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EFFECT OF THE PLASMA PARAMETER PEAKINGS ON THE DD REACTOR OPERATION.

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At present, the practical implementation of an economically viable thermonuclear D-T reactor raises serious doubts [1-2].

In this regard, for the development of thermonuclear energy, it becomes necessary to use alternative sources, for example, deuterium.

Below are the main thermonuclear reactions involving deuterium, which may be of practical interest. The energies released during the course of these reactions are also indicated there.

$$D + D \rightarrow \begin{cases} p + T + 4.033 \text{ МэВ} \\ n + {}^{3}He + 3.269 \text{ МэВ} \end{cases} \quad (1)$$

It can be seen that the D-D reaction proceeds through two channels. The probability of these channels being realized is about the same.

The specific power of the energy released in a thermonuclear reaction has the form:

$$W = \frac{n_e^2}{8} E < \sigma v > \quad (2)$$

Here we assume that the density of the reacting elements is the same and the effective plasma charge $Z_{eff} = 1$. In formula (2), n_e is the electron density, $< \sigma v >$ is the reaction rate, and E is the energy released during a thermonuclear reaction.

To obtain from a D-D thermonuclear reactor a power comparable to that of a D-T reactor, it is necessary to heat the plasma to higher temperatures. An increase in the plasma temperature leads to an increase in energy losses due to cyclotron radiation. This effect can be compensated for by increasing the ratio of the plasma plasma kinetic pressure of the plasma to the pressure of the toroidal field β_T up to a value 0.5 for a spherical tokamak and even up to ~1 for a tandem trap or a trap with a reversed magnetic field FRC [3].

Until now, it was generally believed that in order to obtain the maximum production of thermonuclear energy, it is necessary to maintain the most uniform spatial distribution of temperature and density in the reactor. In reality, this is not the case. In [4], it was shown that an increase in the peak value of plasma parameters is beneficial for the operation of a thermonuclear reactor.

In this paper, we consider the possibility of reducing the operating temperature in the D-D reactor due to the model profiling of plasma parameters.

In this work, we will consider a cylindrical plasma with a circular cross section of the plasma column.

For the convenience of comparing the calculated data, we introduce the concept of the profile peacking $\sigma_Z = Z(0)/<Z>$, where Z (r) is any function that sets the profile of the temperature, concentration or pressure of the plasma, Z(0) is the maximum value of the parameter, $<Z>$ is the value of the parameter averaged over the plasma volume.

The energy generated at different profiles will be compared with the energy generated at a uniform distribution of plasma parameters with a volume-averaged ion temperature equal to $<T>_{DD} = 80$ keV.

For simplicity of calculations, let us set the temperature and concentration profiles depending on only one parameter:

$$T = T_0(1-\rho^2)^{\mu_T} = <T>(1+\mu_T)(1-\rho^2)^{\mu_T} \tag{9}$$

$$n = n_0(1-\rho^2)^{\mu_n} = <n>(1+\mu_n)(1-\rho^2)^{\mu_n} \tag{10}$$

From (9) - (10) it follows that the peakings of the temperature (σ_T) and concentration (σ_n) profiles, respectively, are equal to: $\sigma_T = 1+\mu_T$, $\sigma_n = 1+\mu_n$. For the plasma pressure, the magnitude of the peaking is equal to $\sigma_p = 1+\mu_T+\mu_n = \sigma_T+\sigma_n-1$. The peacking of the uniform distribution of parameters is equal to one. We will assume that the temperature and density of ions are equal to the temperature and density of electrons. In this case, the stored energy of the entire plasma is equal to $\Theta = 3<n(\rho)T(\rho)>V = 3n(0)T(0)V/\sigma_p = 3<n><T>\sigma_T\sigma_n V/\sigma_p$, where V is the volume of the plasma.

The thermonuclear energy released in the entire volume of the plasma, calculated by formula (7) at the temperature and concentration profiles specified by (7) - (9), is equal to

$$W = A\int n^2 E <\sigma v> \rho d\rho = An^2(0)E\int(1-\rho^2)^{2\mu_n} <\sigma v> \rho d\rho \tag{13}$$

here A is the normalization factor.

Let's consider two cases.

a) When the peaking changes, the full plasma stored energy , i.e. the values $<n>$ and $<T>$, are preserved.

The dependences of the normalized power of thermonuclear energy Ω and ion temperature in the center of the plasma column $T(0)$ on the value of the plasma pressure peaking σ_p are shown in Fig. 1. It can be seen from the figure that with an increase in the pressure peaking, both the normalized power and the ion temperature in the center of the plasma increase. At $\sigma_p = 8$ these values are equal $\Omega = 5.8$ and $T(0) = 455\,\text{keV}$, respectively.

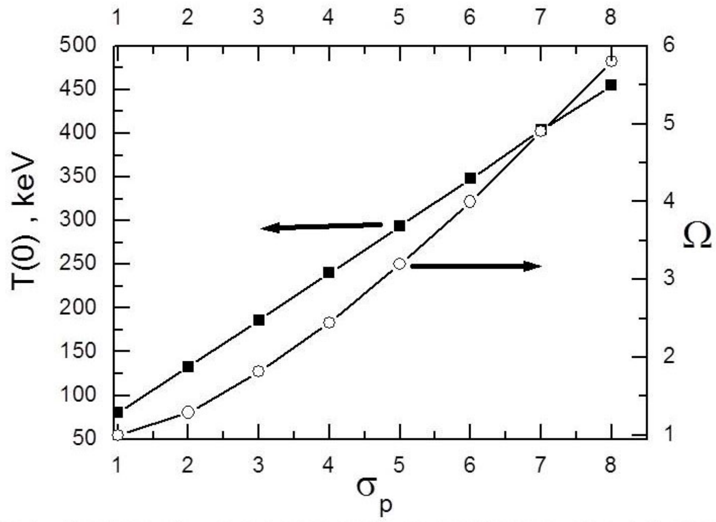

Fig.1. Central plasma temperature and normalized fusion power release versus pressure profile peaking.

b) When the peaking changes, the normalized power $\Omega = 1$ is preserved. We consider, in this case, that the average density $< n >$ does not change.

Figure 2 shows the results of calculations of the dependence of the value Ω on the average temperature $< T >$ of the plasma depending on the value of the pressure peaking. The horizontal line marks the level of the released energy with a uniform distribution over the cross section of the plasma column $\Omega_0(< \mathrm{T} >_{DD} = 80\ \text{кэВ}) = 1$. In what follows, the effective (operation) temperature will be called the temperature averaged over the plasma volume $< T >_{eff}$ at which $\Omega = W(< T >_{eff})/W_{DD} = 1$. The dependence of the operation temperature $< T >_{eff}$ of the plasma and the temperature in the center of the plasma column $T(0)$ are shown in Fig. 3. It can be seen from the figure that with an increase in the pressure peaking, the operation temperature decreases and reaches 15 keV at $\sigma_p = 8$.

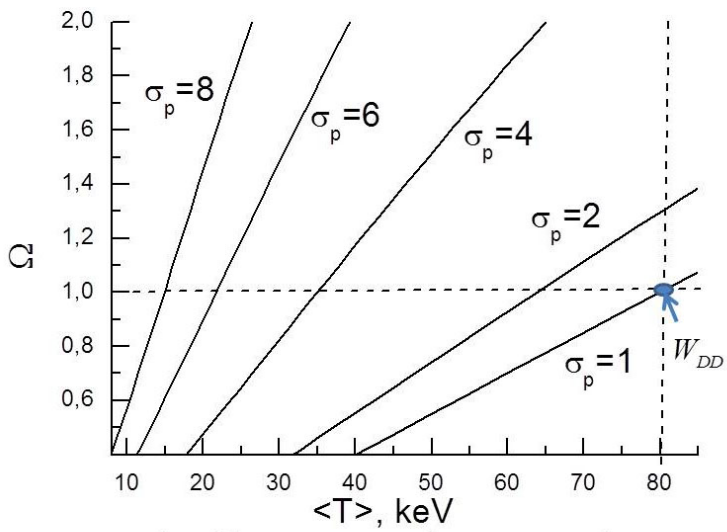

Fig. 2. Normalized fusion power release versus plasma average temperature.

The temperature at the center of the plasma changes nonmonotonically, reaching $T(0) \approx 110$ keV at $\sigma_p = 3$, and decreasing to 83 keV at $\sigma_p = 8$. In this case, the stored plasma energy decreases in 80/15 = 5.3 times. Thus, if a power of 300 MW is required to heat the plasma of an industrial reactor with a released fusion power of 3 GW, then with a pressure peaking $\sigma_p = 8$, this power is reduced to about 60 MW.

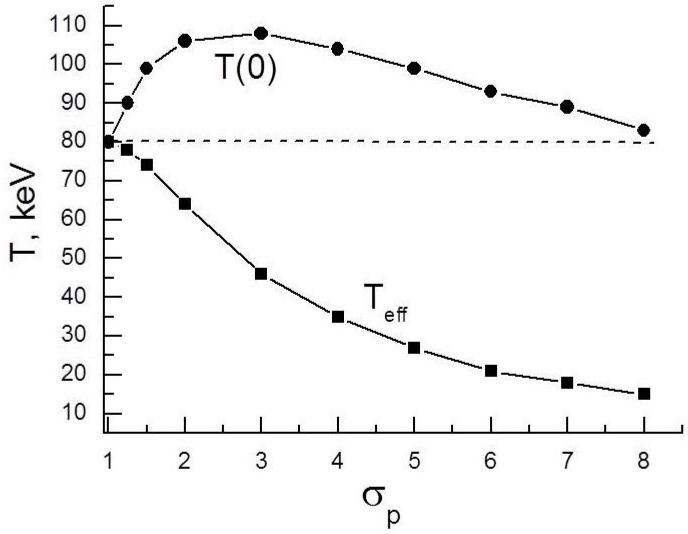

Fig.3. Operating and plasma central temperatures versus plasma pressure peaking.

An increase in the reactivity of the D-D plasma with an increase in the peaking in plasma parameters is accompanied by an increase in the flux of thermonuclear neutrons. This effect was observed at the JET [4] and the ALCATOR-C setups [5.6].

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