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Optimization of fuel assembly with gadolinium for LWRS☆

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Abstract

At present, the fuel assemblies of Light Water Reactors require mainly cost-effective production of electricity. The objective of in-core fuel management is to achieve the objective of minimizing fuel cycle cost by using advanced models of core loading strategies. Current development is focused mainly on optimizing the design of gadolinium fuel, thereby to reduce the average enrichment of fuel assemblies and the binding of the excess reactivity at the beginning of the fuel cycle. This paper deals with different ways of optimizing fuel assemblies containing a burnable absorber for PWR and VVER reactors. These calculations were made in SCLAE 6 code, TRION module.

Keywords: fuel assembly, gadolinium, Gd_2O_3,VVER-440, k_{inf}, multiplication factor

1. Introduction

The development of optimization of fuel assemblies began in the early 1970s. The majority of these optimization concepts using gadolinium as a burnable absorber in the form of GdO mixed with UO, contains 2 to 6% of GdO in the fuel. In recent years fuel assemblies for VVER-440 reactors have also included a burnable absorber and are playing an important part in progress worldwide, especially in terms of operating performance and fuel cycle economy.

1.1. Utilization of gadolinium in light water reactors

From the physical point of view mainly Gd and Gd produce a 'neutron shield' for uranium inside the fuel pin (or tablet), so that the inner area of the fuel becomes accessible to neutrons after both isotopes are progressively burned up. A reactor with gadolinium can operate in longer campaigns (5 to 6 years).

Gadolinium as a burnable absorber uses GdO mixed with UO. The content of GdO in fuel (VVER-440) is 3.35% of the fuel pin weight. A substantial increase in nuclear safety in the handling of fresh nuclear fuel is gained if we use Gd. This fuel has increased enrichment and makes it possible to reduce the concentration of HBO while increasing the initial enrichment load.

Why we use gadolinium:

- greater flexibility when dealing with fuel assemblies and designing new batches,
- gadolinium fuel enables control of: the power peaking factor during burn up, the boric acid concentration and the temperature coefficient of the moderator at the beginning of the cycle,
- no adverse effect on fuel rod performance (cf. increase in internal pressure of fuel covered by boron),

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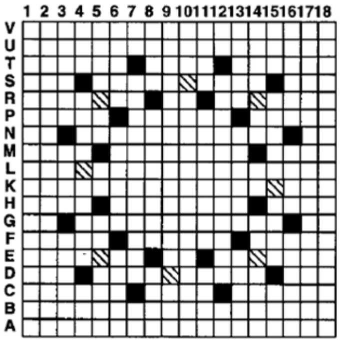

Figure 1: 18x18 U/Gd-fuel assembly with 8 Gd fuel rods [2]

- no negative impact on fuel reprocessing,
- many positive production and operational experiences documented.

2. Optimized gadolinium concentration concepts

Problems exist with loading of uranium+gadolinium (U/Gd) fuel assemblies of standard design:

- GdO displaces uranium in a fuel rod and leads to a reduced heavy metal mass in the fuel assembly,
- uranium+gadolinium fuel has lower heat conductivity, so the U enrichment in the U/Gd fuel rod is reduced to meet the design criterion regarding maximum fuel temperature
- after the burnout of the Gd and Gd, there still remains a residual reactivity binding.

There have been many studies on optimizing fuel assemblies with gadolinium worldwide and various issues have been raised.

2.1. Optimized Gd concentration concepts for PWRs

The project was performed on a balanced cycle of 345 efpd for a Konvoi PWR plant in Germany. It compared the standard Gd-concept with the optimized (low) gadolinium concentration concept and an enriched Gd concept, which involves the enrichment of the main neutron absorbing isotopes, especially Gd [1].

Fig. 1 shows the fuel assembly of the balanced cycle which is loaded into the core. This fuel assembly

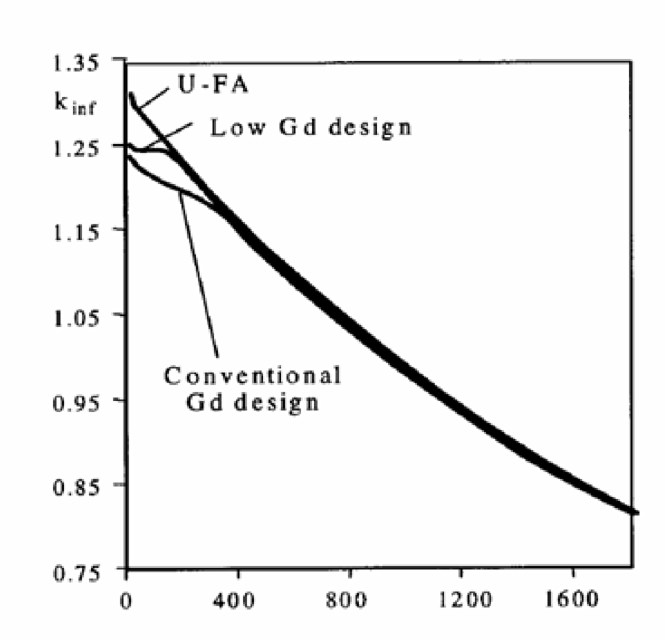

Figure 2: Reactivity characteristics of uranium (U), conventional U/Gd and optimized U/Gd fuel assemblies [2]

was the reference of study in Germany. The reload batch consists of 44 fuel assemblies with a nominal enrichment of 4.4% U (without gadolinium) and 24 fuel assemblies which contain 8 Gd rods. These assemblies have enrichment of 2.6% U with 5 wt. % of GdO for the standard case. The reduced uranium enrichment in the Gd rods zone is to compensate for the lower melting point and the heat conductivity of the UO/GdO mixture. Fig. 2 shows a design of this fuel assembly and the radial positions of the U/Gd fuel rods. The fuel assembly with low Gd contains 2 wt. % natural GdO in 4.4% enriched U. Compared to the basis fuel assembly, the reduced absorber concentration combined with the higher U content leads to a slight increase in initial reactivity and an earlier Gd burnout in the U/Gd fuel assembly. The reactivity characteristics of both fuel assembly designs are shown in Fig. 2 [2].

At the low Gd concentration, the Gd-burnout appears at approximately 90 efpd, compared to 180 efpd for the standard design.

Higher average U enrichment in the U/Gd fuel assembly results in an increase in efpd of 5 in a natural cycle length [2].

A study was performed in Japan which compared Japanese PWR fuel assemblies with various concen-

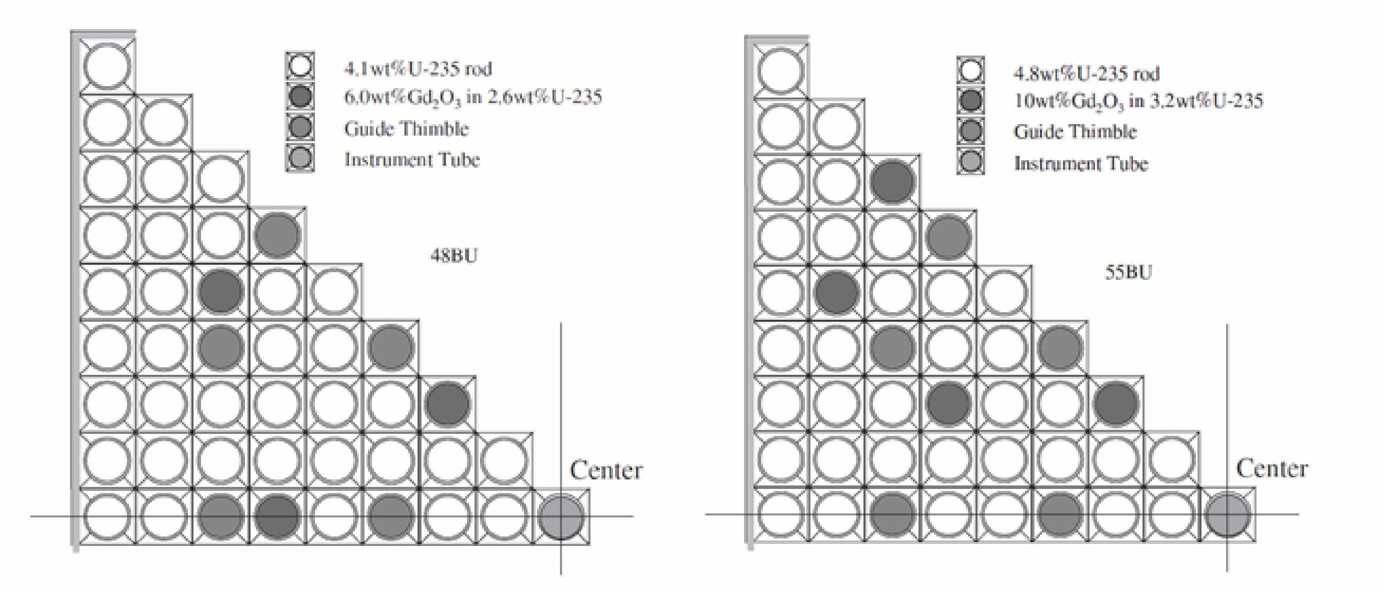

Figure 3: PWR fuel assembly 17×17 with burnup (A) 48 GWd/tHM and (B) 55 GWd/tHM

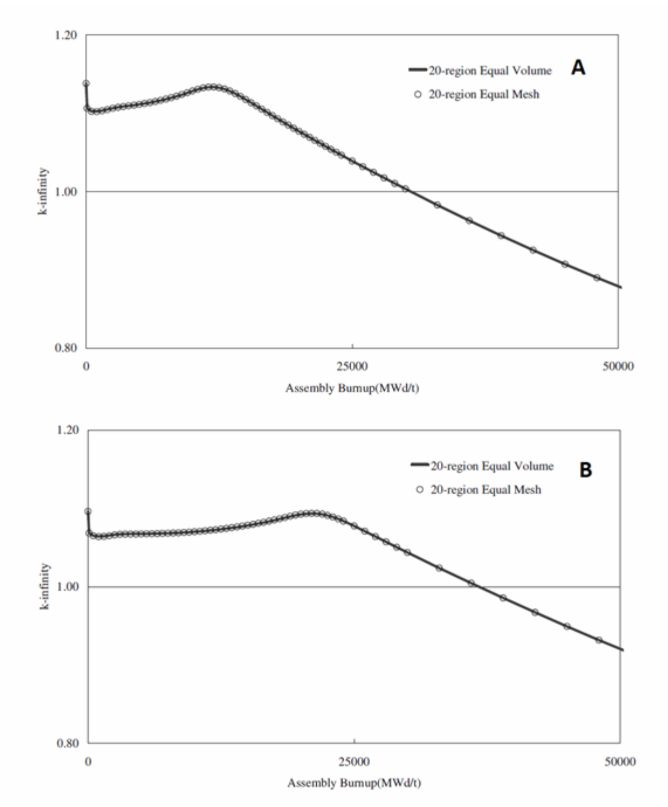

Figure 4: K depending on burnup of PWR fuel assembly 17×17 with burnup (A) 48 GWd/tHM and (B) 55 GWd/tHM

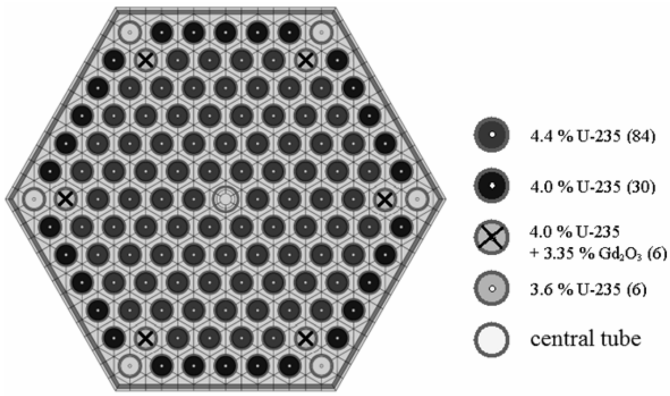

Figure 5: Fuel assembly Gd-2 with enrichment 4.25% (5 year fuel cycle) [4]

trations of gadolinium. Gadolinium in the form of GdO is used in Japanese PWRs, since they achieved maximum fuel assembly burnup of 48 GWd/tHM. This corresponds to 17 x 17 fuel assembly with an average enrichment of 4.1% U with 16 Gd fuel rods (6 wt. % GdO) with enrichment of 2.6% U. At present, in Japan the maximum fuel assembly burnup is up to 55 GWd/tHM, which corresponds to 17 x 17 fuel assembly with an average enrichment of 4.8% U containing 24 Gd fuel rods (10 wt. % GdO) with an enrichment of 3.2% U. Fig. 3 shows the cross-sections of both types of fuel assemblies and the chart of k depending on burnup is shown in Fig. 4 [3].

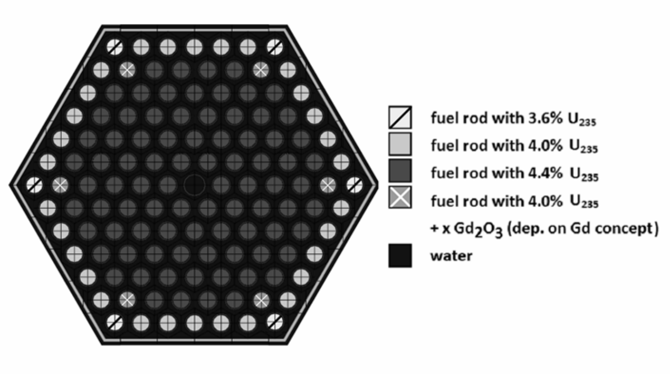

Figure 6: Fuel assembly Gd-2 design, wt. % of GdO depends on Gd concept

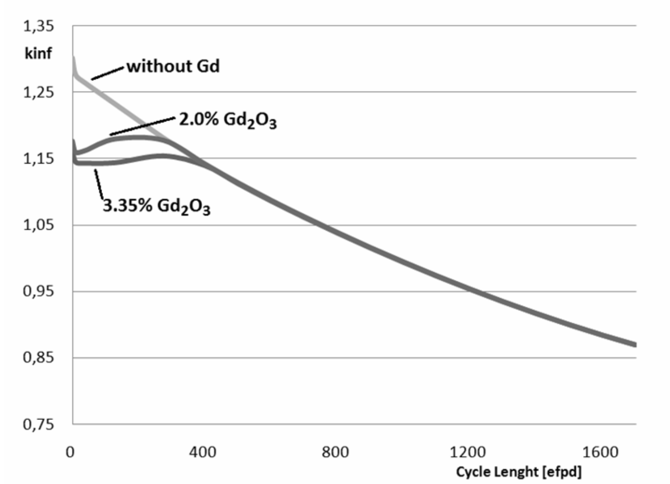

Figure 7: VVER-440 fuel assembly reactivity characteristics of U (without Gd), conventional U/Gd (3.35%) and optimized U/Gd (2.0%)-FAs

2.2. Optimized Gd concentration concept for VVER-440 reactor

In this paper, a study on a balanced cycle with the same number of efpd for a Slovak VVER-440 plant was performed comparing the present Gd-concept (fuel assembly Gd-2 contains 4.25% U + 3.35 wt. % GdO) with the optimized low Gd-concentration concept. Gd-2 is one of the types of VVER-440 fuel assemblies that contain 120 uranium rods and 6 U/Gd fuel rods. This fuel assembly is shown in Fig. 5 [4].

The low Gd design contains 2.0% GdO in 4.0% U (in 6 rods). Compared to the Gd-2 fuel assembly, the reduced content of the absorber leads to slightly increased reactivity at the beginning of the cycle and an earlier Gd burnout as in the Gd-2 assembly. These calculations were made in SCLAE 6 code through TRION module.

The schematic radial representation and reactivity characteristics of compared fuel assemblies are shown in Fig. 6 and Fig. 7.

3. Conclusion

The studies of PWR fuel loading in accordance with the concept of optimized fuel Gd concepts show the technical feasibility and economic attractiveness of this advanced design with a burnable absorber. Operating experience with a batch of this design type confirmed the expected fuel characteristics.

The design of fuel assemblies with lower Gd concentration can be considered as the next developmental step of the present gadolinium assemblies, and one which is based on the vast experience accumulated over the years. This design has both the potential to use the licensed limits to the maximum and the burnup potential, which is the main improvement for reactors that are limited in terms of their maximum reload enrichment. In a nuclear fuel cycle, we do not need as much enriched gadolinium, whose cost is high due to a more demanding fabrication process.

Technical and economic evaluations have shown that the optimized gadolinium concept is better than the previous gadolinium concepts with higher GdO concentrations.

In VVER-440 reactors, the fuel is gradually optimized for increasingly longer cycles. After the first fuel loading of the third generation of gadolinium fuel assemblies in the Russian Federation has become the fuel of VVER-440 type very similar to modern European PWR fuels. This type of fuel could be used in Slovakia from 2015. The Czech Republic already plans to introduce third generation gadolinium fuel in 2014. In 2009 in Slovakia preparations were started on a new type of Gd-2 fuel with an average enrichment of up to 4.87% U, which could be used in the Mochovce nuclear power station, Slovakia from 2011.

Acknowledgments

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