Extending the grid plate life - Incorporation of lower axial shield for FBTR

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Abstract. Operational life of Fast Breeder Test Reactor (FBTR) is limited by the grid plate which is not replaceable. Presently, stainless steel is being used as the lower axial shield. In addition to reducing the flux at the grid plate, stainless steel provides a positive contribution to reactivity by scattering neutrons into the core. An irradiation experiment was carried out in FBTR to determine changes in the mechanical properties of specimens of grid plate material at the desired low fluence irradiation conditions. Based on the analyses of these experiments and flux measurements at the grid plate location, the residual life of FBTR was estimated to be 6.52 full power years (FPY) at the end of 18^{th} campaign. To enhance the remnant life of FBTR, possibility of further reducing the neutron flux with alternate shield materials has been considered. Neutronics studies on the effectiveness of materials such as tungsten, tungsten carbide, boron carbide and Ferro-Boron have been conducted. A suitable arrangement of enriched boron carbide and stainless steel has been analyzed too. Based on these studies, tungsten carbide emerges as the best option. On implementation, it is expected that the life of FBTR would be increased by 35% of its presently available residual life.

Key Words: Grid plate, DPA, FBTR, Tungsten carbide

1. Introduction

The core of FBTR was originally designed with 65 SA of MOX with 30%PuO2 & 70% UO2 (enriched to 85%). Due to certain constraints on fuel availability, an alternate high Pu content carbide fuel was developed for use in the reactor. The reactor attained criticality in the year 1985, with 22 fuel subassemblies (FSA). The reactor core has been progressively enlarged by adding MK-II SA and MOX SA. Presently in its 25^{th} power campaign with a target power of 28.3 MWt, the core has 53 fuel sub assemblies, including 8 MOX subassemblies. Though the reactor power has been lower as compared to the original design power level of 40 MWt, the neutronic fluence and the displacement per atom (dpa) levels seen at the grid plate are comparable to the corresponding values in the 65 SA MOX core as the peak linear power has been the same as envisaged for the high power core.

FBTR grid plate is a permanent structure in the core subjected to low irradiation over the life time of the reactor. The grid plate material is a modified version of Type 316 stainless steel, identified as Type 316 SS (FBTR quality), and has more stringent composition specifications than the ASTM specifications. Data on the change in mechanical properties of this material due to exposure to radiation are not available. In view of the unique role of FBTR as a fast flux facility for material and fuel irradiation experiments, extending the life of FBTR is very pertinent.

2. Studies on alternate lower axial shield material

An assessment of the remnant life of the grid plate was made at the end of 18^{th} irradiation campaign. An experiment was carried out in FBTR to determine changes in the mechanical properties of specimens of grid plate material at the desired low fluence irradiation conditions. Based on the measurements of metallurgical and material properties, the residual life of FBTR was estimated to be 6.52 EFPY at the end of 18^{th} campaign [1]. It is to be noted that FBTR has operated for 200 EFPD after the 18^{th} campaign.

In order to arrive at a better lower axial shield material, neutronics studies were carried out to assess the effect of using materials such as boron carbide (B_4C), tungsten, tungsten carbide (WC) and Ferro-Boron as alternate lower axial shields. The chosen material will replace the stainless steel rods in the lower axial shield region.

In the fuel subassembly, lower axial blanket region has seven stainless steel pins of length 26.3 cm and diameter 1.35 cm. Each pin has top and bottom SS cap of length 1.4 cm. Figure 1 gives the design of axial blanket portion of fuel subassembly. Actual geometries and materials arrangements have been modelled without introducing homogenization. This will correctly account for the direct streaming through the gaps between the pins. Results of the calculation are given in Table 1. Effective dpa rate of different materials have been normalized respect to the corresponding value to that of the stainless steel.

Another aspect of concern is the reactivity loss on introduction of these alternate shield materials as it necessitates additional fuel subassemblies in the core. Boron carbide is available readily and has been in use as the control material in the reactor. Nevertheless, being an absorber, it leads to higher reactivity loss compared to other materials. Considering the higher reactivity penalty of B_4C, it has been decided to use WC as the alternate lower axial shield which is as effective as boron carbide but introduces lesser reactivity loss.

Chemical and metallurgical studies have been carried out to ensure that the material is core eligible. Chemical compatibility has been asserted by allowing the WC sample to be equilibrated with reactor grade sodium at 673 K for about 300 h [2]. No significant change was found in the weight of the sample before and after the experiment. Similarly, XRD patterns of the sample before and after the equilibration were found to be identical. It essentially indicates that the sample did not react with sodium. To study the surface modification due to contact with sodium, Scanning electron microscope (SEM) images and energy dispersive x-ray spectrometer (EDS) spectra were recorded on polished surface of the WC specimen before and after equilibration. The recording did not show any surface modification.

TABLE 1: VARIATION IN DPA OF GRID PLATE AND CHANGE IN REACTIVITY WITH VARIOUS MATERIALS AS LOWER AXIAL BLANKET IN FBTR

Cases Studied	dpa with respect to reference case	Reactivity Change (pcm) with respect to reference case
FBTR-steel (Reference case)	1.00	0
Fe-B	0.82	-959
Tungsten Carbide	0.47	-324
Boron carbide	0.45	-1411

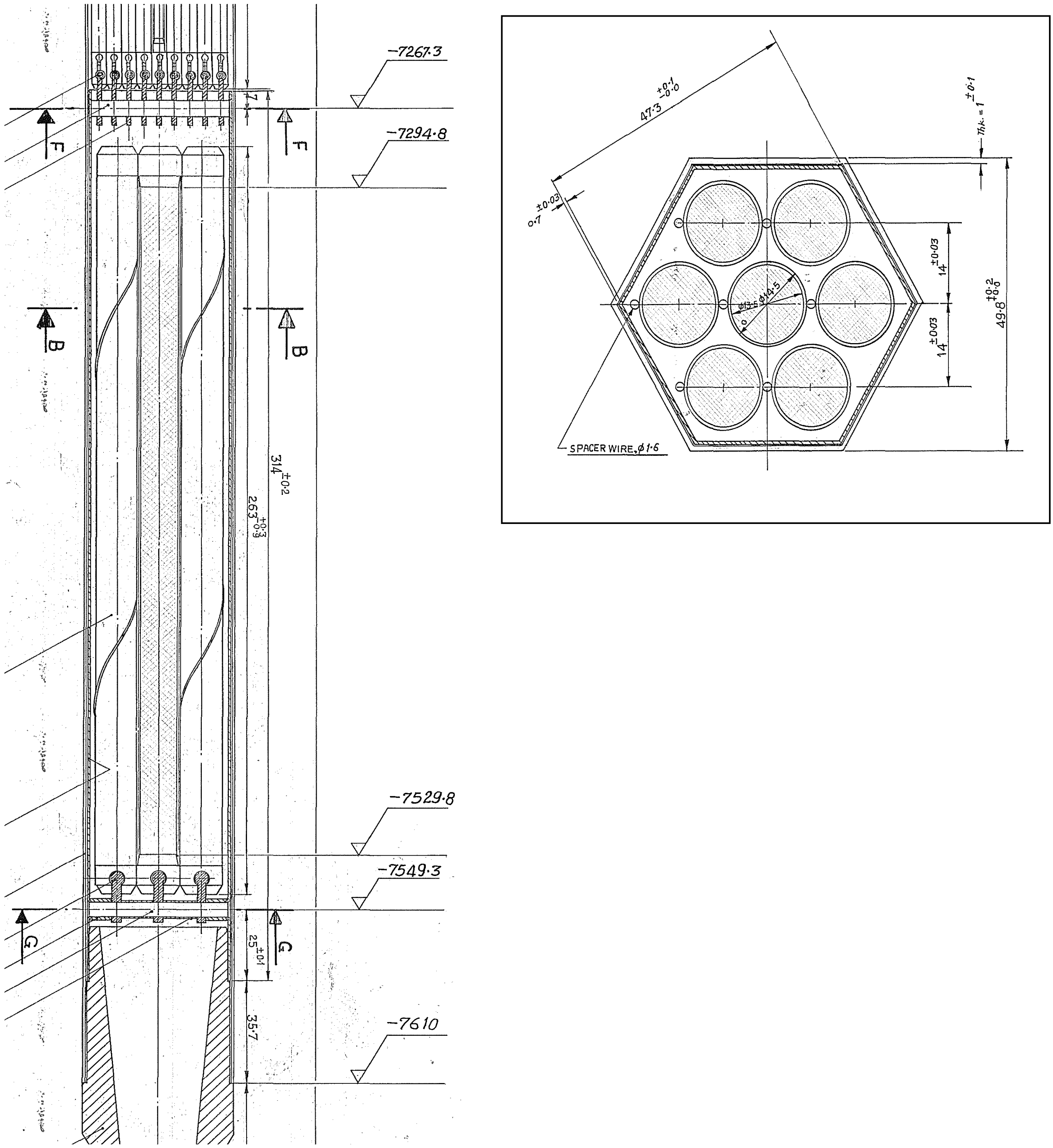

Figure 1: *Sectional view of lower axial shield region of FBTR fuel sub assembly*

Metallurgical studies indicate that no phase other than WC is formed up to 1473 K. Further, thermo physical properties such as the thermal diffusivity, thermal conductivity, density and linear expansion coefficient do not show any significant variation in the range of 300 K to 1473 K that would require consideration in design [3].

3. Summary

Life-limiting factor for Fast Breeder Test reactor at Kalpakkam is the mechanical degradation of the grid plate structure on account of neutron irradiation. At present, the core life is expected to be about 5.5 full power years. Extending the remnant life of FBTR is crucial to make the irradiation facility available for a longer time. It is proposed to achieve this by incorporating alternate lower axial shields. Neutronics studies indicate that the dpa rate is reduced by 50% on using WC as the lower axial shield in place of stainless steel. Chemical and metallurgical studies have shown that WC has excellent compatibility with sodium. Hence, it is proposed to use WC as the lower axial shield material without require any modification in the design of the fuel subassembly.

4. References

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