# Simulation Study on CANDLE Burnup of High Temperature Gas Reactor

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## 1. Introduction

### *1.1 What Is CANDLE Burnup?*

The CANDLE (**C**onstant **A**xial shape of **N**eutron flux, nuclide densities and power shape **D**uring **L**ife of **E**nergy producing reactor) burnup strategy is a new reactor burnup concept, where the distributions of fuel nuclide densities, neutron flux and power density move with the same constant speed along the core axis from bottom to top or from top to bottom of the core and without any change in their shapes (see Fig. 1). [1]

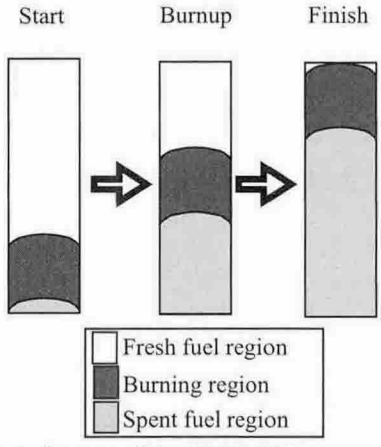


Fig. 1. Concept of the CANDLE burnup strategy

### *1.2 Application of CANDLE Burnup to Block-type High Temperature Gas Cooled Reactor*

In the case of application of CANDLE burnup to block-type high temperature gas cooled reactor, burnable poison is used. [2] Fresh fuels are adjusted to be sub-critical by the burnable poison. If the burning region comes to the fresh fuel region, the burnable poison burns up in a much shorter time than the fissile material, and then the fissile material starts the fission chain reaction. In this analysis, the natural gadolinium is employed as the burnable poison and mixed with the enriched uranium in the fuel kernel.

### *1.3 The Purpose of the Present Study*

The CANDLE burnup is difficult to be analyzed directly, because the burning region moves. Therefore, it is analyzed in two stages, the steady state analysis and the simulation analysis (time dependence analysis). In the previous study [2], Only the core characteristics in the steady state are investigated. In the present study, burnup simulation analysis is performed at the steady state and the startup.

## 2. Calculation Scheme

### *2.1 Calculation Flow*

Since a CANDLE burnup strategy is a strategy that the burning region moves, the nuclides burnup equation takes into account the movement of the burning region. The present analysis uses a newly developed steady state CANDLE burnup analysis code system and conventional simulation code system. The steady state is the state where time has fully passed from the start up, and the CANDLE condition is satisfied in the strict meaning. Solutions are obtained by solving the simultaneous equations of nuclide burnup and neutron diffusion. The obtained nuclide number densities of steady state analysis are used as inputs for the simulation analysis.

### *2.2 Double Heterogeneity Cell Calculation*

The cell calculation employs double heterogeneity model for treating TRISO coated fuel particles. In the present analysis, the cell calculation is performed for the fuel cell like the HTTR of JAERI [3]. The fuel compact region consists of TRISO coated fuel particle and graphite matrix, which is treated as the micro heterogeneity cell. The cell calculation is performed using the collision probability routine of SRAC code system [4] with JENDL-3.2 nuclear data library [5].

### *2.3 Simulation Calculation*

In this study, the simulations of steady state and start up are analyzed.

(1) Steady state simulation
In order to confirm the results of the steady state analysis, the burnup calculation is performed with the nuclide number densities obtained in the steady state analysis as the input.

(2) Startup simulation (Making of the initial fuel core)
The initial fuel core composition is constructed so that the core remains critical during the transient to steady state with small burnup excess reactivity and small transient time.

Table 1 Design Parameters

| | |
|---|---|
| Thermal Power [MW] | 30 |
| Fuel Cell Model | Pin-in-Block Type (HTTR Type) |
| Fuel Type | TRISO Coated $UO_2$ Fuel Particle |
| Kernel Diameter [mm] | 0.60 |
| Coating Material<br>Thickness [mm]<br>Density [g/cm$^3$] | PyC / PyC / SiC / PyC<br>0.060 / 0.030 / 0.030 / 0.046<br>1.143 / 1.878 / 3.201 / 1.869 |
| Packing Fraction [%] | 30.0 |
| Uranium Enrichment [%] | 15.0 |
| Gadolinium Concentration (in Kernel) [%] | 3.0 |
| Compact Inner / Outer Diameter / Sleeve Outer Diameter / Block Inner Diameter [cm] | 1.00 / 2.60 / 3.40 / 4.10 |
| Fuel Cell Pitch [cm] | 6.60 |
| Core Diameter / Height / Reflector Thickness [cm] | 230 / 1200* / 100 |

* This value is only for the calculation to obtain ideal CANDLE shape. In the real design much smaller values are employed.

## 3. Calculation Results

### *3.1 Steady State Simulation*

In order to check the accuracy of the steady state calculation, the nuclide densities obtained from the steady state analysis is used for transient analysis. Obtained change of effective neutron multiplication factor along burnup from the start up is shown in Fig. 2. And the change of the nuclide densities and neutron flux are shown in Fig. 3. The shapes of the nuclide density distributions and the neutron flux remain unchanged and move to the fresh fuel region. The reactivity change during the burnup is very small. From these results, the steady state analysis is considered to be correctly performed.

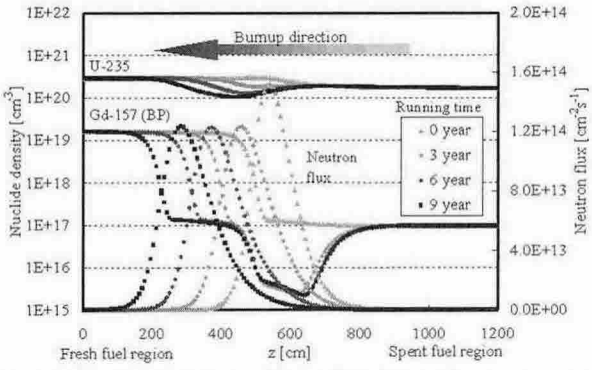


Fig. 2 Effective neutron multiplication factor along burnup for the steady state simulation

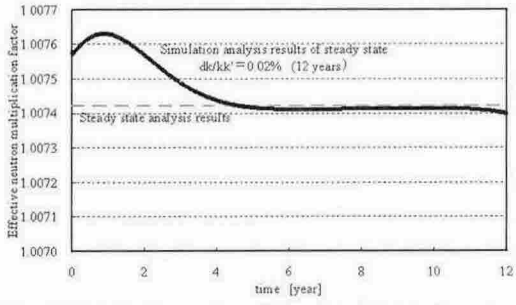


Fig. 3 Distributions of nuclides densities and neutron flux on the reactor core axis for the steady state simulation

### *3.2 Startup Simulation*

The initial core is constructed by easily available nuclides. Gadolinium nuclides are adjusted to give the same values of the macroscopic absorption cross section. Heavy metal nuclides are replaced by the U-235 to give the same value of the macroscopic fission cross section, and the fission products are replaced by the neodymium. The simulation result is shown in Fig. 4. And the change of the nuclide densities and neutron flux are shown in Fig. 5. The maximum reactivity change of 1.7% appears at burnup time of 0.7 years. At initial core (0 year), the neutron flux is too high, therefore the balance of the nuclides densities distribution is broken. In the actual design, the optimization of constructed initial core should be performed by adjusting the nuclide number densities by trial and error in addition to the present technique.

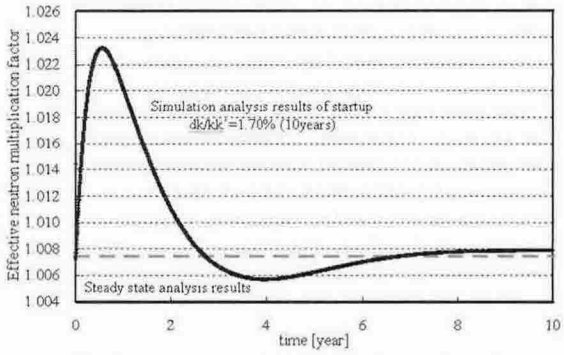


Fig. 4 Effective neutron multiplication factor along burnup for the startup simulation

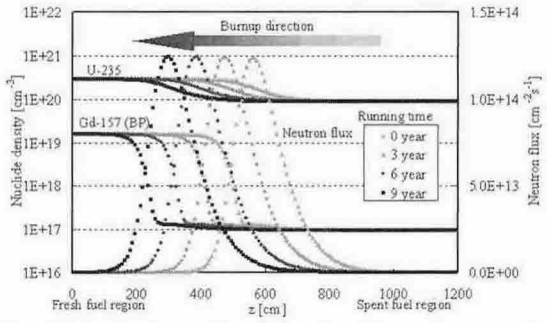


Fig. 5 Distributions of nuclides densities and neutron flux on the reactor core axis for the startup simulation

## 4. Conclusion

In this study, the simulation analysis of steady state and startup is performed.

1, For the steady state simulation with the direct solutions of steady state nuclide densities as inputs, the difference between the results of steady state analysis and simulation analysis is very small. From these results, the steady state analysis is considered to be correctly performed.

2, When the initial core is constructed by easily available nuclides, the reactivity change of 1.7% appears at burnup time of 0.7 years.

## REFERENCES

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