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Study of Some Innovant Reactors without on-Site Refueling with Triso and Cermet Fuel

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Abstract—The evaluation of unit cell neutronic parameters and lifetime for some innovant reactors without on sit-refuling will be held in this work. the behavior of some small and medium reactors without on site refueling with triso and cermet fuel. For the FBNR long life except we propose to change the enrichment of the Cermet MFE to 9%. For the AFPR reactor we can see that the use of the Cermet MFE can extend the life of this reactor but to maintain the same life period for AFPR-SC we most use burnup poison to have the same slope for Kinf (Burnup). PFPWR50 cell behaves almost in same way using both fuels Cermet and TRISO. So we can conclude that PFPWR50 reactor, with CERMET Fuel, is kept among the long cycle reactors and with the new configuration we avoid subcriticality at the beginning of cycle. The evaluation of unit cell neutronic parameters reveals a good agreement with the goal of BWR-PB concept. It is found out that the Triso fuel assembly lifetime can be extended for a reasonably long period without being refueled, approximately up to 48GWd/t burnup. Using coated particles fuels with the Cermet composition can be more extended the fuel assembly life time, approximately 52 GWd/t.

Keywords— Cermet., Trisot, without on site refueling.

I. INTRODUCTION

DURING the CRP period we have studied five types of innovative small and medium reactors (AFPR from USA, FBNR from Brazil, BWR-PB from Russia and pfpwr50 from Japan) have been studied in our laboratory. Those innovative reactors are designed to be long life and without on site refueling. The main feature of those reactors is to provide proliferation resistance and cost reduction. In the first step we studied different cells with Triso micro fuel and to avoid problems associated with this type of MFE (Because of the characteristics of Triso MFE at low temperature) our group decided to adopt a Cermet MFE. In this paper we will give cell parameters results for the two types of MFE (Cermet and TRISO) and give conclusions. The results for the benchmark problems were collected and compared. They cover neutron spectrum, neutron multiplication factors with burnup and other related parameters for all reactor concepts. The final results show that all the reactors proposed or long life and provide more security. The calculations have shown that studied designs are valid as long as core life is concerned.

II. UNIT CELL DEFINITION FOR DIFFERENT REACTOR CONCEPTS

A. AFPR-100$^{3)}$ (USA)

AFPR cell was evaluated for both moderator condition of conventional and supercritical state. The fuel kernel of micro fuel element is uranium dioxide. The enrichment of U-235 is 10%. TRISO coated particle of 2mm in diameter is covered with porous and dense pyrolytic carbon, SiC, and NbC. The unit cell shape is square with 100mm pitch. A 29mm diameter water tube of thickness 1.5mm penetrates the center of the unit cell, and light water flows inside of the water tube. The water density is 0.770g/cm^3. The outside of the water tube is the fuel region. The fuel region is filled with mixture of water and steam. The mixture of water and steam density is 0.0877g/cm^3. TRISO coated particles are loaded there directly. Coated particle fuels fill the fuel regions with porosity of 0.35. The water tube consists of zircaloy-2.

In AFPR-Supercritical the enrichment of U-235 is 15%. The pitch of the square unit cell is 200mm, and the fuel region is filled with supercritical water. The supercritical water density is 0.450g/cm^3. In addition boron carbide as the control rod is inserted inside of the guide tube instead of water. Other parameters are equal to non-Supercritical one. The guide tube consists of steel.

For the Cermet MFE,. From the PNNL-16245 report,

The fuel parameters (dimensions given in micron)are given in Fig. 1:

- UO2 micro sphere diameter = 500
- Micro sphere Zr clad thickness = 25
- Micro spheres embedded in Zr with a porosity of 0.40 (60% microspheres + 40% Zr matrix by volume)

B. BWR-PB (Russian Federation)

TRISO coated particle of which diameter is 1.8mm is composed of the fuel kernel of uranium dioxide enriched with U-235 of 10% and three coating layers of porous and dense pyrolytic carbon, and SiC. The square unit cell pitch is 62.5mm, and the diameter of water tube at the center is 30.31mm. The thickness of the water tube is 0.5mm. Light water flows inside of the water tube. In the fuel region, coated particles are dispersed in light water so that the volume fraction of fuel particles to the fuel region is 61.0%. The density of the water is 0.743g/cm^3. The water tube consists of ZrNb.

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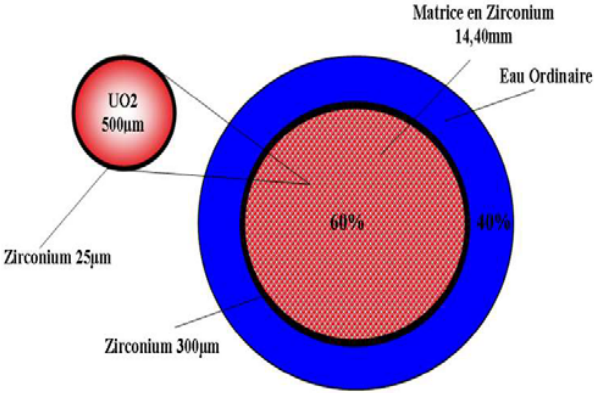

Fig 1 Cermet MFE parameters

C. Fixed Bed Nuclear Reactor (FBNR) (Brazil)

The fuel kernel consists of uranium dioxide enriched with U-235 of 5%. The 2mm diameter micro fuel element covered by coating layers of pyrolytic carbon and SiC. Spherical fuel elements of diameter 15mm are made of compacted coated particles in graphite matrix. The volume fraction of fuel particles to the spherical fuel element is 60% and remaining 40% is graphite matrix. The volume ratio of the spherical fuel element to water is 60%. This pebble beds are loaded in light water as moderator. The water density is 0.710g/cm^3.

In the case of FBNR, the 15000 microns diameter fuel element is cladded by Zr of 300 microns in thickness (14400 diameter microspheres and Zr matrix + 300 thick Zr cladding). It will be useful that all of us use the same parameters in order to be able to compare our results better.

D. PFPWR50 (Japan)

Mixture of thorium dioxide and plutonium dioxide are used as fuel kernels. ThO_2-PuO_2 weight ratio in the fuel kernels is 9 to 1. Th isotope is composed of only thorium-232, and Pu isotope is composed plutonium-238, 239, 240, 241 and 242. Their weight ratios to the total plutonium are 0.02, 0.63, 0.19, 0.12 and 0.04, respectively. The 0.5mm diameter TRISO coated particle is made of this kernel and coating layers of pyrolytic carbon and SiC. The three region hexagonal cell is adopted as unit cell. The inner diameter of the cladding tube is 25.9mm, the outer one is 28.9mm and the cell pitch is 34mm. Inside of the cladding tube where it is fuel region, is loaded with pellets consisted of the coated particles and graphite matrix. The volume fraction of the coated particles to the pellets is 20%. Outside of the cladding tube is water region. The water density is 0.804g/cm^3. The cladding tube consists of zircaloy.

In the first year of this CRP we have prove that all reactors proposed can be long life. In this paper we will focus on the behavior of those reactors with Triso and Cermet MFE.

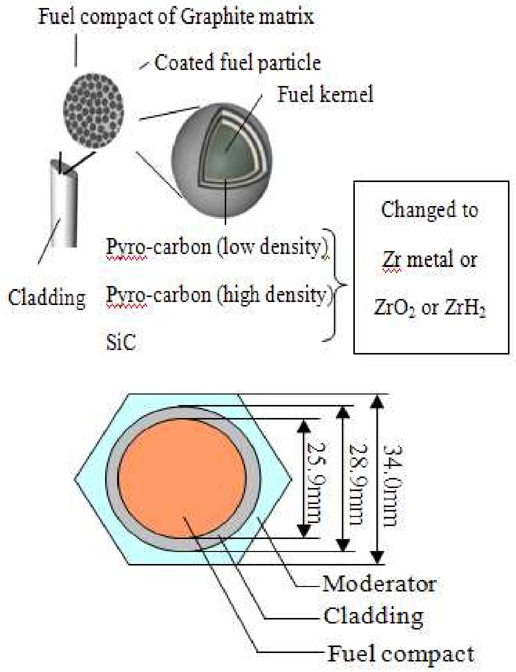

Fig. 2 Cermet MFE and cell parameters

III. CALCULATION RESULTS FOR DIFFERENT REACTORS CELLS

A. AFPR

Fig. 3 shows comparison of k-infinity plots for AFPR. We can see that the k-infinity is higher for Cermet MFE than Triso. The difference is bigger at beginning of life (BOL) and less at the end of life (EOL). This difference can be explained by the shape of the flux. We can see that the TRISO give harder flux than the Cermet for the (BOC) and (EOL) Fig. 4-5.

B. AFPR-supercritical

Fig. 6 shows comparison of k-infinity plots for AFPR-SC. We can see that the k-infinity is higher for Cermet MFE than Triso at the (BOC) and Apollo as shown in Table I and Fig. 1. The difference is bigger at beginning of life (BOL) and less at the end of life (EOL). This is because the gradient is different. We can see that the TRISO give harder flux than the CERMET for the (BOC) and (EOL). We can also see that the shape of thermal flux change between the (BOC) and the (EOC) Fig. 7-8.

C. BWR-PB

The Fig. 9 shows comparison of Infinite Multiplication Factor (kinf) plots for BWR-PB unit cell with CERMET and TRISO fuel composition. The ratio of the kinf of the CERMET unit to TRISO one is 0.9788 at beginning of cycle (BOC) and 0.9753 at the end of cycle (EOC). It hasn’t so large difference.

The unit cell using a zirconium-matrix CERMET fuel attains a critical lifetime at 76 GWd/t and at 80 GWd/t for Triso unit cell. This difference is due to moderation effect.

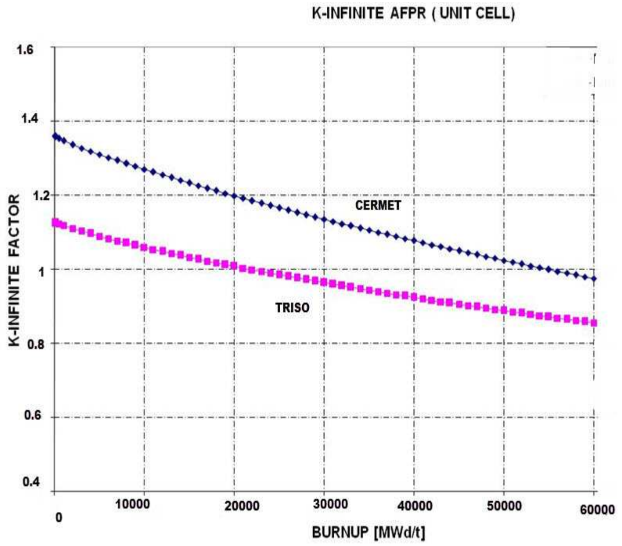

Fig. 3 Infinite multiplication factor vs. Burnup for TRISO and Cermet MFE(AFPR)

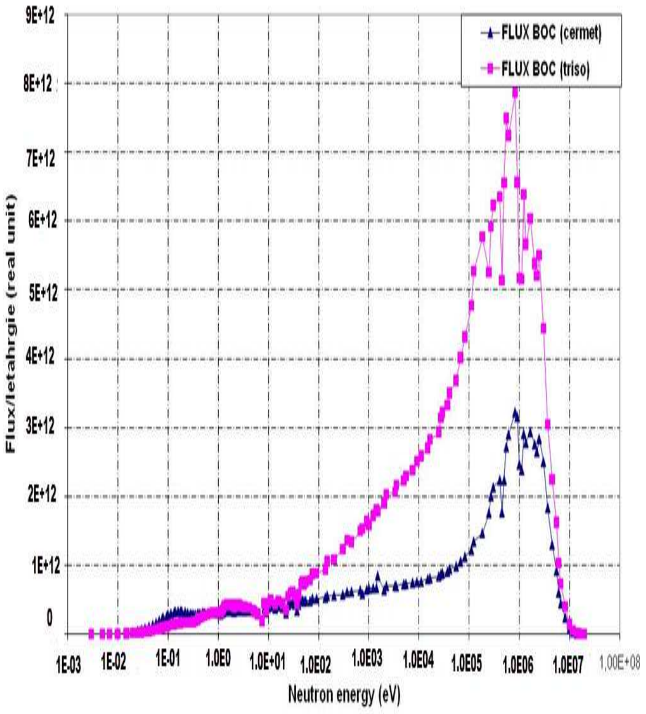

Fig. 4 Flux (energy) for Cermet and Triso at the BOC (AFPR)

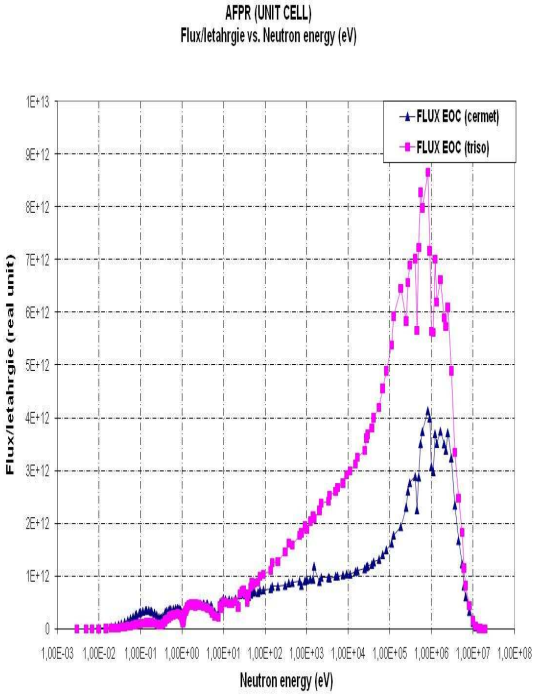

Fig. 5 Flux (energy) for Cermet and Triso at the EOC (AFPR)

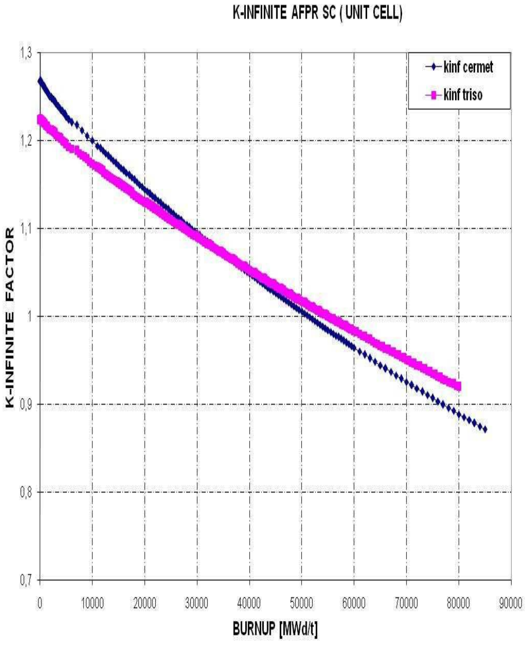

Fig. 6 Infinite multiplication factor vs. Burnup for Cermet and Triso (AFPR-SC)

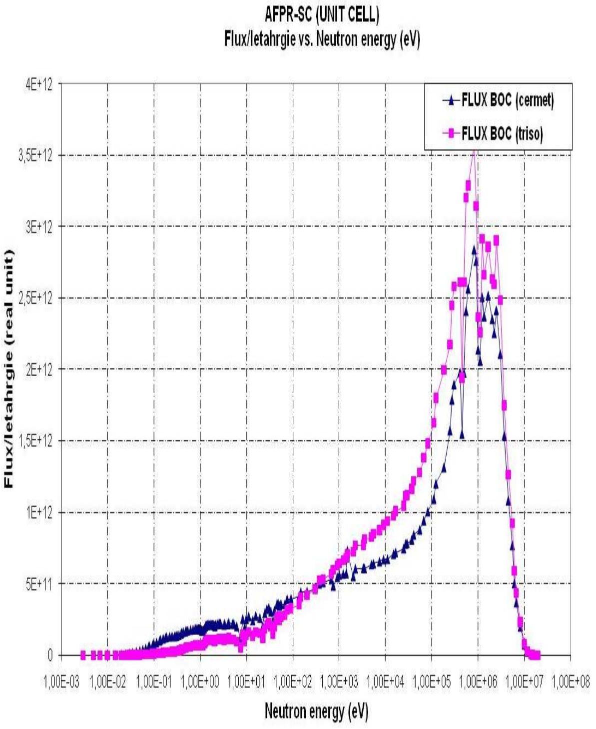

Fig. 7 Flux (energy) for Cermet and Triso at the BOC (AFPR-SC)

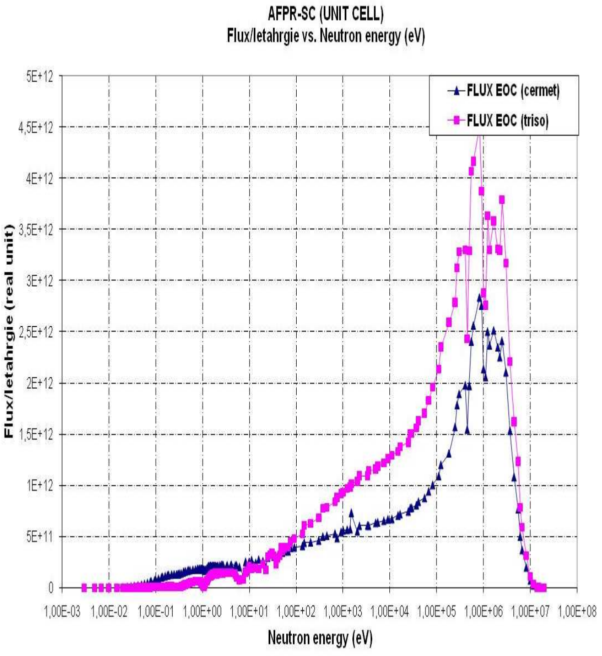

Fig. 8 Flux (energy) for Cermet and Triso at the EOC (AFPR-SC)

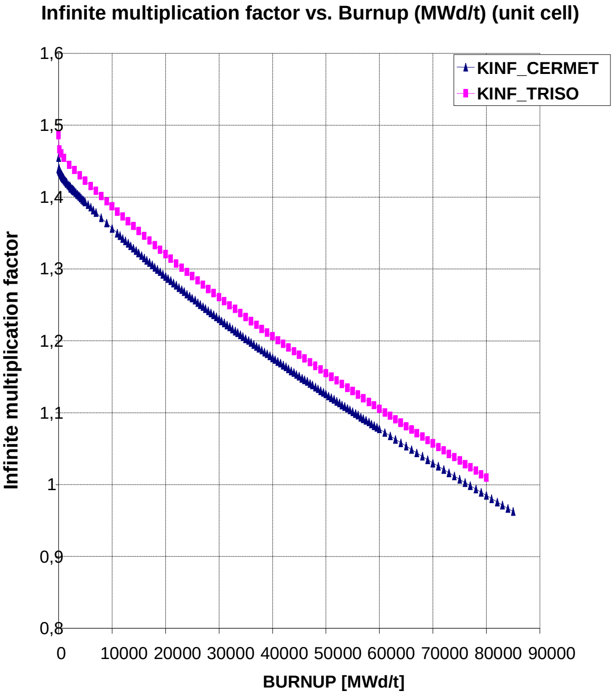

Fig. 9 Infinite multiplication factor vs. Burnup (BWR-PB)

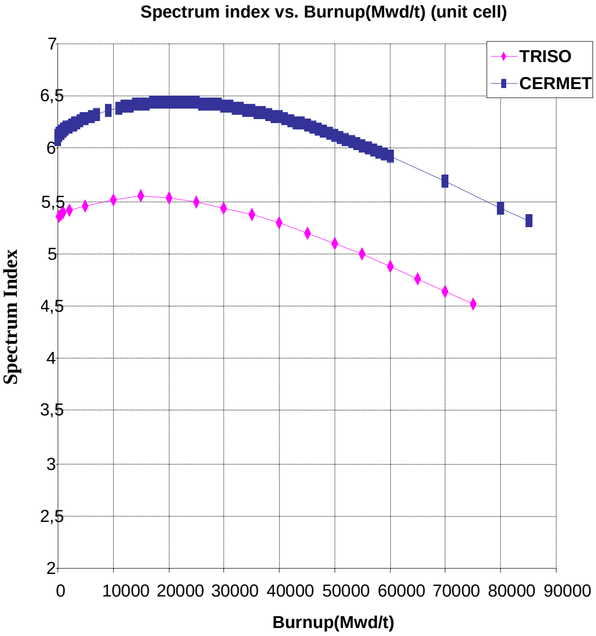

Fig. 10 Spectrum index vs. Burnup for Cermet and Triso MFE (BWR-PB)

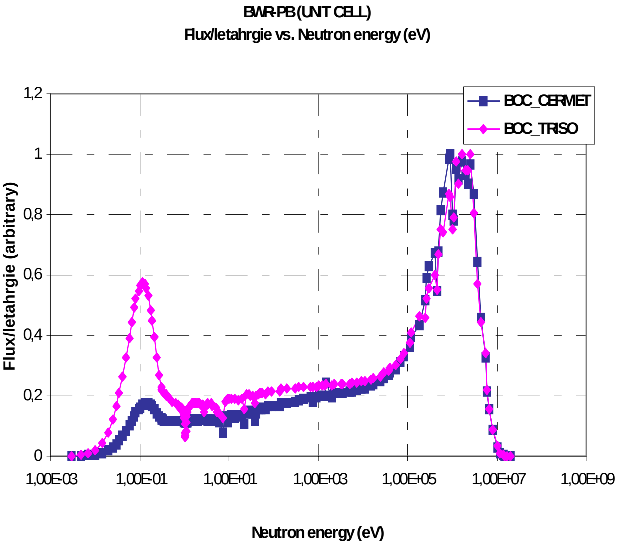

Fig.11 Flux (energy) for Cermet and Triso at the BOC (BWR-PB)

D. FBNR

Fig. 12 shows comparison of k-infinity plots for FBNR. The large pebble beds of 15mm diameter are used in FBNR differing from the reactors above. Better agreement is seen in Fig. 12. The agreement at EOL is better than BOL. The ratio of the k-infinities by SRAC95 [2] to APOLLO [1] is 1.002 at EOL against 1.014 at BOL.

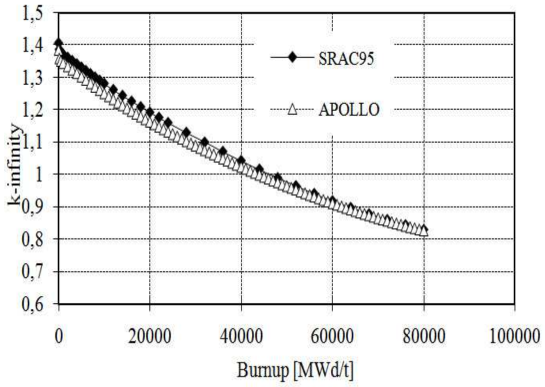

Fig. 12 Infinite multiplication factor vs. Burnup with Triso MFE (FBNR)

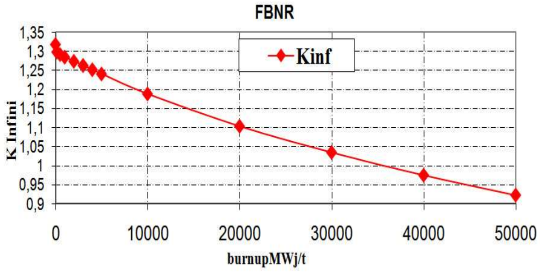

Fig. 13 Infinite multiplication factor vs. Burnup with Cermet (FBNR)

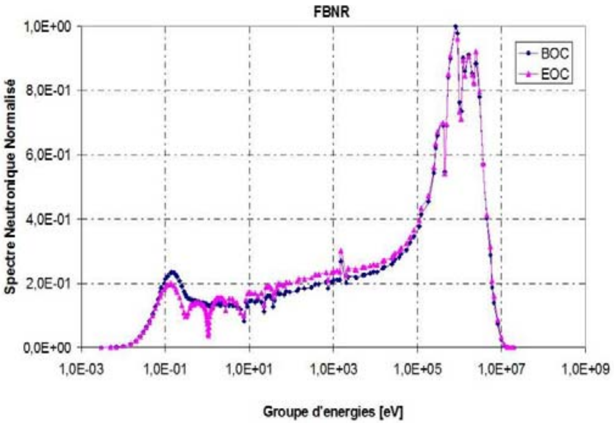

Fig. 14 Flux vs. neutron energy with Cermet MFE at the BOCand EOC (FBNR)

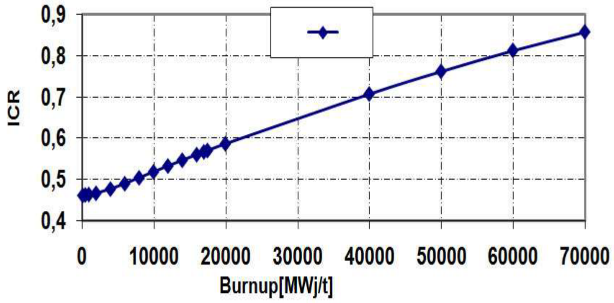

Fig. 15 Index vs. Burnup for Cermet MFE (FBNR)

TABLE I
FBNR LIFE PERIOD VS. ENRICHMENT (%)

Enrichment %	5	6	7	8	9
Life period (Years)	3.5	4.6	5.8	7.3	8.9

E. PFPWR50

Fig.16 shows comparison of k-infinity plots for PFPWR50. The fuel kernels of thorium and plutonium mixture are used only in PFPWR50. We can see that both Cermet and Triso have almost the same shape of the flux at the (BOC) but at the (EOC), the Cermet fuel gives more thermalisation than the Triso. That can be explained by Nu*Fission and Capture cross Sections of the fuel.

The operating burnup predicted by the PFPWR50 cell analysis for the TRISO fuel is reduced by almost 8000Mwd/t with Cermet MFE.

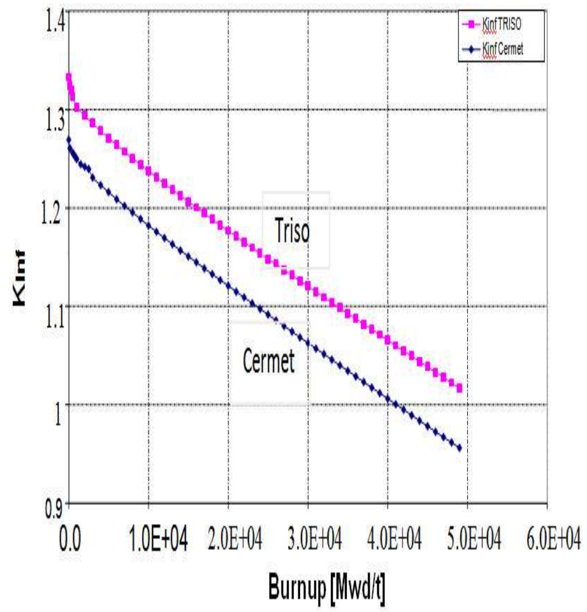

Fig. 16 Infinite multiplication factor vs. Burnup with Cermet and Triso MFE (PFPWR50)

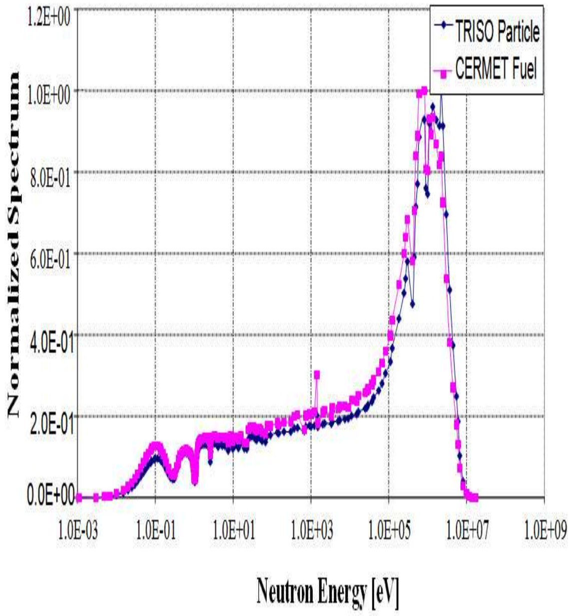

Fig. 17 Flux vs. neutron energy with Cermet and Triso MFE at the BOC (PFPWR50)

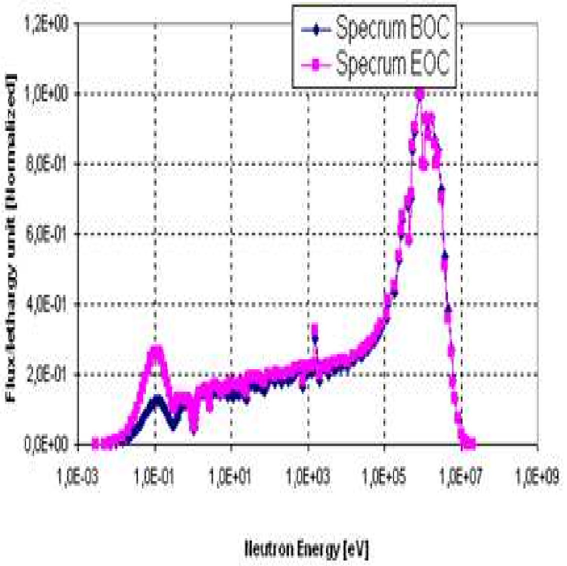

Fig. 18 Flux vs. neutron energy with Cermet MFE at the (BOC) and (EOC) (PFPWR50)

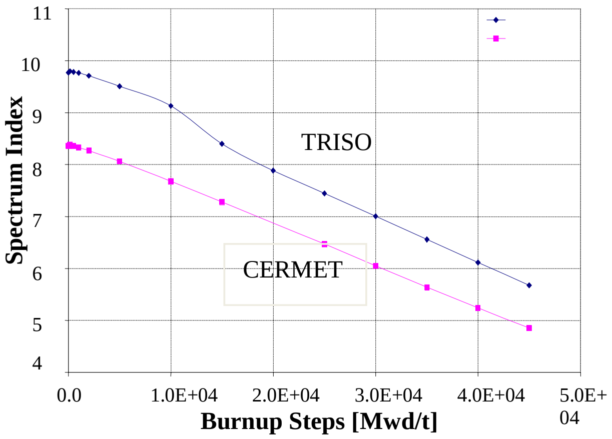

Fig. 19 Spectrum index factor vs. Burnup for Cermet and Triso MFE (PFPWR50)

IV. CONCLUSION

In this study we can see that all the types of SMR without on site refueling can be long life except the FBNR. For this reactor we propose to change the enrichment of the Cermet MFE to 9%.

For the AFPR reactor we can see that the use of the Cermet MFE can extend the life of this reactor but to maintain the same life period for AFPR-SC we most use burnup poison to have the same slope for Kinf (Burnup)

PFPWR50 cell behaves almost in same way using both fuels Cermet and TRISO. So we can conclude that PFPWR50 reactor, with CERMET Fuel, is kept among the long cycle reactors and with the new configuration we avoid subcriticality at the beginning of cycle.

The evaluation of unit cell neutronic parameters reveals a good agreement with the goal of BWR-PB concept. It is found out that the Triso fuel assembly lifetime can be extended for a reasonably long period without being refueled, approximately up to 48GWd/t burn up. Using coated particles fuels with the Cermet composition can be more extended the fuel assembly life time, approximately 52 GWd/t.

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