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Prospect of Very High Burnup Fuel in PWR

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1. Introduction

Since LWR was first introduced in 1950s, fuel discharge burnup has continuously increased. The current burnup, 50 MWD/kgU-fuel assembly is about two times higher than that in 1970's. The burnup increase has been driven by improvements in fuel design and fuel materials to achieve better economy. Doubling the fuel discharge burnup is equivalent to halving both the fresh and the spent fuels required for same energy generation, which gives direct economic benefits in fuel cycle cost. To review the feasibility of very high burnup fuel, special expert group on very high burnup fuel was formed in OECD/NEA in 2004 and published the review report[1].

2. Issues for Very High Burnup Fuel

2.1 Fuel Design and Performance

First concern when increasing the fuel discharge burnup is to maintain fuel integrity. For the fuel pellet, the parameters of primary concern at high burnup are fission gas release, microstructure transformation at high burnup to form high burnup structure and enhanced swelling of pellet by fission gas bubbles. For the cladding, corrosion and ductility reduction due to hydriding are of primary concern. For the fuel assembly structure, degradation of fuel assembly structure with longer irradiation was concerned such as bowing and relaxation of supporting spring force.

Specially, fuel cladding has been a most important factor and actually has led the fuel burnup increase during last 20 years. New cladding materials have been developed. As shown in Figure 1, test results of Zr-Nb alloy cladding showed that it could be irradiated up to the burnup of 100 MWD/kgU-rod average[2]. Improvement in fuel design such as spacer grid with mixing vane, and burnable poison fuel, and improvement in fuel assembly materials and design have supported the fuel burnup increase.

2.2 Core Design

To use the highly enriched fuel to achieve high burnup, the core design technology in reactor physics and reactor safety has been improved. To suppress the initial power peaking, burnable poison is utilized. To enhance the heat transfer, the spacer grid with mixing vane and separate flow mixer were introduced. With the use of higher enriched fuel, the reactor cycle length has been increased up to 24 months, which could increase the effective plant operation efficiency and could save plant maintenance cost[3].

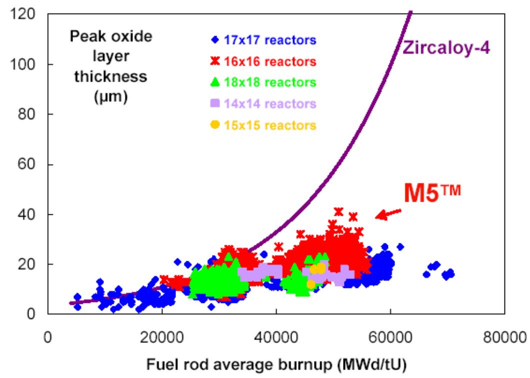

Figure 1. Cladding corrosion with the burnup[2]

Use of higher boron concentration in the coolant to control excess reactivity at the start of reactor cycle resulted in the crud deposition on the cladding and subsequently excessive local corrosion and AOA(Axial Offset Anomaly) in some PWR's[4]. However, by optimizing the coolant chemistry and crud removal procedure, those operational problems could be solved.

2.3 Spent Fuel Disposal

Disposal of spent fuels has been a critical factor in the public acceptance of nuclear power. There are two options such as direct permanent disposal and reprocessing of spent fuels to utilize the usable elements and to minimize the waste. Both options commonly need the temporary storage and transportation of spent fuels. The cost of those processes may be proportional to the number of spent fuels. Therefore, there is clear incentive to decrease the cost of spent fuel disposal since the fuel burnup increase reduces generation of spent fuels per unit energy generation.

In Korea and US, nuclear electric utilities are currently charged for the spent fuel based upon the electricity generation. It does not correctly consider the spent fuel disposal cost and therefore it is desirable to change it to the charge proportional to the spent fuel mass and volume. Anyhow, decrease of spent fuel generation by increase of fuel discharge burnup would allow the utilities more time until the site storage of spent fuels becomes full.

2.4 Uranium Enrichment and Fuel fabrication

To achieve very high burnup, U-235 enrichment need to go beyond 5 % which is the current limit. The cost of uranium enrichment in the market tends to decrease as the enrichment technology improves. The production of highly enriched uranium in the enrichment plant does not seems to be a significant problem.

For fuel fabrication, most of the current fuel fabrication plants are designed and licensed to operate below 5 % enrichment while the new fuel fabrication plant in France is reported to be able to operate above 5 %[1]. Therefore, feasibility and additional cost for the current fuel fabrication plant to be operated above 5 % U-235 need to be evaluated.

2.5 Economy of High Burnup Fuel

Economy is always the most critical factor in the engineering application. However, the difficulty is that it can not be verified clearly in advance before application and it also changes with time due to variation of market costs of the key factors involved. Therefore, it is always necessary to evaluate the economy of fuel at every development stages.

Fuel cost is about 20 % of nuclear electricity generation cost. It consists of uranium(6 %), enrichment(6 %), fuel fabrication (3 %) and spent fuel disposal(5 %). Those costs could change with time depending upon technology development, market demand and other factors.

The price ranges of them vary depending upon the assumptions[1,5,6]. The examples are such that uranium 20~70 $/kgU, conversion 3.5~8 $/kgU, enrichment 50~130 $/kg SWU, fuel fabrication 185~300 $/kgU. Transportation cost of spent fuel is around 230~370 $/kgU and final disposal cost with steel encapsulation is 600~1,250 $/kgU. Reprocessing cost is 700~1,000 $/kgU and high level waste disposal cost after reprocessing is 63~300 $/kgU. Uranium price depends strongly on the demand and supply, so that it expects to increase in the future as its demand increases, like fossil fuel price. Enrichment cost tends to decrease as the enrichment technology improves. As the fuel burnup increases, the required number of fuel assemblies will decrease. Therefore, as the fuel fabrication cost may remain same or slightly increase, the overall fuel fabrication cost per unit energy generation is expected to decrease as the fuel discharge burnup increases.

Depending upon the assumptions in the cost mentioned above, there is indication that it could be economical when the fuel burnup is increased beyond the current 5 % U-235 enrichment limit[5,6].

2.6 Works to be done

During last 30 years, fuel performance has led the fuel burnup increase and other factors have supported it. Improvements of fuel design and materials have increased the fuel discharge burnup up to 45 MWD/kgU-batch average and up to the current limit of 5 % U-235 enrichment. Now is the right time to seriously investigate the feasibility of going beyond 5 % U-235 enrichment. Among the factors to be investigated are fuel enrichment, fuel fabrication, core design, fuel performance, reactor safety, and spent fuel management[1].

For fuel enrichment and fuel fabrication, criticality is one of the key concerned parameters. The core design to satisfy the core safety limits with the high initial excess reactivity needs to be investigated. Validity of nuclear library and nuclear design code needs to be evaluated to be applicable to enrichment above 5 %. The fuel integrity also needs to be confirmed up to the very high burnup like 70~100 MWD/kgU. Fuel behavior under accident conditions such as LOCA and RIA has been investigated during last ten years and needs to be continued. The effect of higher enrichment and higher discharge burnup on the spent fuel management including both options of direct disposal and reprocessing need to be investigated. To decide whether it is worthwhile to go beyond the current 5 % U-235 limit, these factors need to be analyzed and the benefits to go beyond 5 % limit need to be demonstrated in both the economy and the environmental aspects.

3. Conclusion

Fuel discharge burnup of LWR fuel has been increased since its introduction in 1950s. LWR is expected to be the dominant power plant in next 20~30 years and beyond. As the fuel materials and design improves, it is right time to systematically investigate feasibility of going beyond the current U-235 enrichment limit 5 % to reach the burnup of 70~100 MWD/kgU.

Acknowledgement

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