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Study of Tritium Production for Fusion Reactors Using High-Temperature Gas-Cooled Reactors

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How to stably supply a sufficient amount of tritium to

(1) initial fusion power generation reactor
(2) the subsequent startup of the power generation reactors

is an important problem to be solved at an early stage.

- In 90s, the tritium breeding ratio (TBR) and inventory required for startup of the fusion power reactor had been evaluated as 1.10 and 27.6 kg respectively.

  (Asaoka, et al., FT 1996)

- We do not have any actual plans to provide 20~30 kg of tritium to the first power-generation fusion reactor.

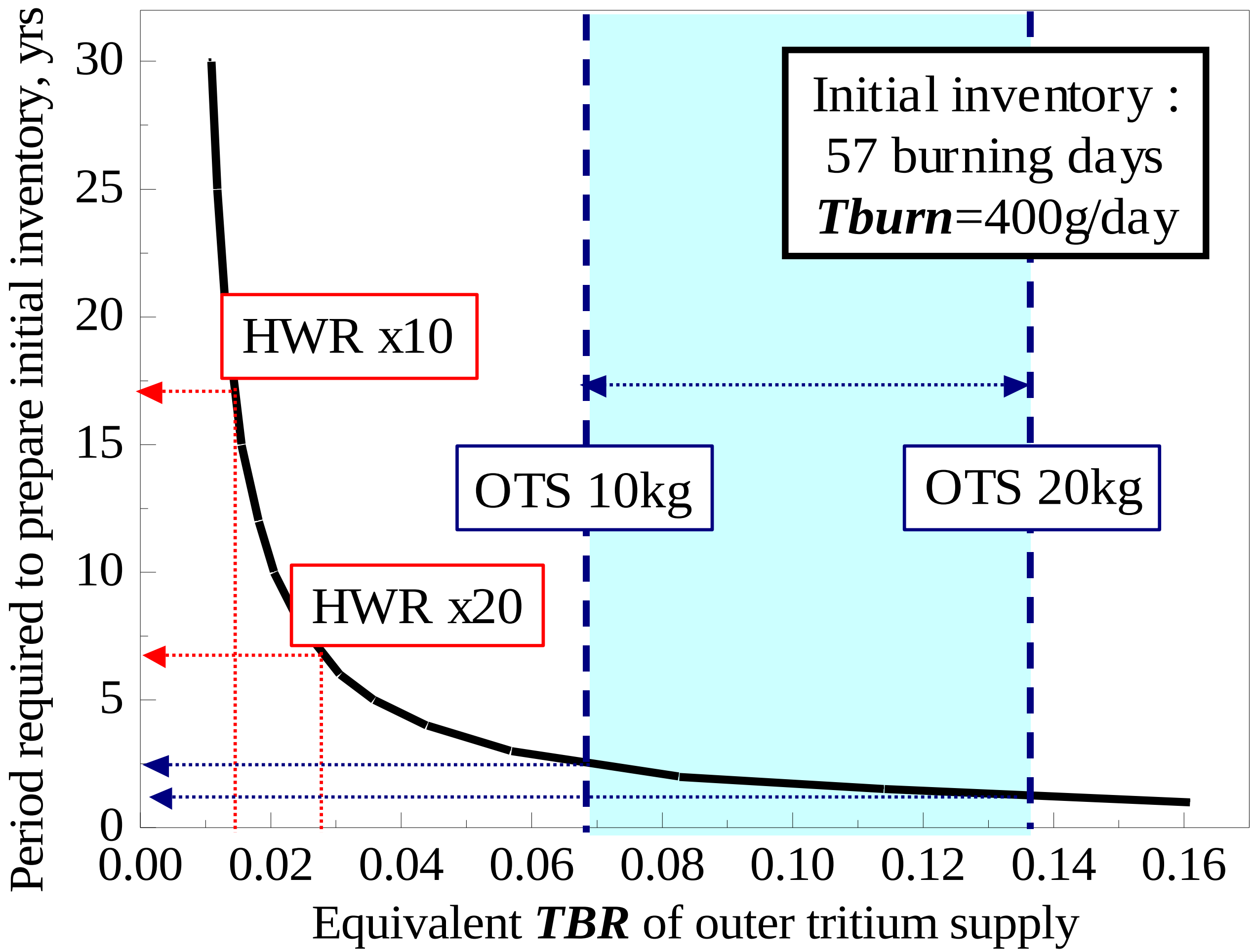
  Recently it was revealed that tritium retention in the plasma vessel have not been taken into account in the previous evaluations.

  (Roth, Nucl. Mater. 2009, Nishikawa, FST 2011)

The uncertainties of the tritium-supply scenario seem to be still increasing.

To secure tritium supply to the first and subsequent fusion reactors at an early stage, it is important to prepare an additional plan to stably supply an adequate amount of tritium.

Period required to prepare initial tritium inventory
(How much the outer tritium source (OTS) reduces the required TBR ?)



evaluated by **M.NISHIKAWA**

(presented at annual meeting of Atomic Energy Society of Japan, 2011)

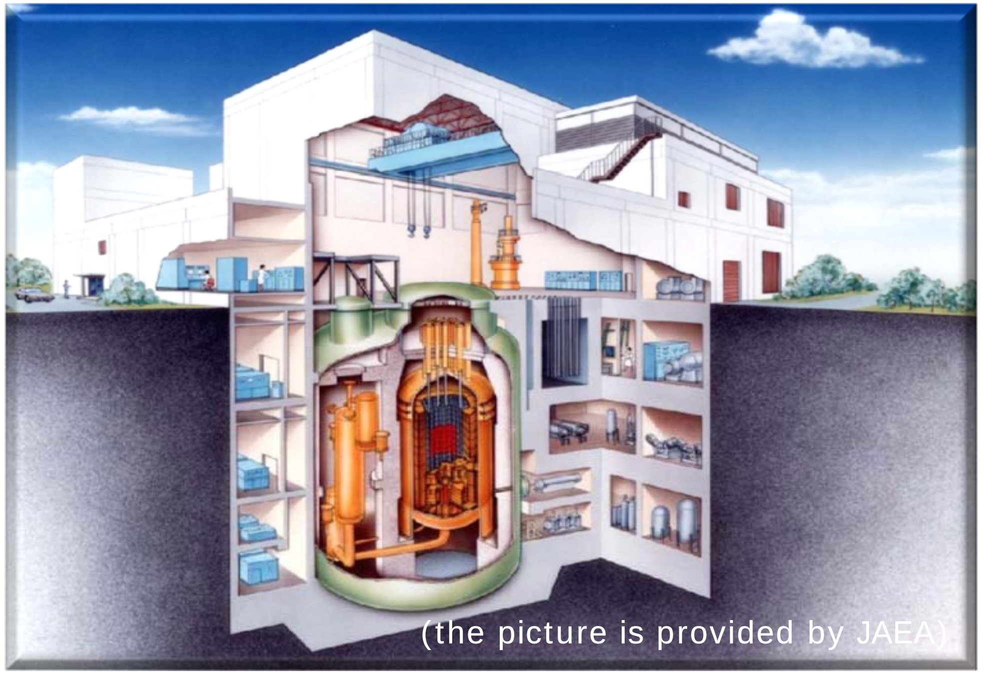
If 10kg of tritium (TBR of 0.07) is provided by any outer tritium source in a year, the initial inventory of the tritium required for fusion reactor can be prepared in 2.5 years.

High Temperature Gas-Cooled Reactor

- High efficiency electric-power generation using the ***gas turbine***.
- High temperature ***heat source***.

HTTR (High Temperature Engineering Test Reactor)

...... operated by Japan Atomic Energy Agency (JAEA)


(the picture is provided by JAEA)

Thermal Output	:	30 MW
Moderator	:	graphite
Coolant	:	helium gas

1991.03	Beginning of Construction
1998.11	First Criticality
2004.04	30MW thermal output 950 ℃ outlet coolant temperature
2007.05	30days continuous operation

⇨ conceptual design study for commercial-base gas-cooled reactor

GTHTR300 (Gas Turbine High Temperature Reactor of 300MWe)

(X.YAN, et al., Nucl. Eng. Des., **222**, 247 (2003).)

Advantage of Gas-Cooled Reactor for Nuclear Transformation

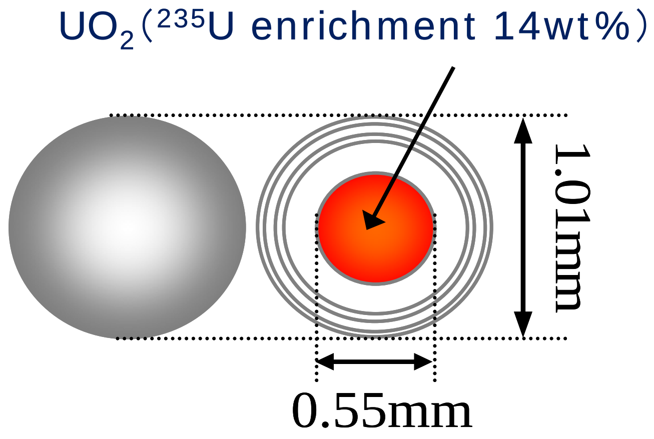
In general a gas-cooled reactor is designed to allow high-temperature operation and provide a high-temperature heat source.

The heat-resistant design is advantageous to the nuclear transformation.

(1) neutron economy (absorption)

Moderator : Graphite, Coolant : Helium gas

	H_2O	C	He
Σ_a [cm^{-1}]	2×10^{-2}	3×10^{-4}	2×10^{-7}



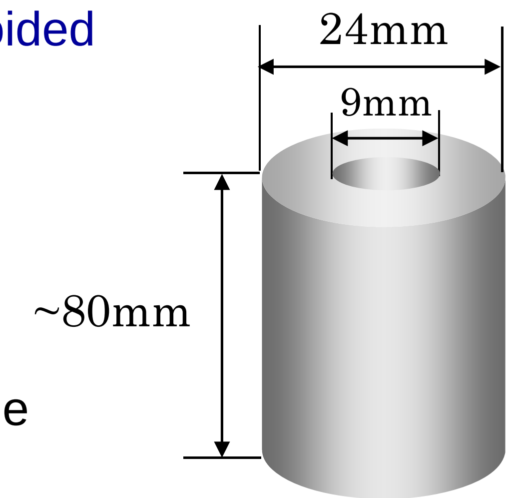
useless consumption of thermal neutrons can be avoided

(2) use of ceramic-coated fuel particle

to reduce local heat (power) density

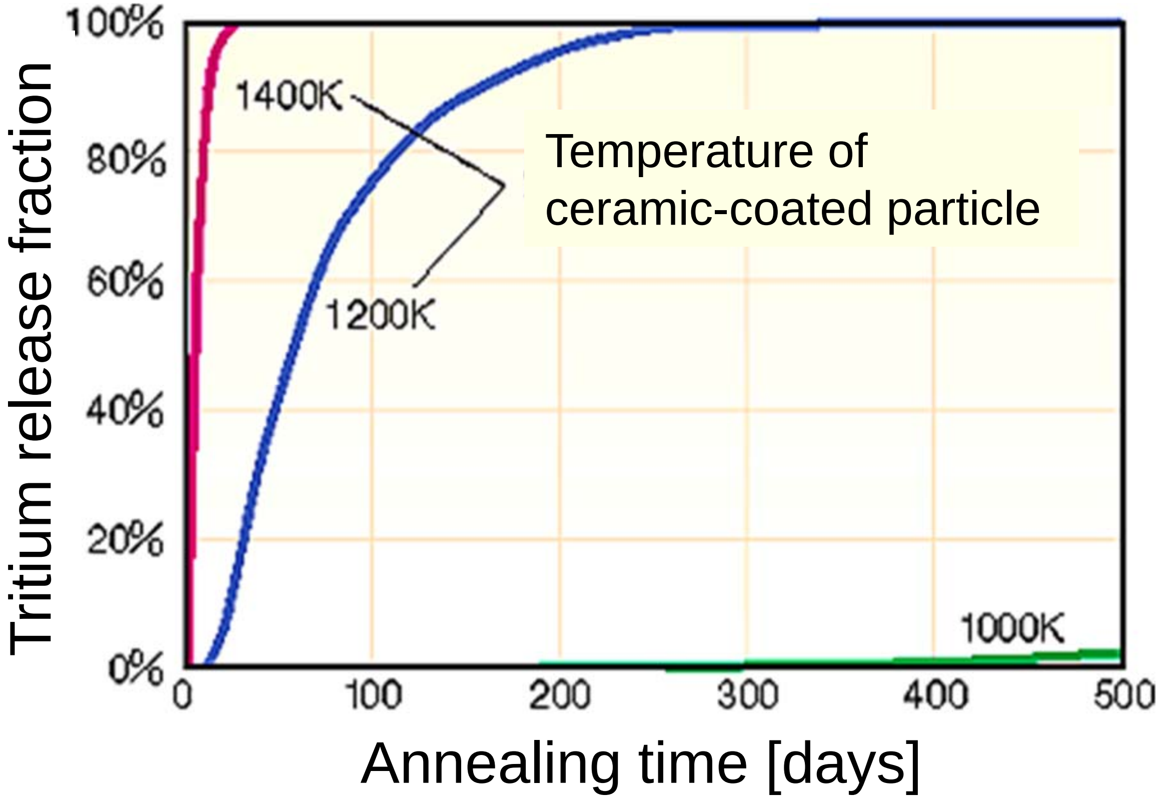
averaged fuel density becomes lower

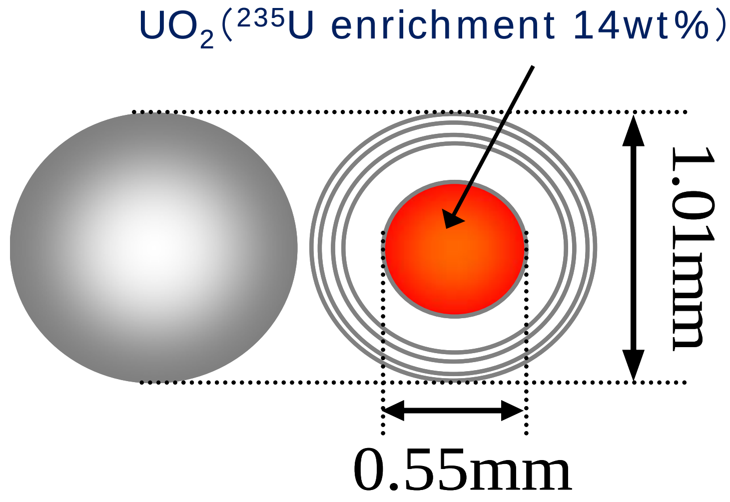
enough space to load a large amount of transmutable nuclear compounds close to the fuel region.



(3) secure containment of FP (transmuted nuclei)

Previously use of ceramic-coated particle in the Fusion Reactor Blanket was considered and Li-containment performance was evaluated.





K.YAMASHITA, et al.,
J. Atomic Energy Society of Japan,
40, 65 (1998). (in Japanese)

(kernel: $LiAlO_2$, coating: Al_2O_3
^6Li enrichment 95wt%)

By controlling the temperature of the ceramic-coated particles within an adequate range during the operation, tritium produced could be contained in the particles.

In this study we examine the possibility and performance of a gas-cooled reactor GTHTR300 as a tritium production device from the viewpoint of reactor physics by numerically evaluating the total amount of tritium produced.

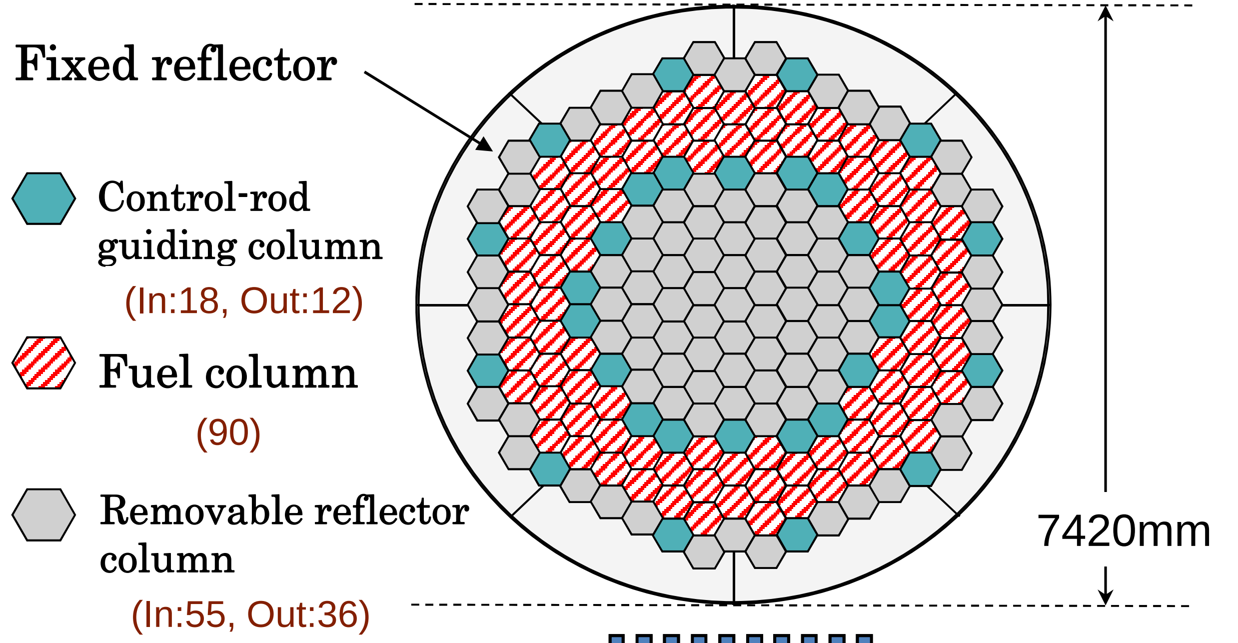
Core structure

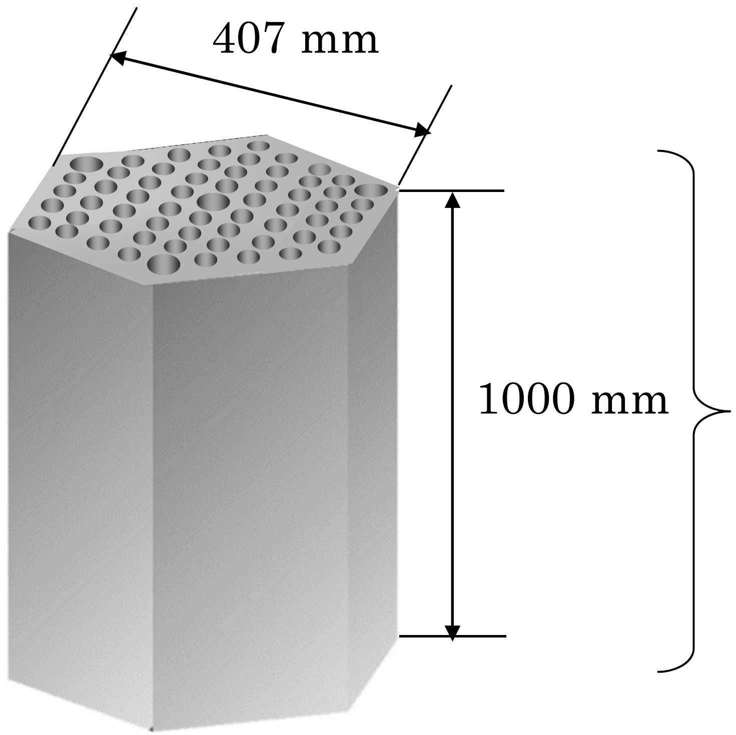
GTHTR300

(X.YAN, et al., Nucl. Eng. Des.,**222**, 247 (2003).)

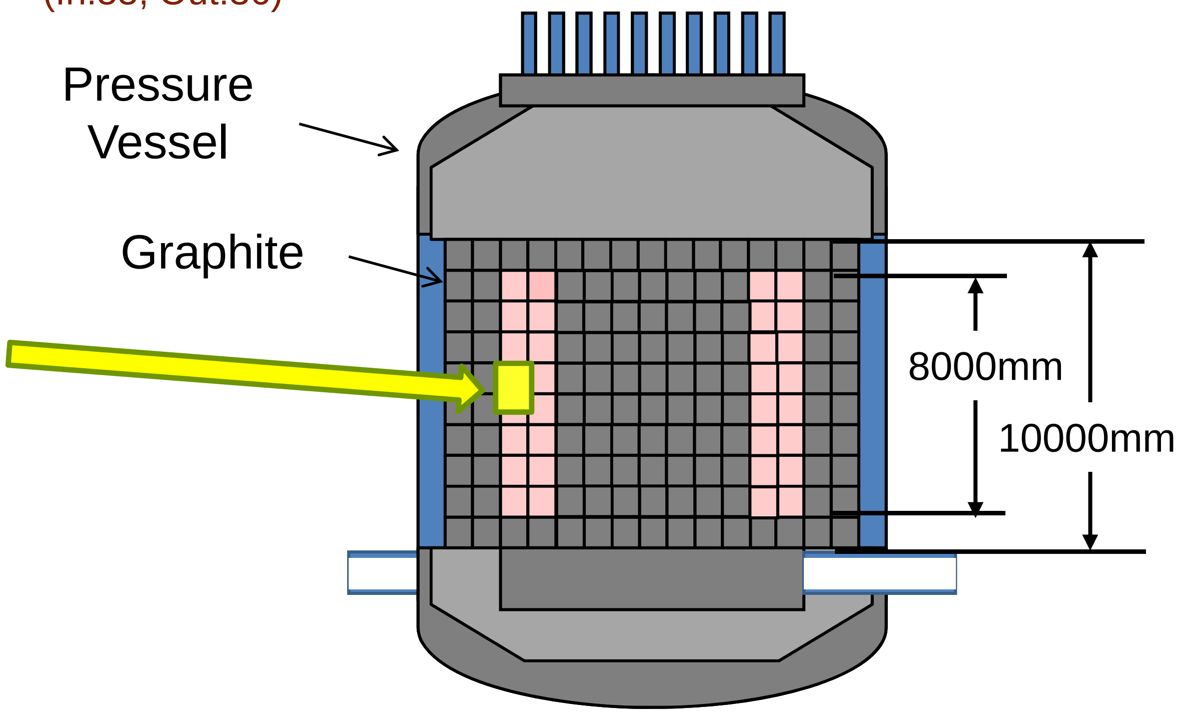
Thermal Output : 600MWt
^{235}U enrichment : 14wt%
Fuel Temp. : 1350K
Moderator Temp. : 1200K

Horizontal cross section of GTHTR300 core.

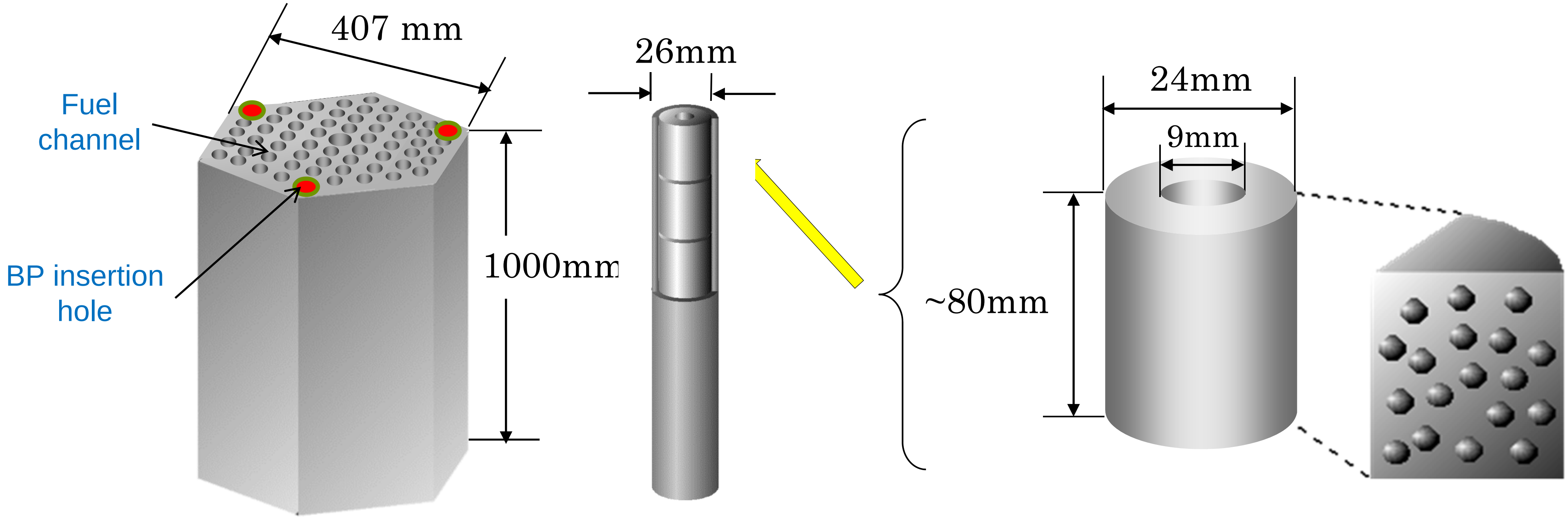




Hexagonal Graphite Block



Vertical cross section of GTHTR300 core.



Hexagonal Graphite Block

Fuel Rod

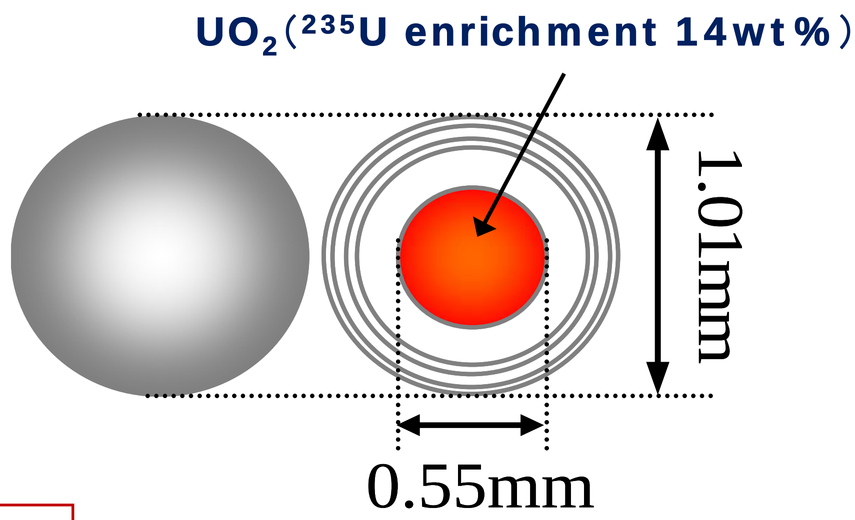
Fuel Compact

continuous-energy Monte Carlo transport code **MVP-BURN**

Okumura K., Mori T., Nakagawa M., and Kaneko K., J. Nucl. Sci. Technol., 37,128(2000)

The nuclear data are taken from JENDL-3.3.

As a first step, all BP holes were assumed to be empty and all control rods were assumed to be pulled out of the core.

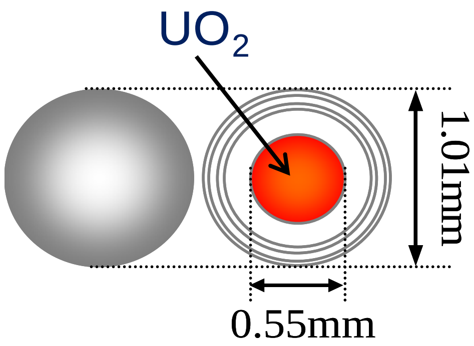


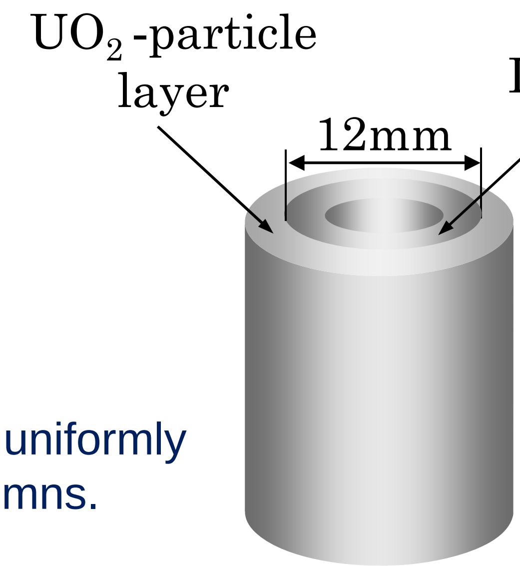
Ceramic-Coated Fuel Particle

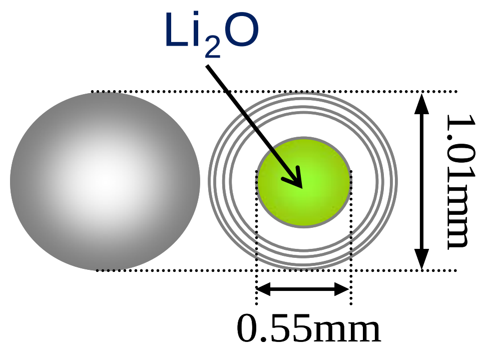
Calculation Conditions

The natural abundance of ^{6}Li (7.5%) was assumed.

(A) Use of Li_2O / UO_2 "*mixed compact*"



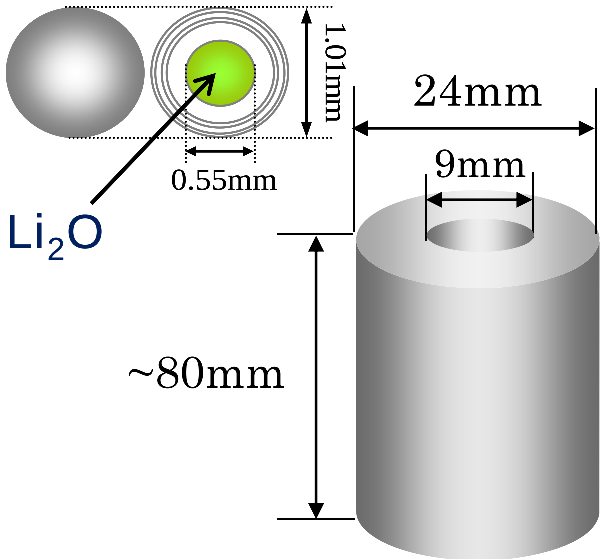


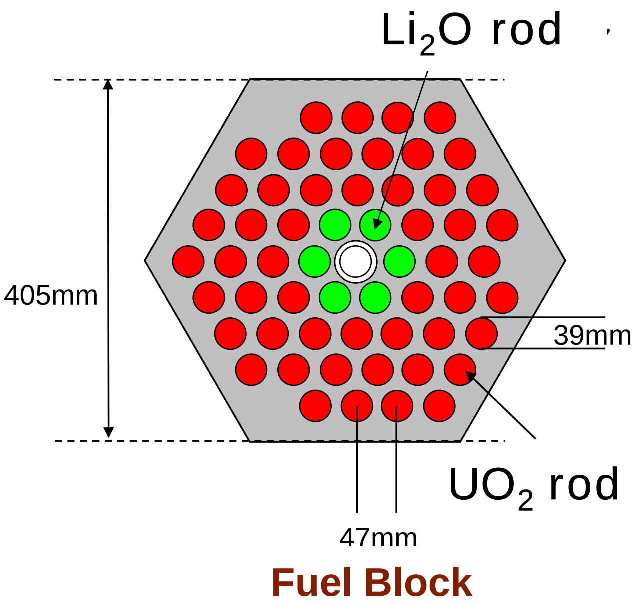


The mixed compacts are inserted uniformly into all the fuel rods in all fuel columns.

We can change the weights of the loaded UO_2 and LI_2O independently.

(B) A part of the fuel rods is replaced by "*only-Li_2O-particle-containing rods*" (compacts).





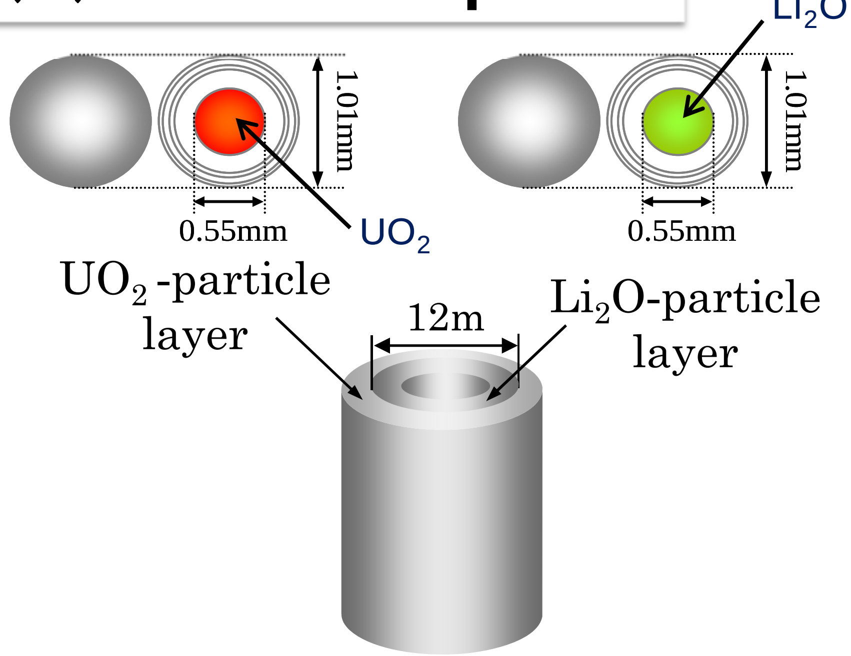
Only 6 fuel-rods are replaced by the Li-containing rods in every fuel block.

The weight of the loaded UO_2 is reduced by the replacement.

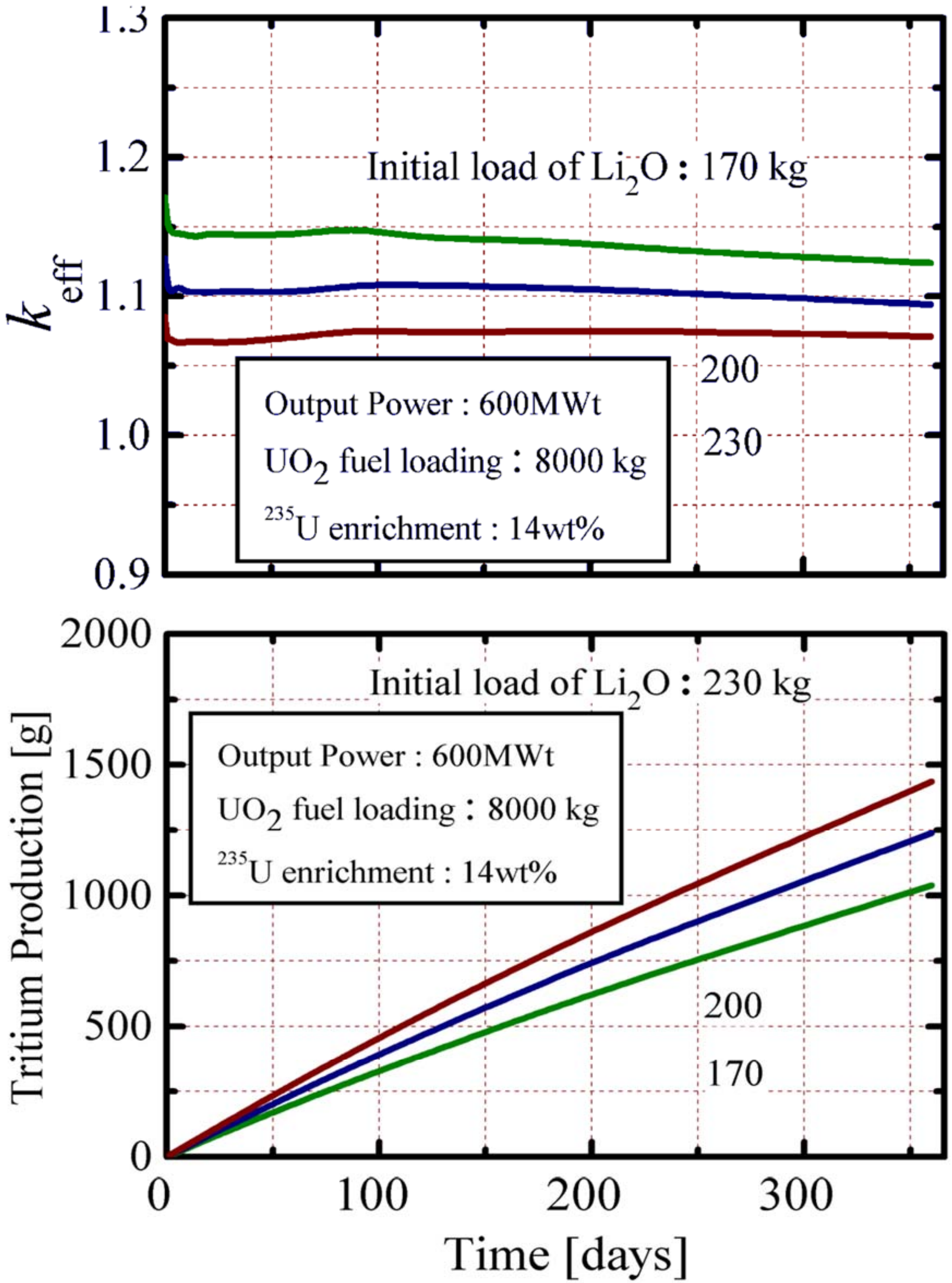
⇩

More realistic Li-loading method.

(A) Mixed Compact

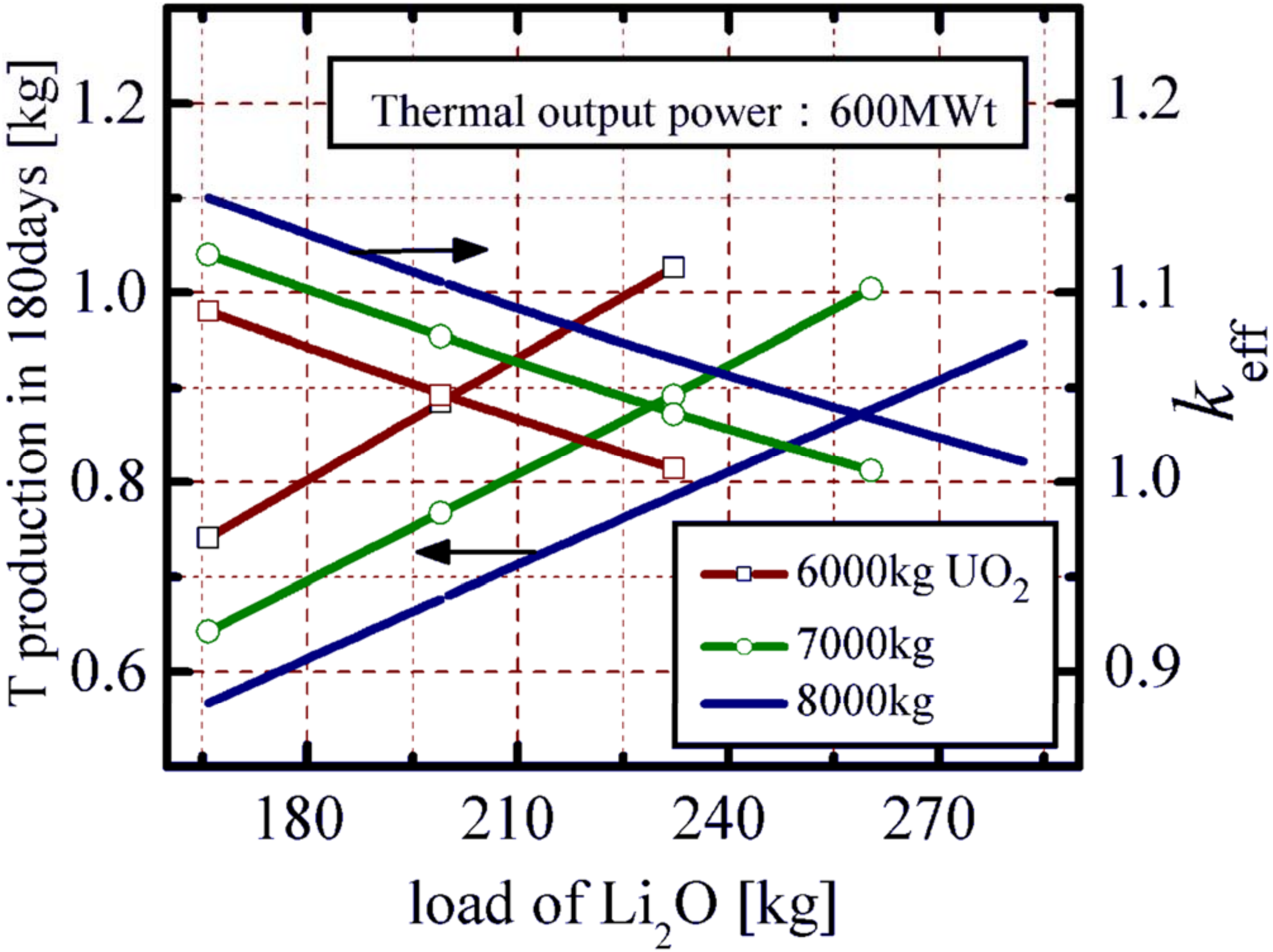


- The multiplication factor changes stably, maintaining almost constant value during the operation.
- The excess reactivity decreases with increasing Li_2O weight.
- When 200 kg of Li_2O was loaded into the entire core region, the minimum k_{eff} value was estimated be ~1.1 and almost 1.25 kg of tritium was produced. (When considering reactors with 3 GW output power, the total amount of tritium production is expected to reach almost 6.3 kg.)



(A) Mixed Compact

The total amount of tritium produced during the 180-day operation and the minimum values of the multiplication factor obtained during the operation are shown as a function of Li_2O loadings for several UO_2 fuel weights.



- The amount of tritium produced in the reactor increases with increasing Li_2O loadings.

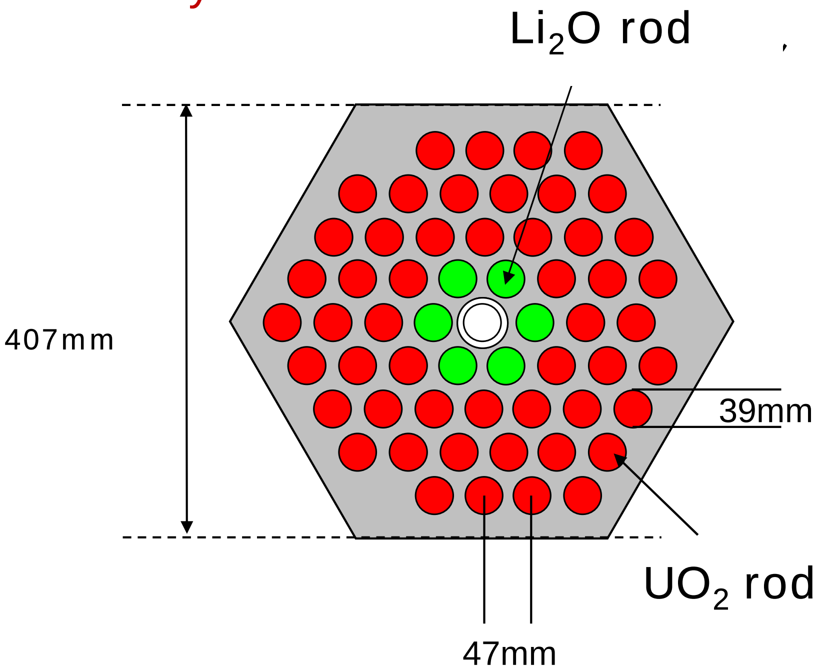
- By reducing the fuel loading, the amount of the produced tritium increases. (This is because when the fuel density decreases, the neutron flux is multiplied to keep the output power constant).

We can roughly estimate the amount of tritium produced in a year by doubling the values. The production weight by using reactors with thermal output power of 3GW in all is obtained further multiplying the value by 5.

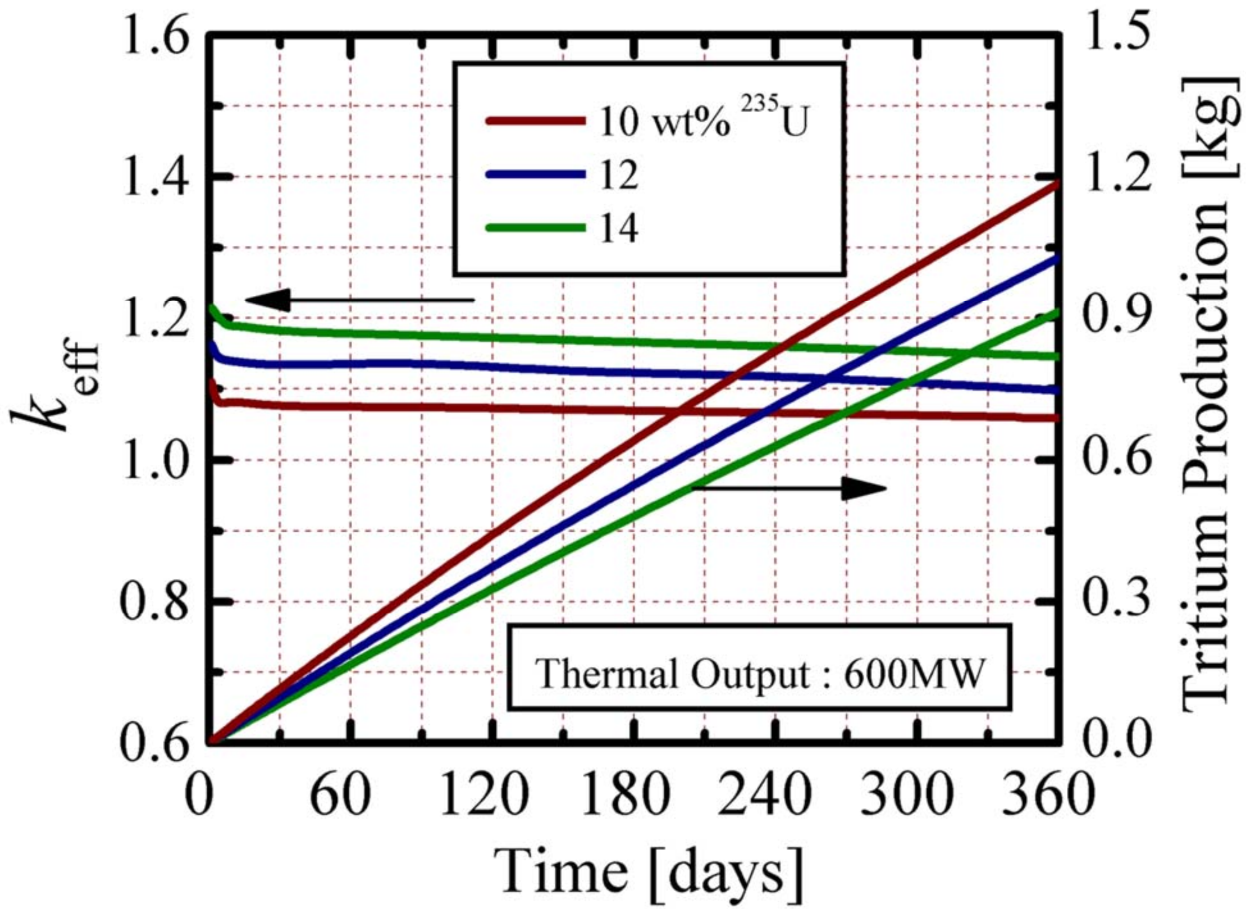
6~10 kg of tritium can be produced in a year by using reactors with thermal output power of 3GW in all

(B) case when only 6 fuel rods are replaced by Li_2O rods

More realistic method of Li_2O loading, from a viewpoint of tritium release and recovery.



Fuel Block



When 14 wt% of ^{235}U enrichment is assumed, the weights of UO_2 and Li_2O loaded into the core are estimated as ~8000 kg and ~160 kg respectively. The tritium production During 180-day operation is ~0.45 kg.

A little bit smaller value compared with the one for mixed compact, i.e., ~0.5kg., is obtained

Summary

- We roughly evaluated tritium production performance by assuming different fuel and Li loading patterns in GTHTR300.

  It was shown that when Li_2O is included using the mixed-fuel compact , 1.2~2.0 (6~10) kg of tritium can be produced in a year by using reactors with thermal output power of 600MW (3GW).

- The total amount of tritium produced varied depending on the fuel and Li loading patterns as well as the core structure. **Optimization is our subsequent focus**.

- The temperature of the Li region was assumed as 1350 K. To avoid the tritium release, the temperature should be maintained at less than 1000 K. **Investigation of lower-temperature operations is a topic of future research**.

- Further detailed studies of **stability and containment of tritium in the ceramic-coated particles** will also be necessary.

- In the present calculations, **modeling of the control rod** was not performed. An effective operation scenario to further improve tritium production should be considered.

*To confirm the present method from the viewpoint of both reactor physics and engineering, **experimental research** using the existing devices, e.g. HTTR, is required.*