SHORT NOTE

Neutronic Feasibility of Supercritical Steam Cooled Fast Breeder Reactor

Kazuyoshi KATAOKA and Yoshiaki OKA

Nuclear Engineering Research Laboratory, Faculty of Engineering, University of Tokyo*

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Although the LMFBRs possess high capability of breeding fissile materials, the chemically active sodium coolant requires extra components compared with LWRs, which leads to high construction cost. Steam is an alternate candidate as a coolant of FBRs at the point of the capital cost since it is chemically less active than sodium and no extra component is necessary unlike the LMFBRs. In addition, there is much experience using steam as the coolant of the LWRs and fossil-fired power plants.

Steam-cooled fast breeder reactors (SCFBRs) were studied in the 1960's in USA and Germany, but the development was abandoned in the late 1960's due to the possibility of higher capture to fission cross section of $^{239}$Pu/$^{240}$Pu/$^{241}$Pu/$^{242}$Pu. The stainless steel is chosen at the cladding material because it is not corroded by steam at high temperatures, up to 723 K. To achieve high power density, the core lattice is quite tight; fuel rods are 0.65 cm in diameter with the 0.04 cm cladding and the 0.01 cm gap between the fuel pellet and the cladding. It is arranged in a triangular lattice with a pitch of 0.75 cm using wire wrapped spacer of 0.1 cm. The MOX fuel and the stainless steel cladding are well within our experience.

Unit cell burnup calculations were carried out by using the code system SRAC[4] and nuclear data library JENDL-2 to find plutonium enrichment, gadolinia density, geometric buckling and operating coolant density which satisfy the negative reactivity against the change of the coolant density throughout the fuel life time. The collision probability method is used for the calculation using the cross section with 59 (fast) and 31 (thermal) neutron energy groups. Gadolinia is used to decrease the flooding reactivity of the fresh fuel core. The geometric buckling has to be large to decrease the void reactivity. The void reactivity tends to be positive at the end of cycle due to the decrease in absorption of fission products and the fuel. Three batch refueling is adopted and linear approximation is assumed between the effective multiplication factor and the burnup.

* Hongo, Bunkyo-ku, Tokyo 113.
We carried out the calculation with the operating steam density of 0.05, 0.1 and 0.2 g/cm³, but we cannot find the core satisfying the criteria (1): the negative reactivity insertion. After the extensive calculation we finally find out the core operated at the steam density of 0.3 g/cm³ satisfies the negative reactivity criteria throughout the fuel life time as shown in Fig. 1.

There are two ways to accomplish the water coolant density of 0.3 g/cm³. One is the mixing of the water droplets and the steam, the other is to increase the pressure into supercritical region. By former method, the corrosion would be excessive due to the accumulation of impurity into the droplets. Then we adopted the supercritical steam as the coolant.

The change of the conversion ratio, which is the ratio of the fissile atom number at the end of life to that of at the beginning of life, and the discharge burnup with the plutonium enrichment were studied at 0.3 g/cm³ density of the coolant. The relation is shown in Fig. 2. The conversion ratio decreases with plutonium enrichment, while the discharge burnup increases with it. From these results, the plutonium enrichment of 15% is chosen, which corresponds to the fissile enrichment of 10.5%. The conversion ratio reaches 0.88 at the gadolinia density of 0.25%, the geometric buckling $1.339 \times 10^{-3}$ cm⁻² and the steam density of 0.3 g/cm³. The total breeding ratio would exceed unity assuming the blanket contribution of 0.1~0.2. The discharge burnup is estimated to be 45.8 GWD/MT.

2. Two-dimensional Calculation

Two-dimensional core design of the supercritical steam cooled fast breeder reactor (SSCFBR) is carried out using CITATION⁴ and the cross sections collapsed by the cell calculations. The radial and the axial blankets are necessary for the breeding, but it deteriorates the void reactivity. First the homogeneous core is studied. But the core is very small, approximately 1,000 MWt for satisfying the negative void reactivity criteria at the end of cycle. Second the heterogeneous core is studied. The void reactivity constraint is also severe in this case. The positive reactivity at voiding is attributed to the decrease in absorption due to spectrum hardening. Zirconium hydride layer is used to mitigate the spectrum hardening. The core layout is shown in Fig. 3. It includes the inner, radial and axial blankets to increase the total breeding ratio. Zirconium hydride layers are
inserted between the seed and the axial blankets. The changes of reactivity with the steam density of the whole core including the blankets are depicted in Fig. 4. The reactivity is maximum at the operating steam density. The introduction of the small amount of zirconium hydrides is very effective due to the largest moderating power of hydrogen. The maximum burnup is 42.7 GWd/MT. The breeding ratio of the core reaches 1.04.

3. Conclusion

The neutronic feasibility of the steam cooled fast breeder reactor is assessed by adopting the supercritical steam as the coolant. The reactivity of the core changes negative against both the voiding and the flooding of the whole core. Use of the fixed moderator, zirconium hydrides, is effective to decrease the positive void reactivity.

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REFERENCES