Simulation Study on CANDLE Burnup Applied to Block-Type High Temperature Gas Cooled Reactor

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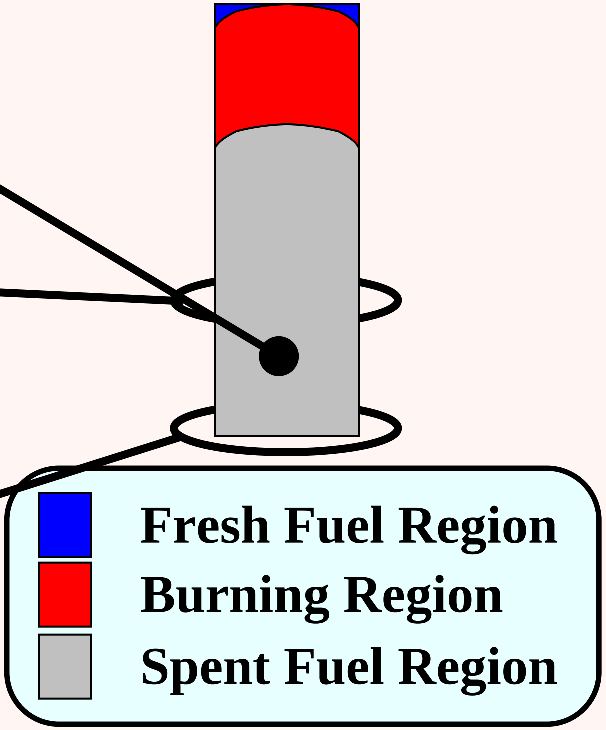
What Is CANDLE Burnup?

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; the burning region **moves automatically** along the core axis from bottom to top (or from top to bottom).

In the burning region, the fissile material burns and produces neutrons and energy.

In the front side of burning region, neutrons leak to the fresh fuel region.

In the back side of burning region, fission products are accumulated.



Features of CANDLE Burnup

Merits

1) The excess burnup reactivity becomes zero. Burnup reactivity control mechanism is not required.

2) Reactor characteristics do not change with burnup. (e.g. power peaking, reactivity coefficients.)

3) Radial power distribution can be optimized more thoroughly.

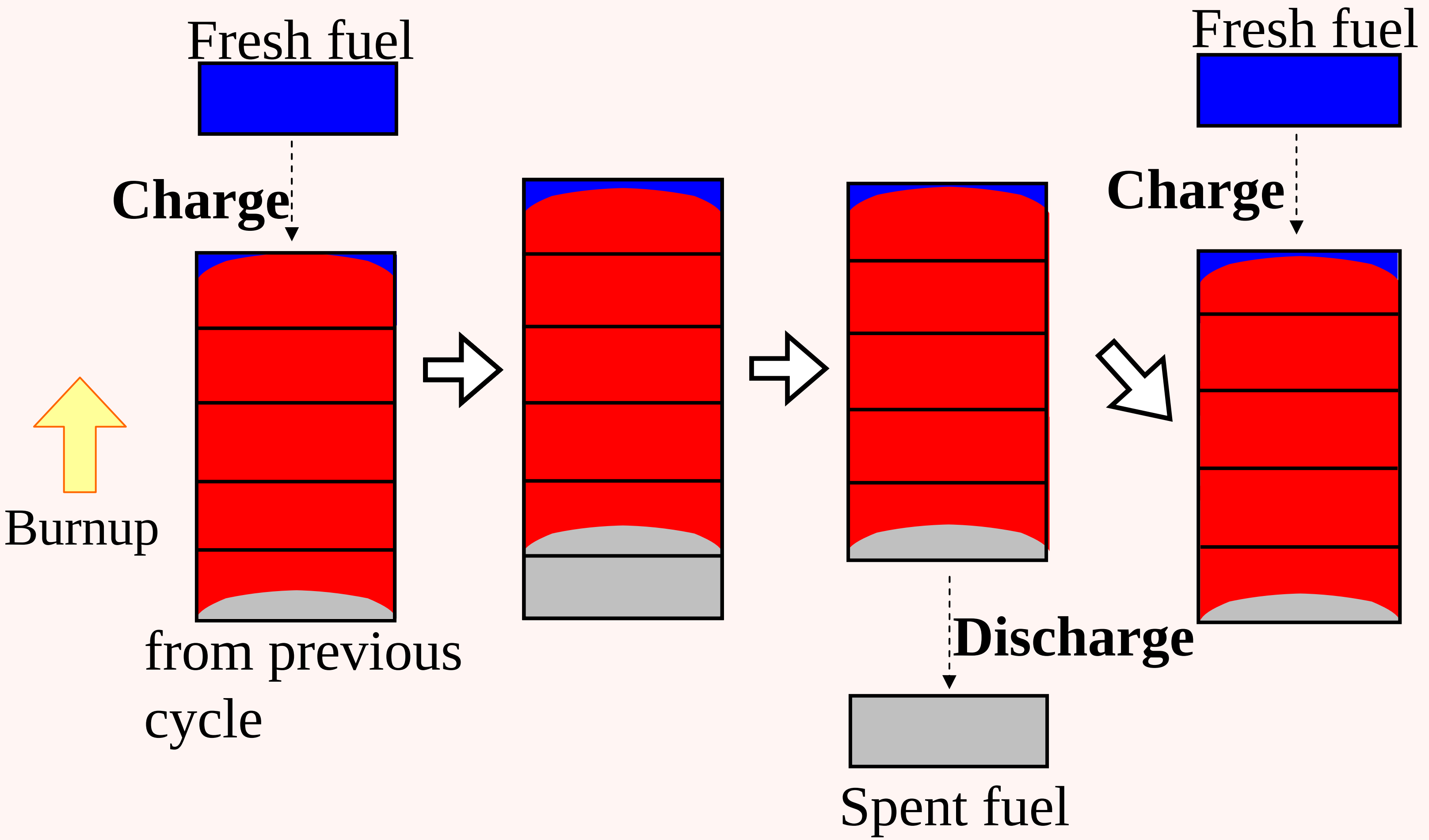
4) Design of long-life reactor core becomes easier.The core height is proportional to a reactor core life.

5) Infinite neutron multiplication factor of fresh fuel is less than unity. Transportation and storage of fresh fuel are safe and easy.

Demerit

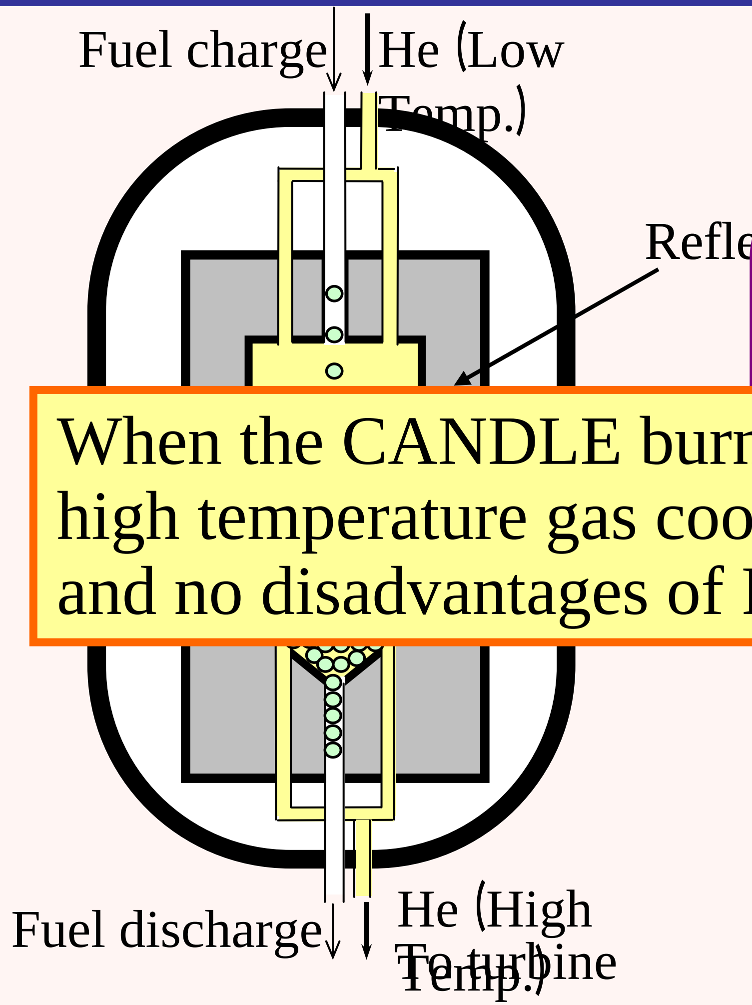
*) To construct initial fuel core composition is difficult. Needs of the core remains critical during the transient to steady state with small burnup excess reactivity and small transient time.

CANDLE Burnup Refueling Concept



"DARUMA OTOSHI" concept

Type of High Temperature Gas Cooled Reactor



Pebble-bed type

Features of Pebble-bed type in comparison with Block type

ADVANTAGES

1, The excess burnup reactivity becomes zero.

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When the CANDLE burnup is applied to Block type high temperature gas cooled reactor, it has advantages and no disadvantages of Pebble-bed type reactor.

DISADVANTAGES

1, The refueling equipment is complicated.

2, Contact between fuel pebbles during their movement may cause fuel damage.

3, The fuel position cannot be identified.

Block type does not have these.

CANDLE Burnup Application to Block-Type High Temperature Gas Cooled Reactor

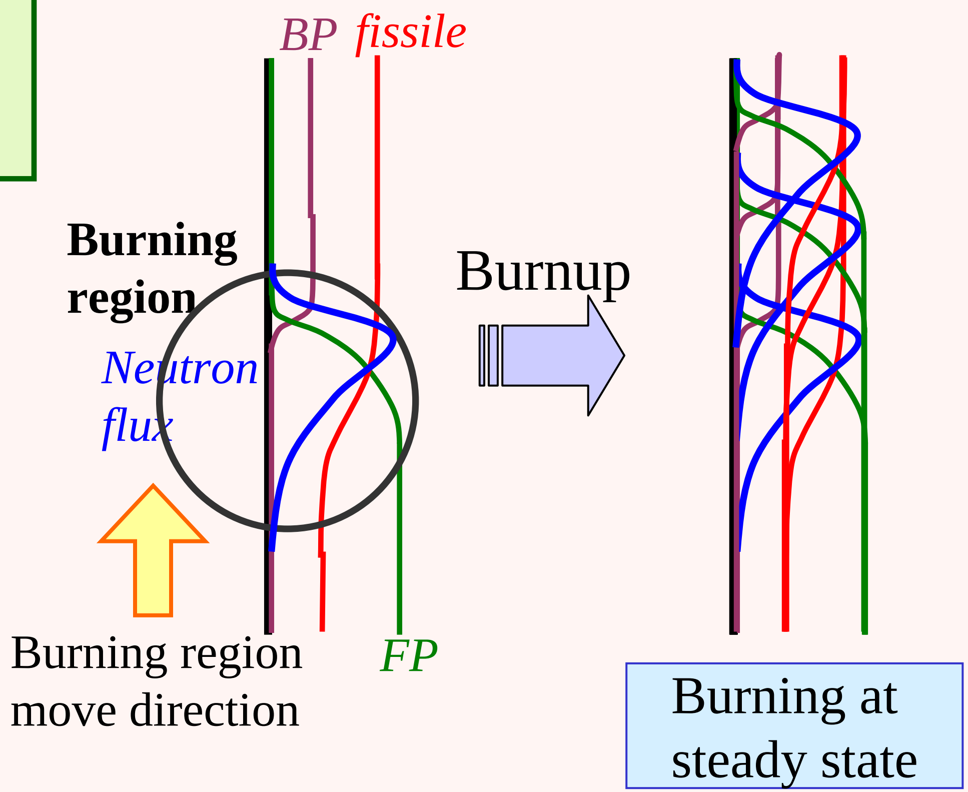
The fresh fuel is constructed with fissile material and burnable poison.

When neutron flux becomes larger,

the **BP** decreases by absorption for short time.

After then **fissile nuclides** decrease and

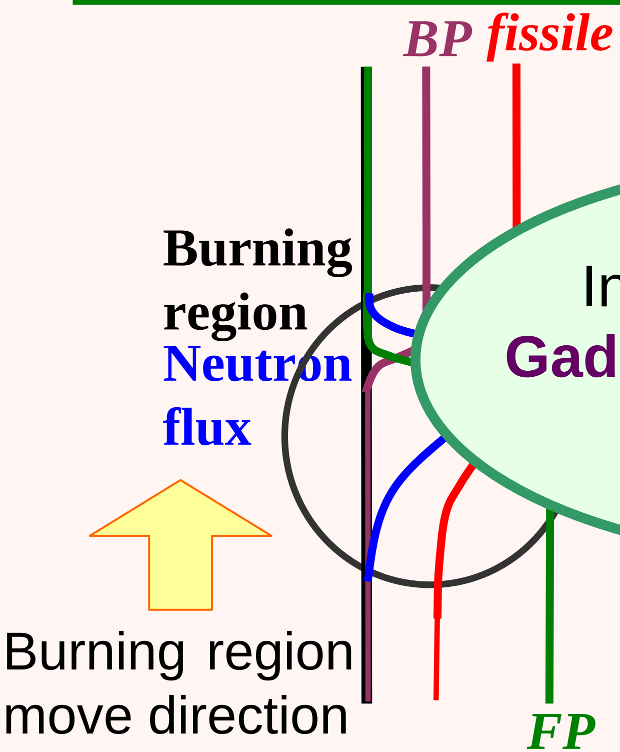
FPs increase by fission reactions.



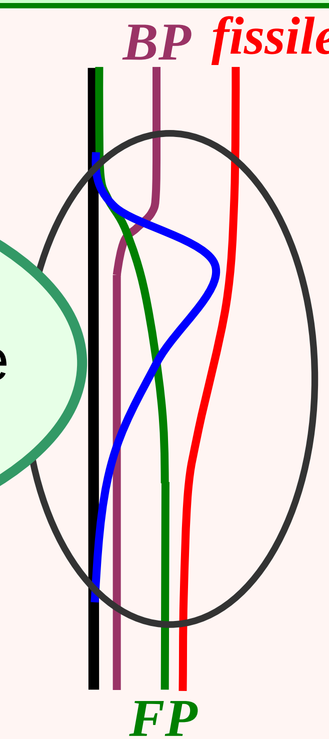
BP; Burnable Poison
FP; Fission Products

Feasibility of CANDLE Burnup

The thermal microscopic absorption cross section of burnable poison nuclides is important.



In this study, **Natural Gadolinium** is used as the burnable poison.



Feasibility condition

Core critical

and Fresh fuel subcritical

Infeasibility condition

Core subcritical

or Fresh fuel critical

CANDLE Burnup Analysis

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.

Input

Output

Fresh Fuel Composition

Reactor Design Parameters
- Thermal Power
- Core Size

etc…

Steady State Analysis Code System

Steady State Characteristics
- k-effective
- Burning Region Move Speed
- Neutron Flux Distribution
- Nuclides Density Distributions

Nuclides Density Distributions

Time Dependent Analysis Code System

Simulation
- Time Change of k-effective
- Time Change of Neutron Flux Distribution
- Time Change of Nuclides Density Distributions

The Purpose of This Study

In this study, the simulations of steady state and start up are performed by the steady state analysis results.

(1) Steady State Simulation

In order to confirm the results of the steady state analysis, the burnup calculation is performed with the nuclide densities obtained in the steady state analysis as the input.

(2) Startup Simulation (Construct 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.

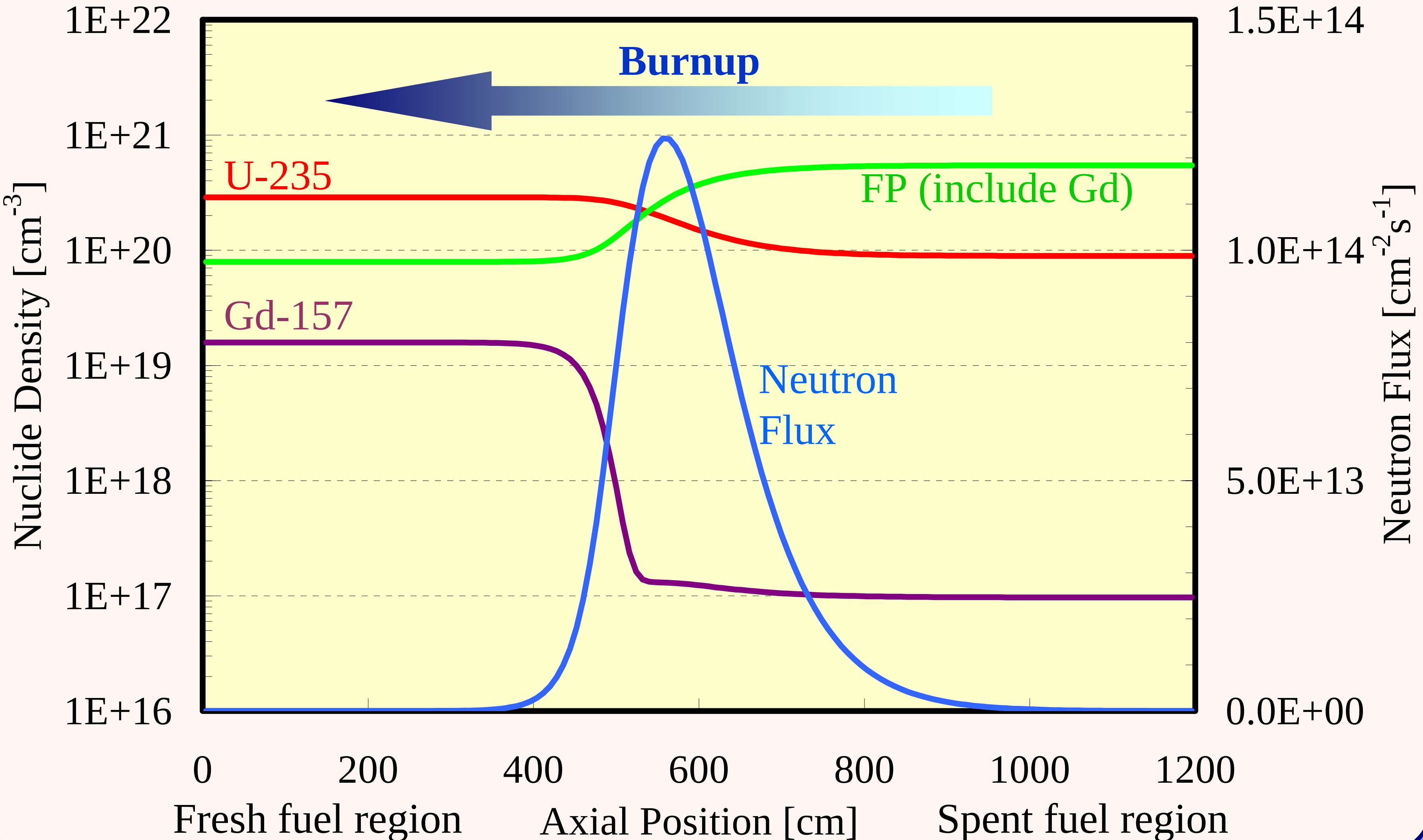
Design Parameters

Reactor Type	Block-Type High Temperature Helium Coolant Reactor
Thermal Power [MW_{th}]	30
Fuel Cell Model	Pin in Block Type (HTTR Type)
Fuel Type	TRISO Coated UO_2 Fuel Particle
Kernel / Particle Diameter [mm]	0.608 / 0.940
Coating Material Thickness [mm] Density [g/cm^3]	PyC / PyC / SiC / PyC 0.060 / 0.030 / 0.030 / 0.046 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

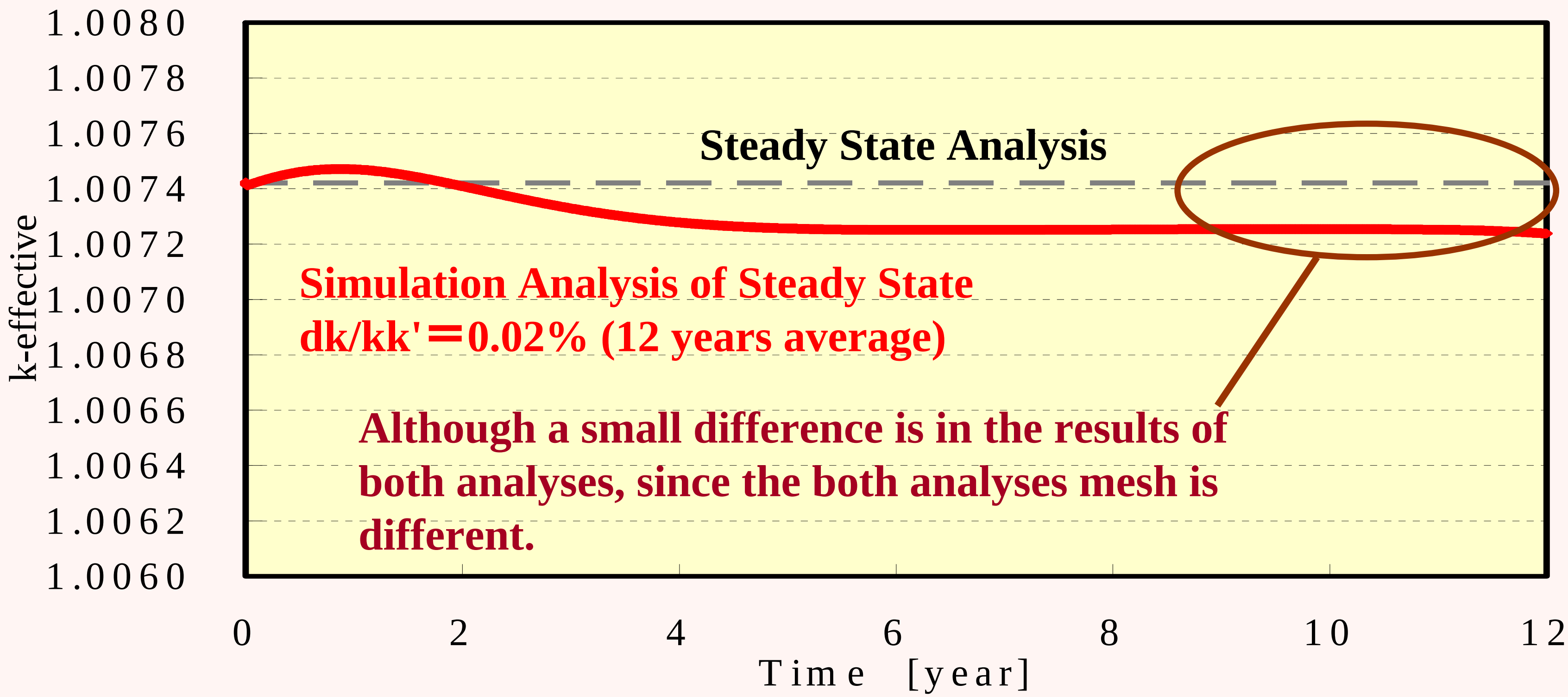
HTTR Type Fuel Cell Model

* This value is only fo… …l design much smaller values are employed.

Neutron Flux & Nuclide Densities on the Reactor Core Axis for the Steady State Analysis

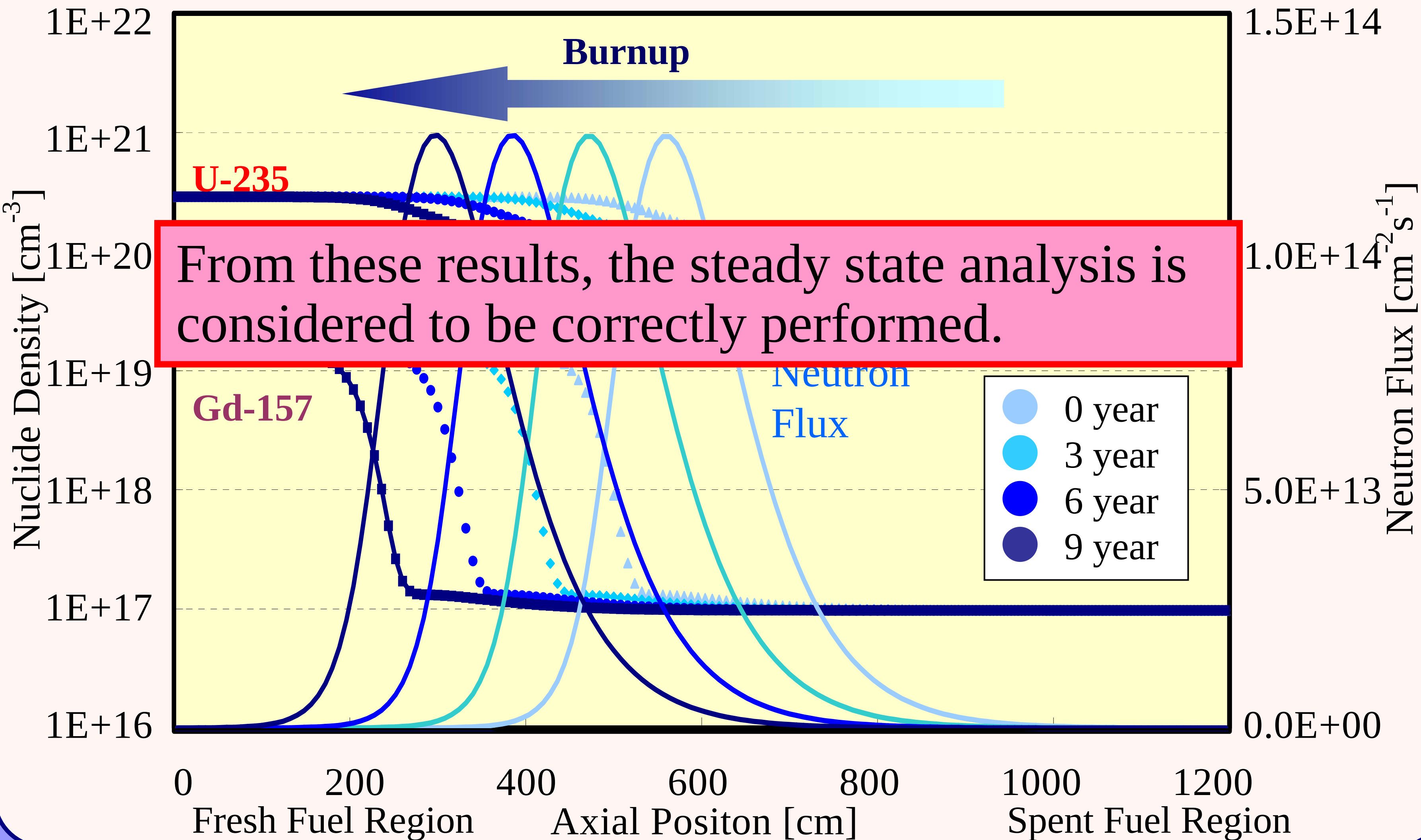


(1) Effective Neutron Multiplication Factor along Burnup for the Steady State Simulation



	Steady State Analysis	Simulation Analysis (12 years)
Effective Multiplication Factor	1.00742	1.00730
Burning Region Move Speed [cm/year]	29.2	29.1
Maximum Power Density [W/cm^3]	4.76	4.76
Half width of axial power shape[cm]	153.9	153.7

(1) Neutron Flux & Nuclides Densities on the Reactor Core Axis for the Steady State Simulation



From these results, the steady state analysis is considered to be correctly performed.

(2) How to Construct Initial Core

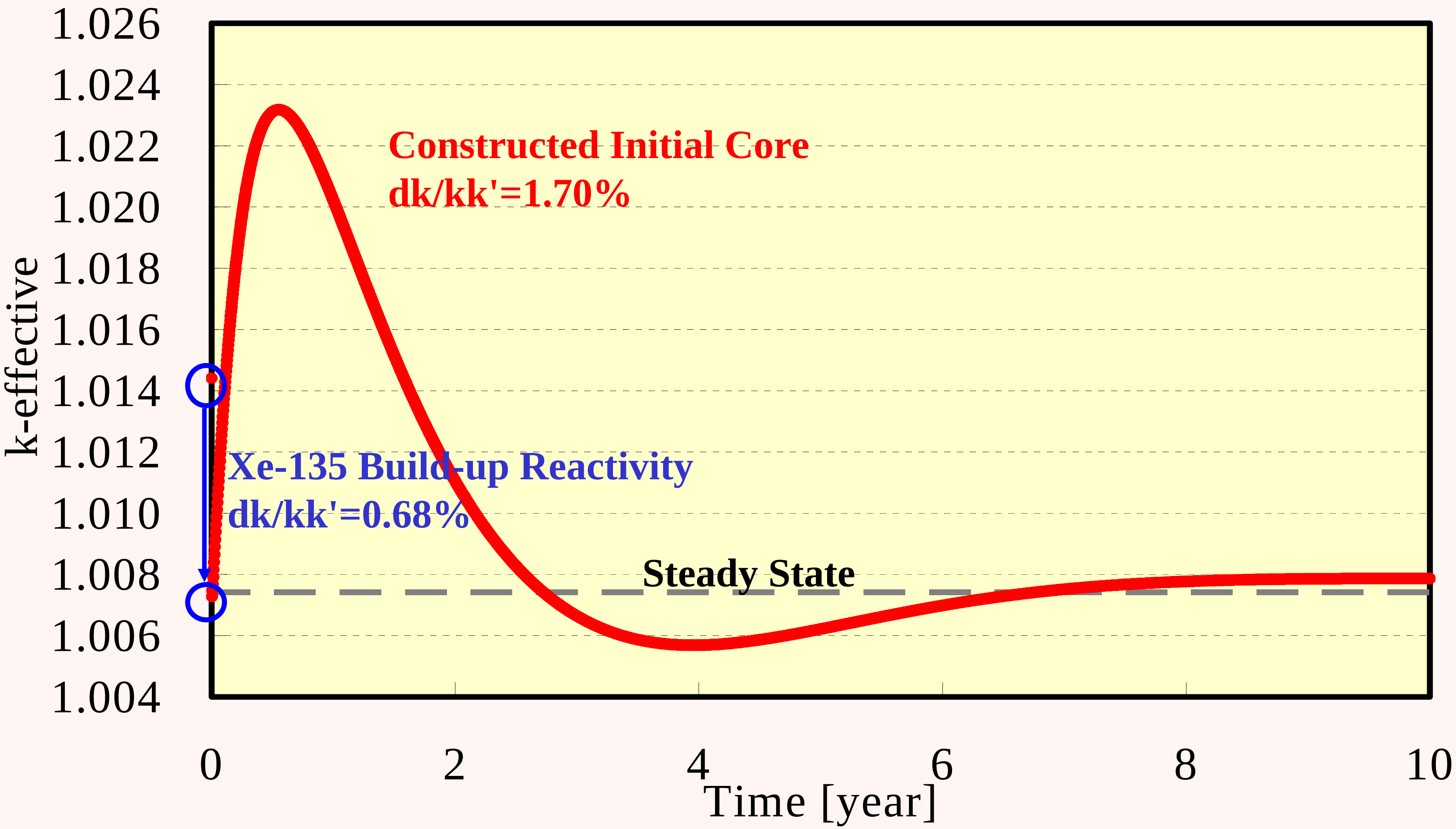
In this case, Gd-157 as the BP nuclide density distribution is most important.

Construct Nuclides Densities of Initial Core – Gd-157 Base

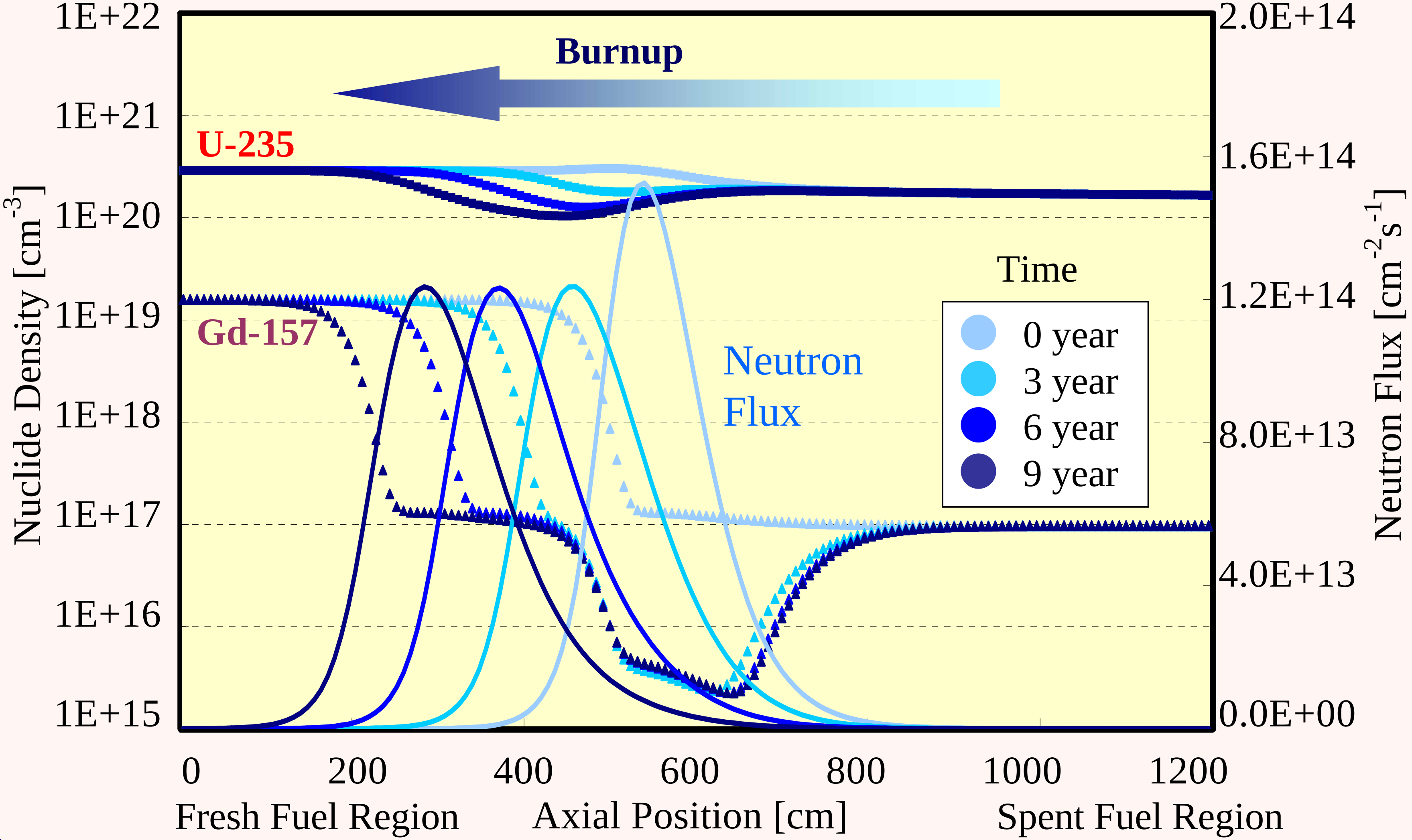
1. Gadolinium nuclides are adjusted to give the same values of the macroscopic absorption cross section.
2. Heavy metal nuclides are replaced by the U-235 to give the same value of the macroscopic fission cross section.
3. FPs are replaced by the neodymium as the near value of the macroscopic absorption cross section of FPs.

The initial core is constructed by easily available nuclides.

(2) Effective Neutron Multiplication Factor along Burnup for the Startup Simulation



(2) Neutron Flux & Nuclides Densities on the Reactor Core Axis for the Startup Simulation



Conclusions

In this study, the simulation analysis of steady state and startup are 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. In the actual design, the optimization of constructed initial core should be performed by adjusting the nuclide densities by trial and error in addition to the present technique.