Development of the nuclear radiation shield concept for the Volumetric Fusion Source

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Abstract

Within the development of the shield concept for the VNS (Volumetric Neutron Source) compact fusion machine the selection of the suitable shielding materials and the compounds was caried out utilizing realistic 3D geometry model and the particle transport simulations. The nuclear responses obtained as the results of these simulations are compared with the available design limits to justify the efficiency of the shield. A design layout of the shielding blankets, vacuum vessel, NBI ports and divertor are suggested.

Keywords: VNS, Volumetric Neutron Source, nuclear radiation, shielding options, design layouts

1. Methodology and main outcomes

The comprehensive results of the nuclear transport simulations with MCNP code [1] making use of the 3D layout of the VNS, Fig. 1, for the different materials and their combinations enable to define the most efficient material composition for the shield in the VNS [2], Fig. 2. The mandatory use of tungsten as the main component of the shield inside the shielding blankets and in the vacuum vessel in the most loaded locations of the reactor is the most essential outcome of the results. The protecting capabilities of the tungsten shield can be amplified if the efficient neutron moderators (hydrides or water) are added to the mixture. Three metal hydrides were studied: TiH_2, ZrH_2 and HfH_2 [3,4]. All these compounds have a very high potential for their use in the shield of the VNS. The TiH_2 was selected due to its physical and technological properties as well as fabrication costs. Although water moderator is less efficient for the shielding applications inside the VV it can be also used alternatively. The use of SS316(L)N-IG steel does not provide additional advantages to the shielding capabilities of the reactor.

Unlike this steel, SS304B7 could be used in the shield inside the tokamak but with caution because of the helium accumulation due to B(n,α) reactions in the shield structure resulting in its swelling. B_4C ceramic shield is not as efficient as hydrides or water ones but it can also be used in the combination with tungsten in such locations where cooling is difficult to provide or cooling conditions are not optimal. The combination of W (up to 60%) with the neutron moderator and the steel could be applied for the compact shield in different locations in the reactor such us ports and various plugs. The optimal material composition for the effective protection of the Toroidal Filed Coils including 60%W, 15%TiH_2, 12%H_2O and 13% SS316(L)N-IG steel provides an accumulation of a dose to insulator below 20 MGy/10FPY and a power density in the winding pack below 150 W/m^3. These results were obtained with a total radial thickness of the shield (shielding blanket plus vacuum vessel) of ~65 cm.

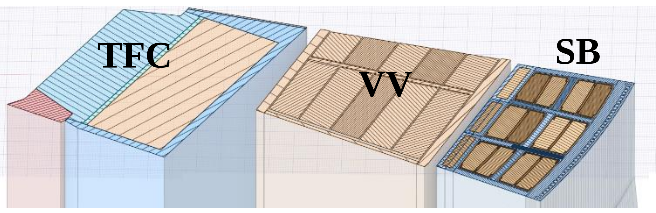

Figure 1. The geometry layout of the shielding structure in the VNS: Toroidal Field Coil (TFC), Vacuum Vessel (VV) and Shielding blanket (SB).

2 Activation analyses

The use of the shielding materials for the radiation protections in the VNS reactor inevitably leads to an accumulation of various radioactive isotopes in the shield blocks. The 3D simulations were carried making use of FISPACT II [5] code to assess the waste accumulations in the blankets and vacuum vessel of the VNS. The shield made of SS316(L)N-IG steel plus water coolant accumulate much more activity and respectively radioactive waste compared to the W, TiH_2 and B_4C ones discussed above. Once the detritiation procedure is applied to these materials, they can be classified as LLW [6,7] already 30 years after the reactor shutdown, Fig. 3. In case of a special dilution procedure is used for the disposal of these materials, i.e. the reduction of the specific activity, for instance, in a concrete matrix, their disposal could be started even earlier. It is also possible that the shielding blankets will be replaced during reactor lifetime that reduce naturally the waste accumulation. From this point of view these materials do not present safety issue for the VNS project.

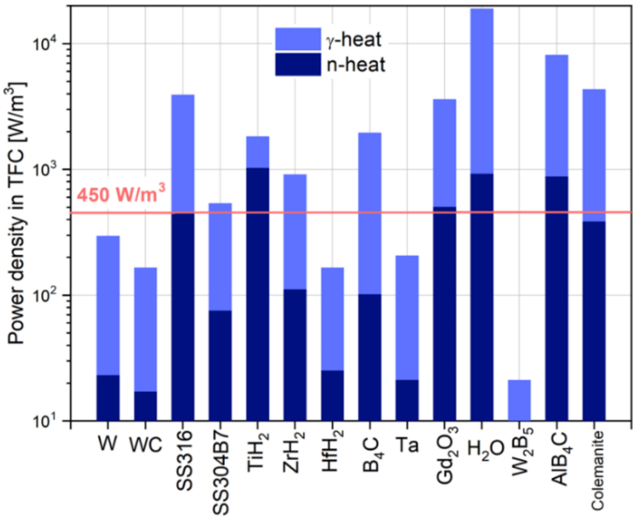

Figure 2. The nuclear power density in the winding pack of the TFC in case of the different shield configurations.

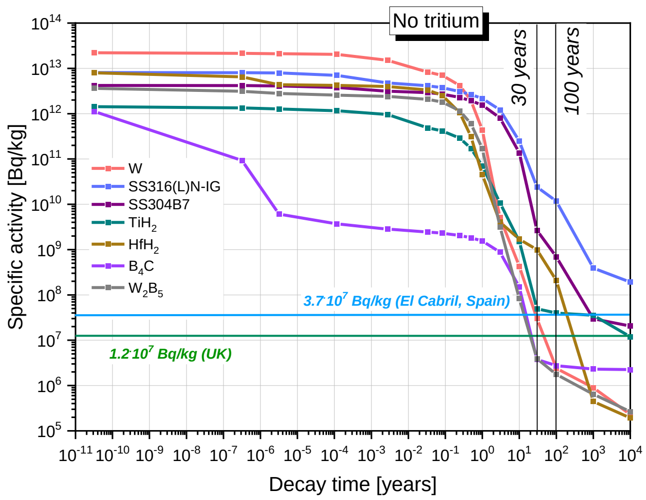

Figure 3. The specific activity of the different shielding materials in the VNS.

3. Conclusions

The use of the tungsten for the protection from the high energy neutron and gamma radiation appears to be the key option for the feasibility of the VNS project. Combinations of the tungsten with hydrides, water and B_4C provide the requested nuclear responses with the significant safety margins compared to the VNS project limits. The geometry layout of the shielding blanket provides also a reliable protection of the inner shell of the vacuum vessel with a sufficient safety margin on the *dpa* accumulation.
Preferably, the final selection of the shielding materials suitable for the applications in the VNS should be overruled by integral experimental data obtained through specially dedicated tests on samples exposed to similar stress conditions (heat and radiation loads) planned during the reactor lifetime to justify the reliability of these materials. The second round of the iterations, therefore, will be proceeded with the radiation transport calculations that should be carried out (in case of the need) to update the geometry layout of the shield and to confirm the shielding performances of the design.

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