Creation of internal radiation barrier in MOX-fuel for protection against uncontrolled proliferation.

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ABSTRACT

It is demonstrated a possibility to create long-term radiation barrier in MOX-fuel. Achievable protection levels and conditions for its creation are evaluated.

INTRODUCTION

Presently, one of the main issues for resolving non-proliferation problem is to make nuclear materials unaccessible for any potential unauthorized actions. It concerns, in the first turn, the materials containing plutonium and highly enriched uranium. In addition to exterior physical protection, it is important to give self-protection ability to these materials. According to acting regulatory documents [1], irradiated nuclear materials containing plutonium or highly enriched uranium are regarded as materials with the lowest attractiveness for diversion. So, creation of inherent radiation barriers in high-attractive nuclear materials is a promising way to enhance non-proliferation safeguards.

Fresh fuel assemblies (FA) of LWRs containing MOX-fuel are regarded as products of the highest attractiveness, and they require appropriate protective measures. Availability of inherent radiation barrier in these FA would promote more active implementation of this promising fuel type into the world's nuclear power.

TASK DEFINITION

An approach proposed in [2] to creation of long-term protective radiation barrier in MOX-fuel implies admixture of small ^{232}U quantity to fuel during fabrication process and short-term irradiation of manufactured FA in blanket of accelerator-driven system (ADS) for accumulation of fission products (FP) - emitters of hard γ-radiation. After 90-days irradiation of FA containing MOX-fuel with 0.01% ^{232}U at power level of 2.8 MW, rate of exposure dose (RED) at 1 m distance from FA exceeds 100 rem/h for 25 years. This radiation barrier is higher than radiation background of fresh FA by several hundred times.

It should be noted that protective radiation barrier is mainly created by γ-emission of FP contained in peripheral fuel rods due to strong attenuation of radiation emitted by internal rows of fuel rods. Relative contributions of fuel rod rows to RED for FA irradiated in power LWR are presented in Table 1.

Table 1.

Contribution of fuel rod rows to total RED of FA

Number of row	1-3	4	5	6	7	8	9
Contribution to RED, %	0.6	0.8	2.4	4.4	10.2	23.0	58.6

It can be seen that the last row of fuel rods gives more than 50%-contribution to total RED. Therefore, when defining conditions for FA irradiation in ADS blanket, it is expedient to concentrate γ-emitters at FA periphery, i.e. FP should be mainly built-up in peripheral fuel rods. Then, having kept RED at approximately the same level, power generated by FA may be substantially reduced, and, by this, requirements to current in accelerator beam may be relaxed.

MODEL FOR NUMERICAL STUDIES

ADS blanket represents a light-water pool where FA with MOX-fuel are placed for irradiation. Heavy water is used as an internal coolant and moderator of FA. Effect of increasing the FA lattice pitch was investigated. When pitch of FA lattice increases, neutron spectrum in FA peripheral region is softened, and FP accumulation there is uprated. Additional factor enhancing the effect is an application of different coolants inside and outside of FA. Light water is rather more effective moderator than heavy water. Therefore, combination of D_2O(inside)/H_2O(outside) is able to enhance spectrum softening effect at FA periphery when pitch of FA lattice is increased.

Spatial distributions of FP accumulation in FA and RED values from irradiated FA have been calculated for FA polycell with application of computer code SCALE 4.3 [3].

RESULTS OF CALCULATIONS

The calculations of FP distribution in fuel rod rows for different pitches of FA lattice have demonstrated that maximal value of FP content ratio "periphery/center" was about 9 and achieved for inter-FA gap equalled to 9 cm. So, increasing the inter-FA gap from 0.2 cm (power LWR) to 9 cm makes it possible to shift FP accumulation significantly towards FA periphery.

FP re-distribution effect leads to similar re-distribution of power generation field in FA. Total FA power reduces because of drastical reduction in central part contribution. As a consequence, the same value of specific heat generation of peripheral fuel rods can be achieved with less power of ADS blanket, i.e. with less current of accelerator beam. Meanwhile, RED from irradiated FA will be changed insignificantly because of dominant contribution of peripheral fuel rods to dose value.

It should be noted that FP re-distribution effect towards FA periphery in extended lattice of MOX FA is higher than that for uranium FA. It is explained by

fission resonance of ^{239}Pu near to 0.3 eV. Correspondingly, under the same power and the same inter-FA gap, RED from irradiated MOX FA is higher than that from uranium FA. Maximal FP content ratios "periphery/center" are equal to 6.5 and 8.9 for uranium FA and MOX FA, respectively. In two years after irradiation, RED at 1 m distance from irradiated uranium FA was about 250 rem/h, that is about half of RED from irradiated MOX FA.

The following results have been obtained under adopted limitations (specific heat generation - 110 kW/l, as in power LWR; irradiation time - 95 days):

1. "Tight" lattice of MOX FA: FA power - 19 MW; RED at 1 m distance in two years - 740 rem/h.
2. "Extended"lattice of MOX FA (inter-FA gap - 9 cm): FA power - 7.5 MW (lower by a factor of 2.5); RED at 1 m distance in two years - 500 rem/h (32% less).

The RED value decreased by 32% may be restored to previous value by proportional increase of FA irradiation time. Time dependence of RED from MOX FA irradiated in ADS with "extended" lattice is presented in Fig. 1.

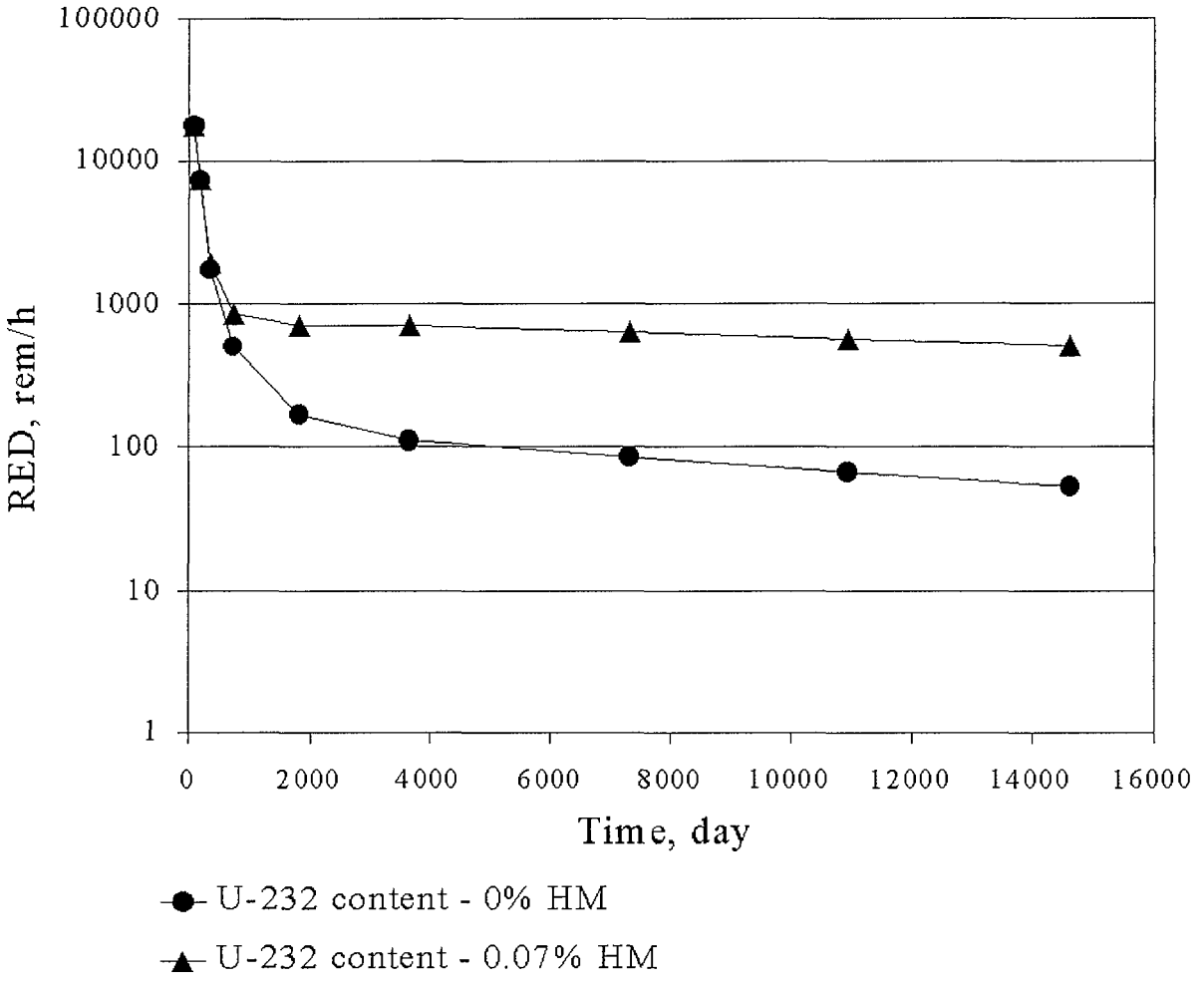

Fig.1. Time dependence of RED at 1 m distance from MOX FA irradiated in ADS with "extended" lattice.

It can be seen that during initial two years after irradiation, RED value exceeds level of 500 rem/h adopted now as a sufficient level for self-protection of nuclear materials [4]. Admixture of insignificant ^{232}U quantity into MOX-fuel at fabrication

stage makes it possible to achieve substantial prolongation of self-protection period. For example, admixture of 0.07% ^{232}U prolongs the term of radiation barrier up to 40 years.

CONCLUSION

Performed evaluations on possibility to create inherent protective radiation barrier in FA with MOX-fuel by short-term irradiation in ADS blanket allowed to make the following conclusions:

1. Increase of lattice pitch and application of coolants with different moderating ability inside and outside of FA lead to re-distribution of FP accumulation towards FA periphery. The FP re-distribution effect appears to be more strongly pronounced in MOX FA than that in uranium FA.
2. The FP re-distribution effect towards FA periphery insignificantly reduces RED value from irradiated FA but drastically reduces its power, thus relaxing requirements to accelerator parameters.
3. After short-term irradiation of MOX FA in ADS blanket with "extended" lattice, RED from irradiated FA exceeds adopted level of self-protectability in two years. If insignificant quantity of ^{232}U is admixed to MOX-fuel at fabrication stage, the self-protectability period can be prolonged up to 40 years and over.

REFERENCES

1. Basic rules on nuclear materials control and accounting. Draft version (IPPE Report No. 39-50/443 of May 14, 1999).
2. Glebov V.B., Shmelev A.N., Apse V.A., Tsvetkov P.V., Sintsov A.E. Long-term radiation protection of MOX-fuel assemblies against uncontrolled proliferation of nuclear materials. – Proceedings of the International Conference on Future Nuclear Systems GLOBAL'99 "Nuclear Technology-Bridging the Millennia" (August 29 – September 3, 1999, Jackson Hole, Wyoming, USA).
3. SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation. NUREG/CR-0200, ORNL/NUREG/CSD-2/R5, Oak Ridge, January, 1997.
4. Management and Disposition of Excess Weapon Plutonium. – Committee on International Security and Arms Control, National Academy of Sciences. National Academy Press, Washington, D.C., 1994, p. 151.