NEUTRONIC MODEL OF A FUSION NEUTRON SOURCE

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The MCNPX numerical code has been used to model a fusion neutron source based on a combined stellarator-mirror trap. Calculation results for the neutron spectrum near the inner wall and radial leakage of neutrons through the mantle surface of the fusion neutron source are presented.

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INTRODUCTION

Powerful sources of fusion neutrons with energies ~ 14 MeV are of particular interest to test suitability of materials for use in a fusion reactor. Developing materials for fusion reactors has long been recognized as a problem nearly as difficult and important as plasma confinement, but it has received only a fraction of the attention. The neutron flux in a fusion reactor is expected to be about 100 times higher than in existing pressurized water reactors. Each atom in the blanket of a fusion reactor is expected to be hit by a neutron and displaced about a hundred times before the material is replaced. Furthermore the high-energy neutrons will produce hydrogen and helium in various nuclear reactions that tends to form bubbles at grain boundaries and result in swelling, blistering or embrittlement. One also prefers to choose materials which primary components and admixtures, after neutron, exposure do not result in long-lived radioactive waste. And also, the mechanical forces and temperatures are large, and the cyclic variations add to the difficulties to find suitable materials.

Realistic material tests ought to expose samples to neutron fluxes of a similar level for a similar period of time as those expected in a fusion power plant.

MODEL OF A FUSION NEUTRON SOURCE

In this research, the neutronics of a fusion neutron source is studied. The fusion neutron source consists of a magnetic trap for plasma confinement at which fusion neutrons are generated. The magnetic trap is of a combined type: it is a toroidal stellarator with an embedded magnetic mirror with lower magnetic field [1]. The stellarator part is for confinement of warm dense deuterium target plasma. Hot tritium sloshing tritium ions are confined at the mirror part of the device. At this part the plasma column is straight. It is surrounded by a cylindrically symmetrical shield.

The hot minority tritium ions are sustained in the plasma by neutral beam injection (NBI). The NBI is normal to the magnetic field and targets plasma just near the main part (Fig. 1). The sloshing ions bounce inside the magnetic mirror and fusion neutrons are generated there. Some fusion neutrons are generated outside the main part near the injection point. There is a need of protection from these neutrons.

The purpose is to calculate the neutron spectrum near the first wall of the installation, where will be a neutron irradiation facility in special volumes, and compute leakage of neutrons through the mantle surface of the model.

CALCULATION MODEL

The model has a cylindrical symmetry with a horizontal axis. Its radial and axial structure is shown in Fig. 1. The vacuum chamber contains the D-T plasmas which supplies the fusion neutrons. The inner radius of the vacuum chamber is 0.5 m. The space between plasma and the first wall is reserved for the irradiation specimens. The first wall thickness is 3 cm. The thickness of the buffer (LBE) is 15 cm and the shield thickness is 20 cm. The LBE [2] was assumed to be a mixture of 44.5 wt.% lead and 55.5 wt.% bismuth. The shield contains a 60:40 vol.% mixture of the stainless steel alloy S30467 type 304B7 [3,4] with water. The steel contains 1.75 wt.% of natural boron. The total length of the main part of the model is 4 m.

The ends of the neutron irradiation zone are surrounded by a vessels filled with borated water to absorb the outcoming neutrons. The water slows down the neutrons and boron then absorbs slow neutrons. Boron has an exactly stable isotope B10 which absorbs neutrons very efficiently: the absorption cross section of thermal neutrons is about 4000 barn. As a result of neutron absorption by boron-10 the excited nucleus B11 is formed, which immediately decays into the nucleus Li7 and the alpha-particle.

The concentration of boron in the water was taken 10 g/kg. The isotopical content is B_{10} - 20 % and B_{11} - 80 %. The part with borated water has a length of 2 m at both sides of the main part and a thickness is of 35 cm. At the right side of the main part, openings with square 79 cm^2 are made to provide access to the plasma for the neutral beam (see Fig. 1, inlet hole for neutral beam injection).

In the calculation model, the volumetric source of neutrons is represented by a number of cylindrical volumes of radius 10 cm and with a total length of 4 m. At every source point, the fusion neutrons were emitted with a fixed kinetic energy of 14.1 MeV and isotropic velocity distribution.

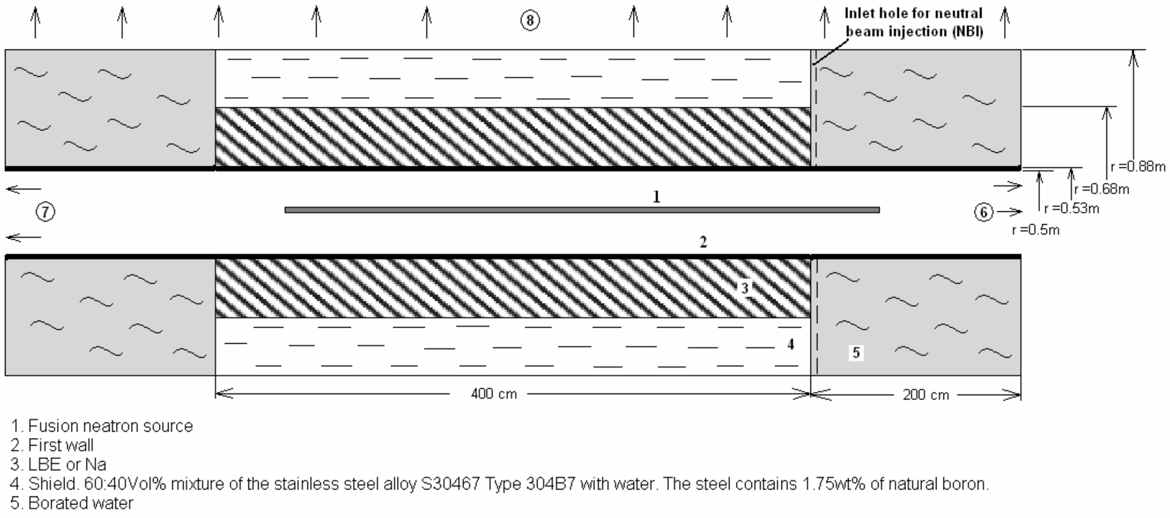

Fig. 1. Radial and axial structures of the neutron source model

The intensity distribution along the length of the neutron source [5], which was used in the MCNPX model, is shown in Fig. 2. The total number of the particles emitted by the source is normalized to unity.

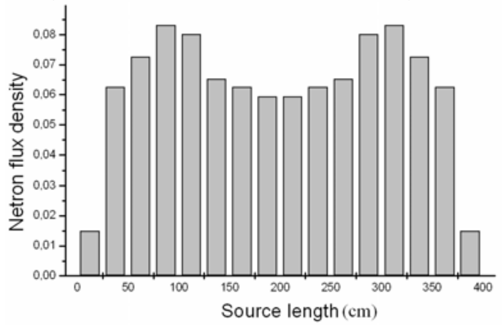

Fig. 2. Intensity distribution of the source neutrons for Einj=300 keV

RESULTS OF CALCULATIONS

The MCNPX numerical code has been used for neutron calculations. Calculation results for the leakage of neutrons through the mantle surface of the model are presented below. Calculations were performed for two coolants – LBE and Na. Neutron leakage, normalized per fusion neutron, through the separate surfaces see (see Fig. 1) is:

coolant – LBE

- Surface 6: 0.0147± 0.5 %
- Surface 7: 0.0351± 0.5 %
- Surface 8: 0.0263± 0.5 %

coolant – Na

- Surface 6: 0.026 ± 0.5 %
- Surface 7: 9.54×10^{-3} ± 0.5 %
- Surface 8: 0.0369 ± 0.5 %.

As seen from the above results, radial leakage of neutrons is sufficiently small. The estimates predict that the energy released with neutrons from the fusion neutron source to outer space is 4.2×10^{-17} Ws with LBE and 5.9×10^{-17} Ws with Na per fusion source neutron. This power loading should be considered in the calculation of the cooling requirements for the magnetic coils of the stellarator-mirror magnetic trap.

Flux of neutrons at the first wall of main part of the model equal 2×10^{14} and 1×10^{14} $cm^{-2}s^{-1}$ using as coolant LBE and Na, respectively, for a fusion neutron source with intensity 3×10^{18} neutrons per second [1].

In Fig. 3,a,c shows the spectrum of neutrons at the first wall of the main part of the model, using as coolants LBE and Na, respectively. Fig. 3,b,d shows the average along the entire length of the model spectrum of neutrons at the first wall. As can be seen from the graphs, the neutron spectrum depends significantly on the coolant material. In the range of 0.8…1.0 MeV, an increase of the neutron flux through the first wall is observed, which can be explained by the reaction (n, 2n), for example $Pb^{207}(n,2n)Pb^{206}$. The peak at 14 MeV is due to the fusion neutrons from the plasma source.

This spectrum is different from the spectrum computed for the powerful neutron source IFMIF (International Fusion Material Irradiation Facility) [6, 7]. The IFMIF requirement of 250 mA of deuteron beam current delivered to the lithium target (7.5 %-Li^6 and 92.5 %-Li^7) will be met by two 125 mA beams, with energy of 40 MeV for the accelerator modules. A continuous 155 mA deuteron beam is extracted from the ion source at 95 keV. The IFMIF ion injector has to provide excellent beam quality, sufficiently high beam current and high operational availability. In developing a source model for the Li(d,xn) reaction, there are three possible routes: $Li^7(d,2n)Be^7$; $Li^7(d,n)Be^8$; $Li^6(d, n)Be^7$. The neutrons with energies up to 55 MeV are irradiated.. The IFMIF/test cell spectra are smoothed functions of neutron energy without a prominent peaks at 14 MeV and 15...25 % of the total flux is distributed throughout the high energy domain. The majority of the flux (between 75 and 80 %) has energy below 14 MeV. Thus, the spectrum is noticeably different from that of a fusion reactor, with the most important difference being the high energy tail of the IFMIF flux.

The Russian Federation is actively developing a fusion neutron source based on a spherical tokamak for burning transuranic elements and for breeding the fuel isotops ^{239}Pu and ^{233}U from ^{238}U and ^{232}Th, respectively [8].

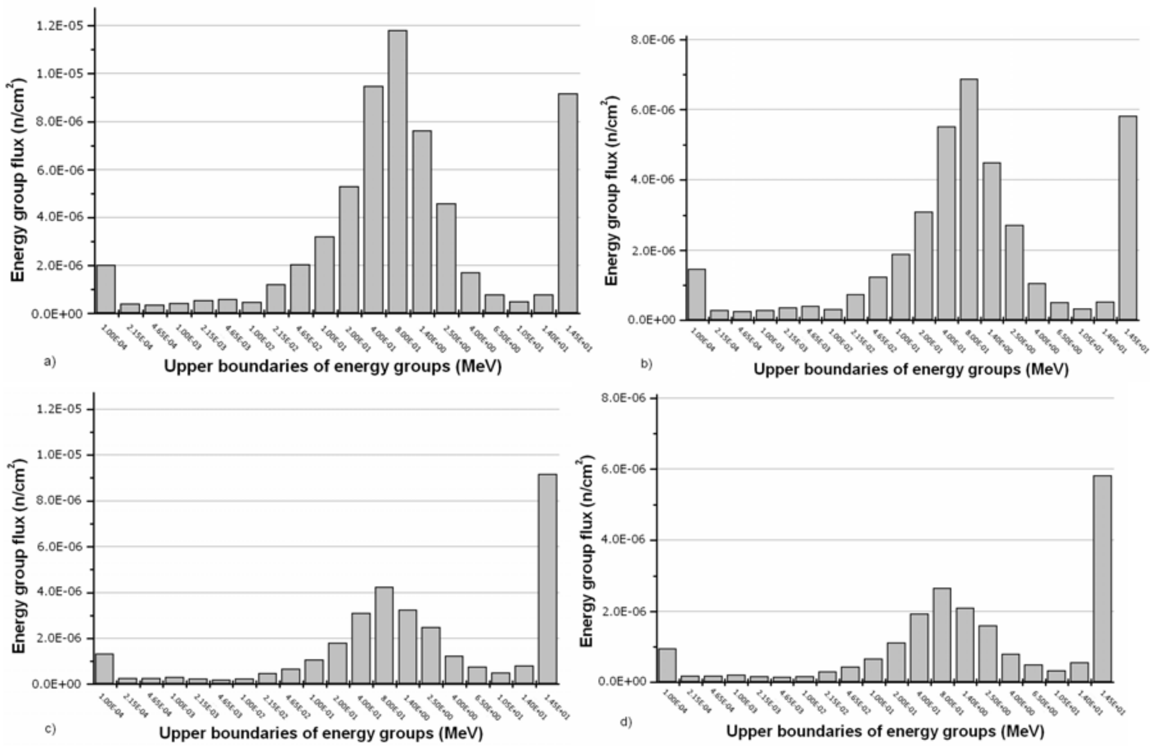

Fig. 3. Energy group fluxes averaged over the first wall

CONCLUSIONS

By means of neutron transport calculations a principal design for fusion neutron source has been devised. The calculations were carried out with the Monte Carlo code MCNPX.

Neutrons outflux and neutron spectrum near the first wall of the simulated model was calculated. The vessels filled with borated water at the ends of the neutron irradiation zone absorb the outflowing neutrons and sufficiently reduce the neutron flux to outer space. The neutron fluxes that are emitted into the stellarator vacuum chamber at both sides of the neutron source have also been calculated.

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REFERENCES

1. V.E. Moiseenko, K. Noack, O. Ågren // *J Fusion Energ (25).* 2010, p. 65.
2. OECD NEA, 2007. http://www.oecd-nea.org/science/reports/2007/pdf/chapter2.pdf
3. D.V. Fix et al. *LLNL report* UCRL-PROC-202920 2004.
4. K. Noack et al. // *AIP Conf. Proc*. 2012, v. 1442, p. 186-198
5. V.E. Moiseenko, O. Ågren. AIP Conf. Proc. 2012, v. 1442, p. 199-207.
6. P. Vladimirov, A. Möslang // *Journal of Nucl Materials*. 2004, v. 329-333, p. 233-237.
7. http://bibliothek.fzk.de/zb/berichte/FZKA6218.pdf
8. E.A. Azizov et al. // *PAST. Ser. «Fusion»*. 2009, v. 3, p. 3-9.

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НЕЙТРОННАЯ МОДЕЛЬ ТЕРМОЯДЕРНОГО ИСТОЧНИКА НЕЙТРОНОВ

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С помощью программы MCNPX разработана концепция термоядерного источника нейтронов на основе открытой ловушки. Представлены спектры нейтронов вблизи первой стенки, а также результаты расчетов радиальной утечки нейтронных потоков за пределы моделируемой системы.

НЕЙТРОННА МОДЕЛЬ ТЕРМОЯДЕРНОГО ДЖЕРЕЛА НЕЙТРОНІВ

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За допомогою програми MCNPX розроблена концепція термоядерного джерела нейтронів на основі відкритої пастки. Представлені спектри нейтронів поблизу першої стінки, а також результати розрахунків радіального витоку нейтронних потоків за межі модельованої системи.