unpublished)
4. Dmitriev V.F. Physics of Atomic Nuclei, Vol.72,N7, pp.1165-1187.
5. Rostoker.N., Binderbauer M., Monk H. Science 278,1419,1997.
6. Stave S., Seo P.-N., Weller H., Report on APS conference 2009.(Unpublished).
7. Nevins W.M. 1998 J. Fusion Energy 17. 25.
8. Frank-Kamenetskij D.A. Lektcii po Fizike Plazmy, Atomizdat,1964 (in Russian),
9. Trubnikov B.A. Voprosy teorii plasmy, Gosatomizdat,1963,red. M.A.Leontovich, V.1 98-182(in Russian)
10. Volosov V.I. Transactions of fusion science and technology Jan.2005 v47 N1T p.351-353

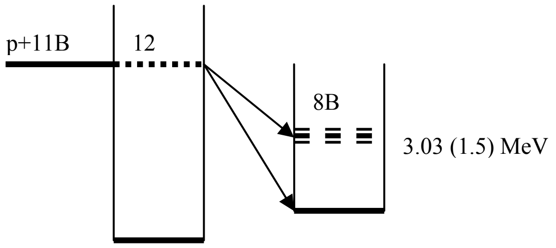

Fig.1.Reaction P11B through two intermediate compound nuclei of 12C and 8Be.

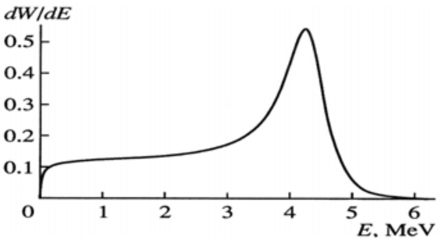

Fig.3.Alpha energy spectrum in reaction through the excited 8Be nuclei

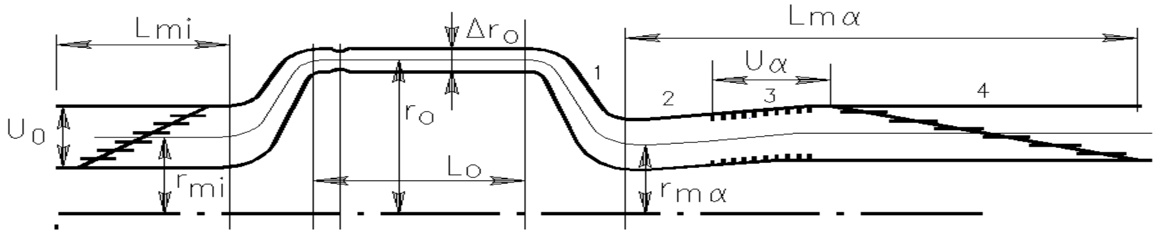

Fig.4.Schematic view of the ACT reactor and magnetic and centrifugal potentials of the ACT.Left–the ion plug and ion collector, right-the α plug and collector;1-4 the four steps of the collector-converter, r_0=4m; r_{mi}=2m; r_{ma}=1.8m; Δ r_0=0.6m; L_0=5(10)m; L_{mi}=5(10)m; L_{ma}=100(250)m