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Assessment of radiation damage of the first wall of a fusion neutron source DEMO-FNS with a blanket for transmutation of minor actinides

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ABSTRACT

A distinctive feature of the DEMO-FNS is the combination of fusion plasma neutrons and hybrid blanket fission neutrons in the energy spectrum of materials. For the implementation of the DEMO-FNS project, it is important to assess the effect of the fast neutron spectrum on radiation-induced damage to the device materials, primarily the materials of the first wall, which is the most problematic unit of the device. Due to the lack of real hybrid fusion devices, the study was carried out using computer simulations of the experiment. The developed three-dimensional full-scale model of the DEMO-FNS reactor with a blanket for the transmutation of minor actinides was used. The results were obtained at the power of a volume fusion D-T neutron source is equal to $1.42 \cdot 10^{19}$ n/s.

BACKGROUND

The work aims a computational study of the neutron load on the cooled components of the first wall of the DEMO-FNS hybrid fusion reactor in a three-dimensional full-scale model of the device. To achieve this goal, it is planned to calculate the neutron energy spectrum in materials for the first wall and compare it with the energy spectrum of the fission neutrons, calculate and analyze of the radiation damage dose and energy release in the materials of the first wall, estimate the rate of transmutation reactions that cause the accumulation of solid and gas impurities in the first wall materials.

METHOD AND CALCULATION MODEL

A Monte-Carlo computer simulation was carried out for the calculations of three-dimensional full-scale model of the reactor DEMO-FNS developed for solving the neutron-physical problems. The MCNP-4 code was used with cross sections from the files FENDL-2 [8], ENDF/B-6 and cross sections for calculating radiation damage. The design of the first wall is under development. (Figure 4).

The blanket consists of two sections. Each section is presented in the form of a homogeneous layer which has the following composition:

— a mixture of oxides of minor actinides (79.0% vol.) (see Table 1) and coolant (21% vol.);

—— Li_4SiO_4 (88% vol.), steel (5% vol.), and coolant (7% vol.).

FIG. 1. View of the horizontal equatorial (a) and central vertical (b) cross-section of the DEMO-FNS model.

(a) (b)

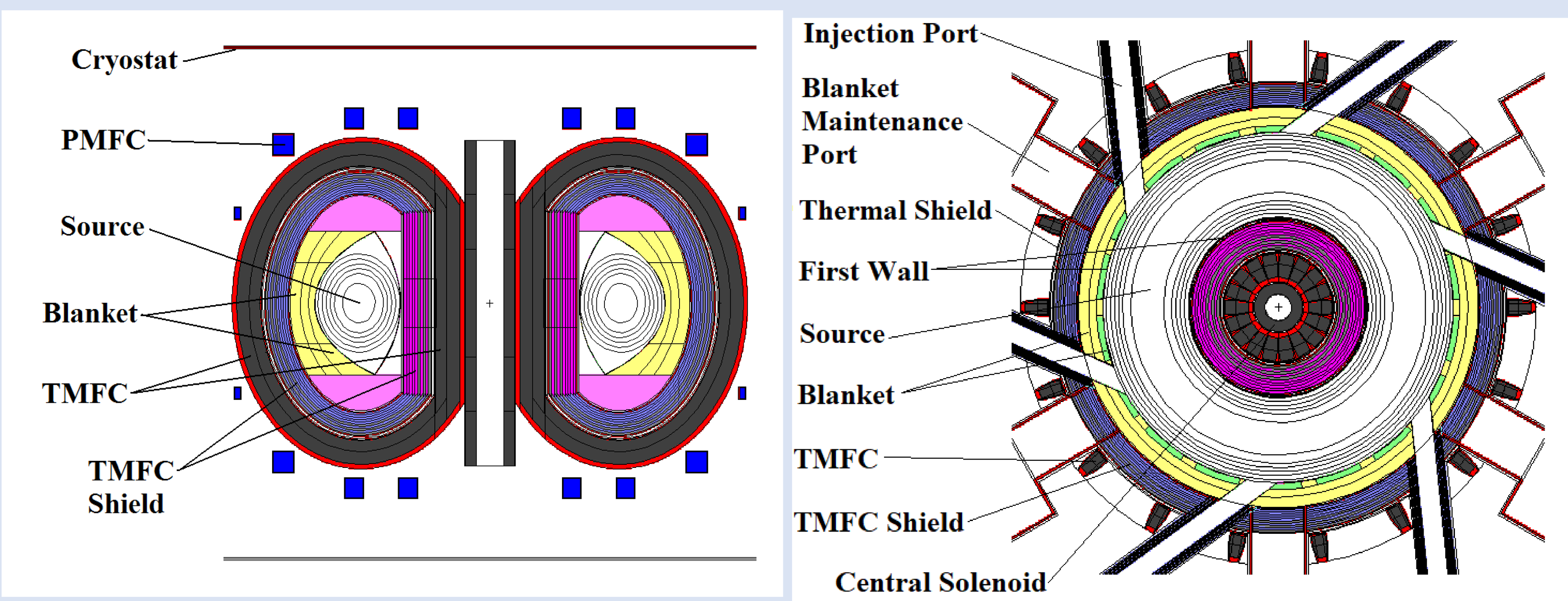


FIG. 2. The volume neutron source.

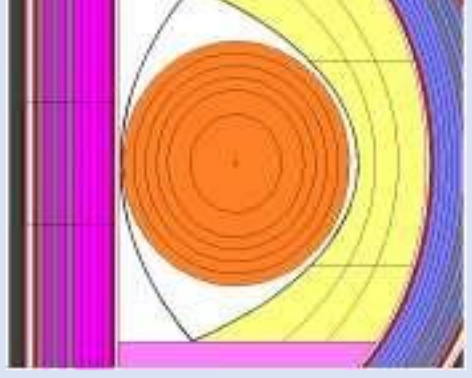
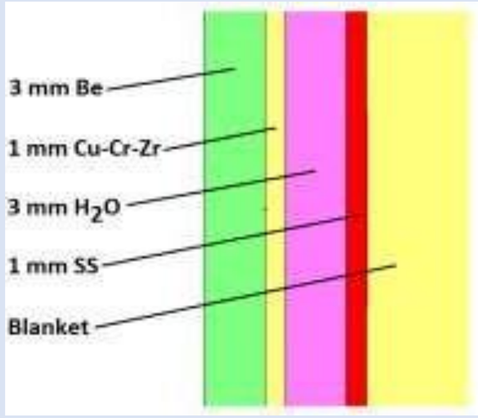


FIG. 3. The layers of the first wall.



OUTCOME

1. A difference between the neutron energy flux distributions in individual layers of the first wall and the average value is insignificant. A number of fast neutrons in the spectrum of DEMO-FNS is higher compared to the fission spectrum.
2. The total dose of radiation damage is 3.7 dpa/fpy in Be, 5.9 dpa/fpy in Cu, 6.3 dpa/fpy in Fe at total fluence is ~10^{22} n/cm^2. The neutron damage dose for E_n >6.5 MeV (the dose from the thermonuclear neutrons) is 1.7 dpa/fpy for Be (45% of the total dose), 1.6 dpa/fpy for Cu (27% of the total dose), and 1.5 dpa/fpy for Fe (24% of the total dose).
3. The energy deposition in water (6.684 W/cm^3) is approximately 1.3-1.4 times higher than the average value over the layers. In other layers, it is 75-80% of the average value.
4. The energy deposition in water is 95% due to neutrons. The contribution of neutrons in energy deposition in beryllium is approximately equal to 85 %. The energy deposition from neutrons in Cu-Cr-Zr and steel is 12-13% and 22-24% of the total value, respectively. In these layers, the greatest contribution to the energy deposition is made by the secondary photons.
5. The accumulation of helium in beryllium is equal to 2630 appm/fpy, the accumulation of tritium is 8.36 appm/fpy.

Table 1. Radiation damage dose.

Material	Dose, dpa/fpy			
	E > 6.7 MeV	U*, %	Total	U, %
Be	1.695	0.3	3,744	0.3
Cu	1.607	0.3	5,905	0.3
Fe	1.491	0.3	6,292	0.3

**statistical uncertainty*

FIG. 4. The neutron energy flux.

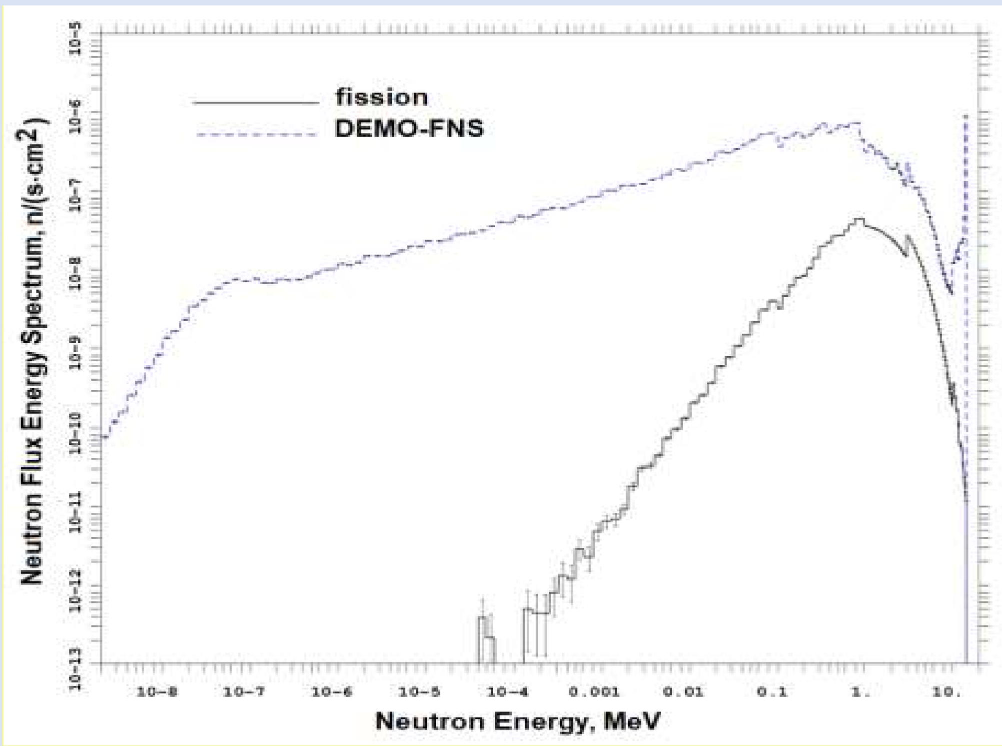


Table 2. Reaction rates in the first wall materials.

Reaction rate, 1/cm^3	Section of the first wall near the injection port							
	Be	U, %	CuCrZr	U, %	H_2O	U,%	Steel	U, %
Rt	$4.023 \cdot 10^{-8}$	0.4	$1.120 \cdot 10^{-7}$	0.4	$1.323 \cdot 10^{-8}$	0.2	$6.756 \cdot 10^{-8}$	0.4
(n,g)	$3.600 \cdot 10^{-10}$	0.4	$9.760 \cdot 10^{-8}$	0.5	$2.272 \cdot 10^{-9}$	0.6	$4.039 \cdot 10^{-8}$	0.5
(n,p)	$1.278 \cdot 10^{-14}$	16	$1.085 \cdot 10^{-8}$	0.3	$1.414 \cdot 10^{-9}$	0.2	$2.176 \cdot 10^{-8}$	0.2
(n,d)	$3.065 \cdot 10^{-14}$	31	$4.809 \cdot 10^{-10}$	0.2	$4.975 \cdot 10^{-10}$	0.2	$5.021 \cdot 10^{-10}$	0.2
(n,t)	$2.307 \cdot 10^{-9}$	0.2	$1.053 \cdot 10^{-12}$	0.2	–	–	$5.874 \cdot 10^{-12}$	0.2
(n,^{3}He)	–	–	$1.927 \cdot 10^{-10}$	0.2	–	–	$4.298 \cdot 10^{-14}$	0.2
(n,^{4}He)	$3.756 \cdot 10^{-8}$	0.4	$2.888 \cdot 10^{-9}$	0.2	$9.047 \cdot 10^{-9}$	0.2	$4.896 \cdot 10^{-9}$	0.2
(n,2n)	$3.436 \cdot 10^{-7}$	0.3	$5.177 \cdot 10^{-8}$	0.2	$3.117 \cdot 10^{-12}$	0.2	$3.083 \cdot 10^{-8}$	0.2
(n,3n)	–	–	$6.322 \cdot 10^{-15}$	62	–	–	$1.594 \cdot 10^{-14}$	19

CONCLUSION

1. The radiation damage in the materials of the first wall of DEMO-FNS (4-6 dpa at a fluence of 10^{22} n/cm^2) can be 2 times higher than the one in the BN-600 fast neutron reactor (3 dpa in the core).
2. The dose of radiation damage in the materials of the first wall from fission neutrons generated in the blanket (E < 6.5 MeV) is from 55% to 75% of the total dose. The maximum permissible dose for the materials of the first wall (20 dpa) will be reached after 3-4 years of the device operation at full power.

ACKNOWLEDGEMENTS / REFERENCES

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