# Preliminary Safety Evaluation of LWR Deep Burn Core

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## 1. Introduction

For effective management of high-level waste from light water reactors (LWRs), a modified open fuel cycle concept [1] that deeply burns recycled transuranics (TRUs) from LWR spent fuel in existing LWR fleet is proposed (hereinafter called LWR-DB (deep burn)). LWR-DB introduces a fully ceramic microencapsulated (FCM) fuel that can achieve super high burn-up, thus, to burns TRUs up to ~60% by a single irradiation. LWR-DB fuel assemblies contain both typical $UO_2$ pins and FCM fuel pins in which TRISO TRU particles are distributed in SiC matrix pellets. Assets of FCM fuel are its high thermal conductivity leading to low fuel temperature, thus initial stored energy, and the highly refractory and fission product (FP) retentive features of FCM pellet composed of TRISO particles and SiC matrix. In this work, the safety of LWR-DB core is preliminarily evaluated for reference plant, YGN 3&4 using MARS3.1. Major accidents analyzed are the large break loss-of-coolant accident (LBLOCA) and loss-of-flow-accident (LOFA).

## 2. Analysis Methods and Models

Safety of LWR-DB core was preliminarily evaluated for reference plant, YGN 3&4, using MARS3.1 [2], a realistic system thermal-hydraulic analysis code. Accident analyses are performed for the cold leg LBLOCA and complete LOFA that are limiting transients for key safety parameters, peak cladding temperature (PCT) and minimum departure-from-nucleate-boiling (MDNBR).

Fig. 1 shows a reference configuration of LWR-DB fuel assembly and core modeling concept. Core is modeled in hot and average flow channels each of which contains lumped typical $UO_2$ pins and TRU FCM pins. Hottest pins are also added in the hot flow channel for detailed evaluation of key safety parameters. In the analysis, thermal properties of a TRU FCM pin are modeled based on its composition and irradiated properties [3]. And, the core physics parameters such as power distribution and core kinetic parameters that are obtained from preliminary core neutronics exploration study [4] were used. For the LBLOCA analysis, two cases for the safety injection (SI) performance were assumed; 100% SI available and 50% SI available (single failure). AECL look-up table is used for calculating the MDNBR.

Analysis was carried out to compare steady state performance of the $UO_2$ and TRU FCM fuels. Then, a scoping analysis was performed to quantify the sensitivity of core physics parameters on the LBLOCA and LOFA performance using YGN3 cycle6 DB core. Finally a safety margin of YGN3 DB equilibrium core was assessed using a set of limiting core physics parameters based on the results of the scoping studies.

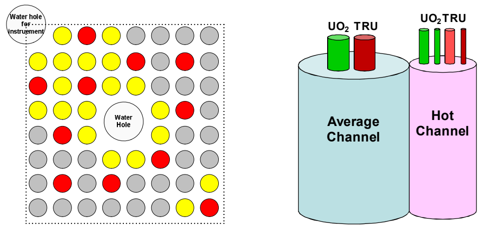
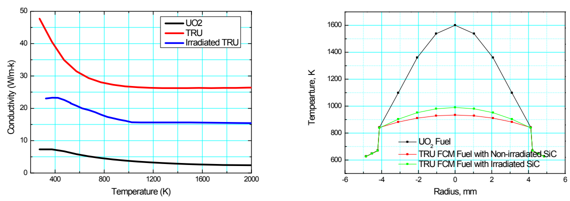



Fig. 1. LWR-DB Fuel Assembly Configuration and Modeling

## 3. Analysis and Result

### *3.1 Steady State Fuel Performance*

Thermal conductivities of $UO_2$ and TRU FCM pellets and their steady state temperature profiles at full power operating conditions are given in Fig. 2. It is shown that the TRU FCM fuel has quite lower fuel centerline temperature than the $UO_2$ fuel due to high thermal conductivity of SiC matrix pellet. This implies that there are more margins to LBLOCA due to lower internal energy.




*Thermal Conductivities* *Fuel Temperature Profile*

Fig. 2. Comparison of $UO_2$ and TRU FCM Fuel Performance

### *3.2 Scoping Analysis*

In order to identify limiting core physics parameters on the LBLOCA and LOFA performance, sensitivity analysis has been carried out using YGN3 cycle6 DB core physics parameters. Ranges of selected parameters are given in Table 1. Axial power shapes applied are reference 1.5 peaked shapes. Also given are the limiting cases for the LBLOCA and LOFA. These limiting parameters are used in the assessment of the YGN3 DB equilibrium core safety.

Table 1. Ranges of Core Physics Parameters and Identified Limiting Cases

| Parameters | Ranges | Limiting LBLOCA | Limiting LOFA |
|---|---|---|---|
| Radial Peaking Factor (Fr) | Multiplier: 1.0 – 1.3 | High | High |
| Moderator Density Coeff. | Multiplier: 0.1 - 10.0 | *Least Negative* | N/A |
| Delayed Neutron Fraction | Least / Most | Most | Most |
| Axial Power Shape | Top, Cosine & Bottom | Top | Top |

### *3.3 LWR-DB Equilibrium Core Analysis*

Safety of YGN3 DB equilibrium core is assessed using core physics parameters obtained from reference [4]. A set of limiting core physics parameters is selected based on the scoping analysis results. Since the axial power shapes of the DB equilibrium core were specified at the beginning, middle and end of cycles (BOC, MOC, EOC) as shown in Fig. 3, additional sensitivity analysis was performed to identify a limiting cycle states. It was found that, in LBLOCA, BOC is the most limiting state for the blowdown PCT while MOC is the most limiting for the reflood PCT and that, in LOFA, BOC is the most limiting state as to the MDNBR.

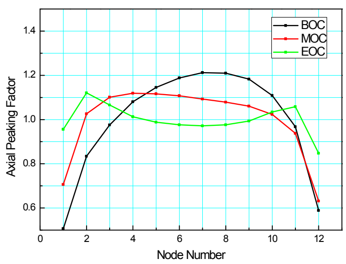
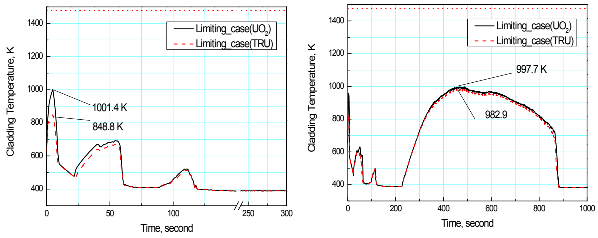



Fig. 3, Axial power shapes of YGN3 DB equilibrium core

Fig. 4 shows the limiting PCT transients during LBLOCA. It is found that PCT of the DB equilibrium core meet the safety criterion, PCT < 1473K. Both the blowdown PCT at BOC and the reflood PCT at MOC occur in the $UO_2$ fuel and they are 1001.4K and 997.7K respectively. The blowdown PCT of the TRU FCM fuel is 848.8K and is quite lower than that of the $UO_2$ fuel, since initial stored energy of the TRU FCM fuel is lower due to its high thermal conductivity. The reflood PCT is slightly lower for the TRU FCM fuel, since core decay heat is already redistributed inside fuel.

Fig. 5 shows the limiting DNBR transients during LOFA. MDNBRs are 2.322 for the $UO_2$ fuel and 2.462 for the TRU FCM fuel. MDNBR occurs in the $UO_2$ fuel, however, meets the safety limit, MDNBR > 1.3.




*Blowdown PCT at BOC (100% SI)* *Reflood PCT at MOC (50% SI)*

Fig. 4. PCT Transients during LBLOCA

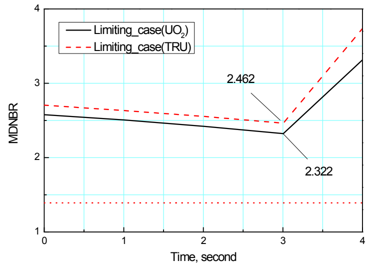



Fig. 5. DNBR Transients during LOFA

## 4. Conclusions

Preliminary safety evaluation of the LWR-DB core has been carried out referencing YGN 3 System 80 plant. It is found that the TRU FCM fuel has more margins to safety due to its high thermal conductivity and that the DB core proposed by core physics design meets the safety criteria with sufficient margins in both LBLOCA and LOFA limiting scenarios. In conclusion, deep burn of the TRUs from LWR spent fuel using a System 80-type core has been demonstrated feasible.

## REFERENCES

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