IAEA Technical Meeting on Back End of the Fuel Cycle Considerations for Small Modular Reactors

Fuel Cycle Scenarios and Back-end Technologies of HTGR in Japan

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Sector of Fast Reactor and Advanced Reactor Research and Development

Japan Atomic Energy Agency
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Background and Objective

Background

- In the previous meeting held in March, we introduced Japanese reprocessing technologies and fuel cycle scenarios for HTGR.
- Basically, Japan considers the technologies for HTGR Back-end process had completed if an industrial revel demonstration is necessary in the First-of-a-Kind (FOAK) plant.
- However, in some innovative fuel cycle scenarios, further Research and Development (R&D) necessary. International cooperation is expected for the R&D.

Objective

- To overview of Japanese Back-end technologies for HTGR.
- To introduce technological subject to improve the specification for some fuel cycle scenarios.

Overview of Back-end Technologies in Japan

History of Reprocessing Plant Development

History

Japan had developed the reprocessing technologies based on French technologies.

Time	France	Japan	Purpose
1958	UP1		Generate Pu for nuclear weapon
1966	UP2		Reprocessing Calder Hall reactor SF
1976	UP2		Update for LWR SF
1977		Tokai Reprocessing Plant	Reprocessing LWR SF, Negotiation with U.S.*
1989	UP3		Reprocessing LWR SF
2006		Rokkasyo Reprocessing Plant (RPP)	Reprocessing LWR SF

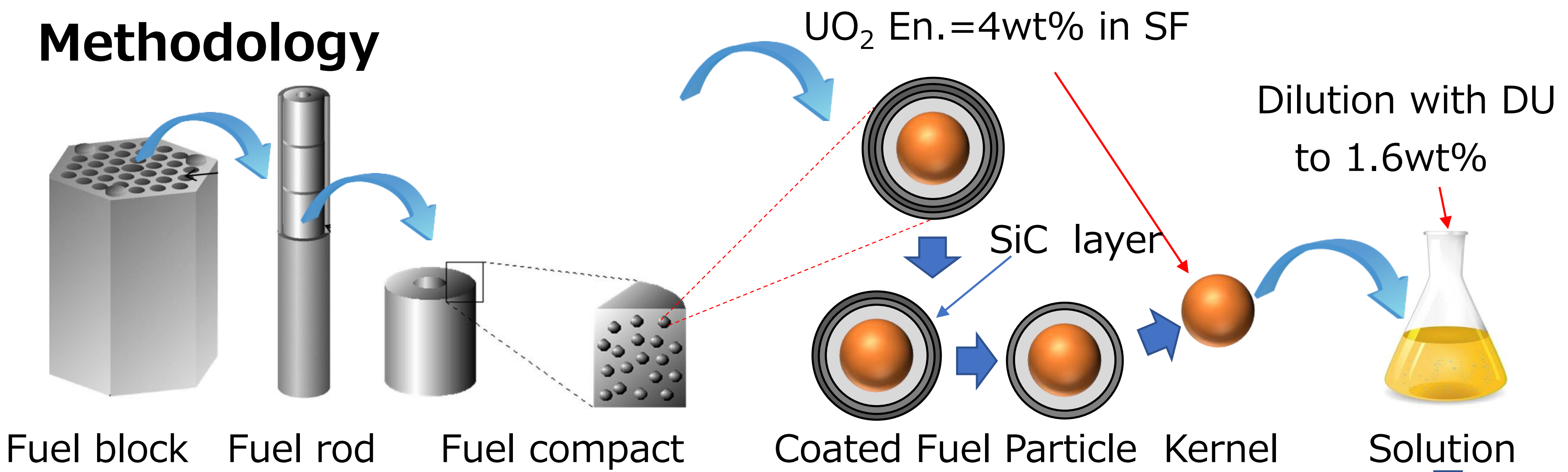
*Japan-U.S. reprocessing negotiation;

Japan, which is non-nuclear-weapon state, is accepted to extract Pu with same amount of U by U.S.

HTGR technologies had also been developed with assuming reprocessing in Japan.

Development of Head-End Process for HTGR

Methodology

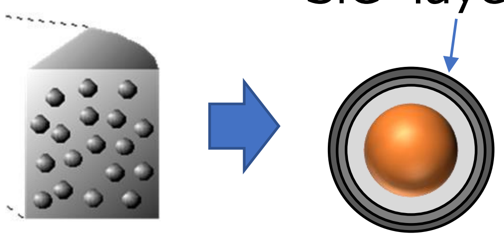


Rokkasyo Reprocessing Plant

Technology

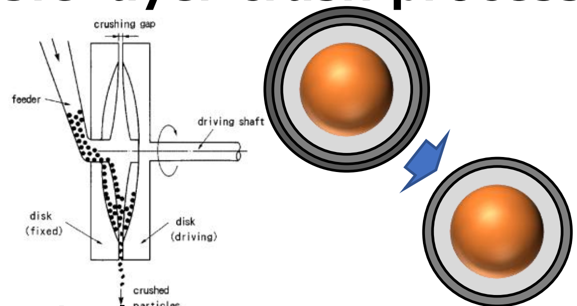
Burn process

SiC layer



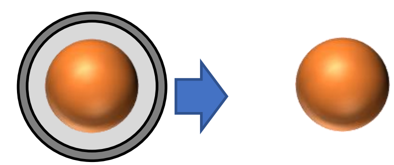
Carbon material is removed by burning.

SiC layer crash process



SiC layer is mechanically crashed.

Reburn process



Carbon layer is removed by burning.

Nuclear Fuel Industries, Ltd. have used these technology to recover uranium from failure products.

Advantage of Japanese Head-End Process

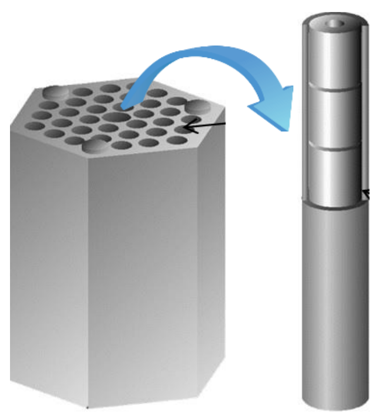
IAEA-TECDOC-1645 concludes that HTGR spent fuel reprocessing is challenging by referring Dr. Greneche's opinion.

Ref.: Greneche, D., Masson, M., Brossard, P., "The Reprocessing Issue for HTR Fuels: An assessment of Its Interest and Its Feasibility", Global 2003 Conference, New Orleans, LA November, 2003.

He referred to **Oak Ridge grinding technology**, which crashes **whole fuel block**.

The waste amount is increase and recovery ratio become worse.

To conquer this problem, **Japan select the pin-in-block type fuel**.



Pin-in-block type fuel

Fuel block

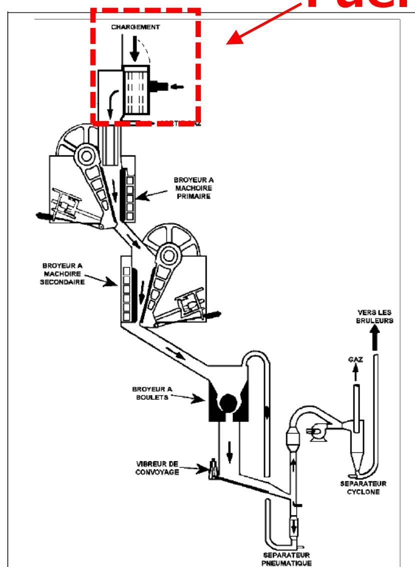


Figure 1. Schematic of the Oak Ride grinding technology.

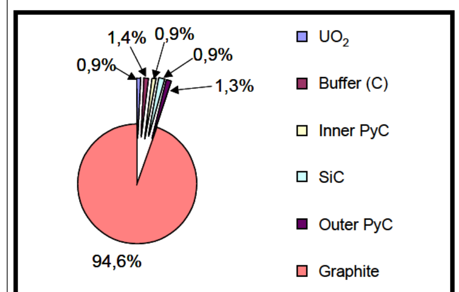


Figure 2. Elementary composition of one GTMHR compact (in % vol.)

Oak Ridge grinding technology

Japanese head-end process reduces waste amount with high recovery ratio.

History of Disposal Technologies Development

History

Japan had developed the disposal technologies based on Swedish technologies.

Time	Sweden	Japan	Remarks
1970		LWR operation started.	Tsuruga (BWR), Hamaoka (PWR)
1976		Disposal study started.	By government's decision.
1983	KBS-3 concept		Svensk Kärnbränslehantering AB (SKB) proposed a multiple barriers concept
1991		First FS, H3 was performed.	FS for vitrified waste disposal
2000		Second FS, H12 was performed.	FS for vitrified waste disposal
2000		Final disposal law was decided.	NUMO, utility of disposal, was organized.
2014		Full scale Engineered Barrie System (EBS) demonstration was performed in Horonobe.	If RRP started operation in 2000, the vitrified waste should be disposed of after cooling 50 years.

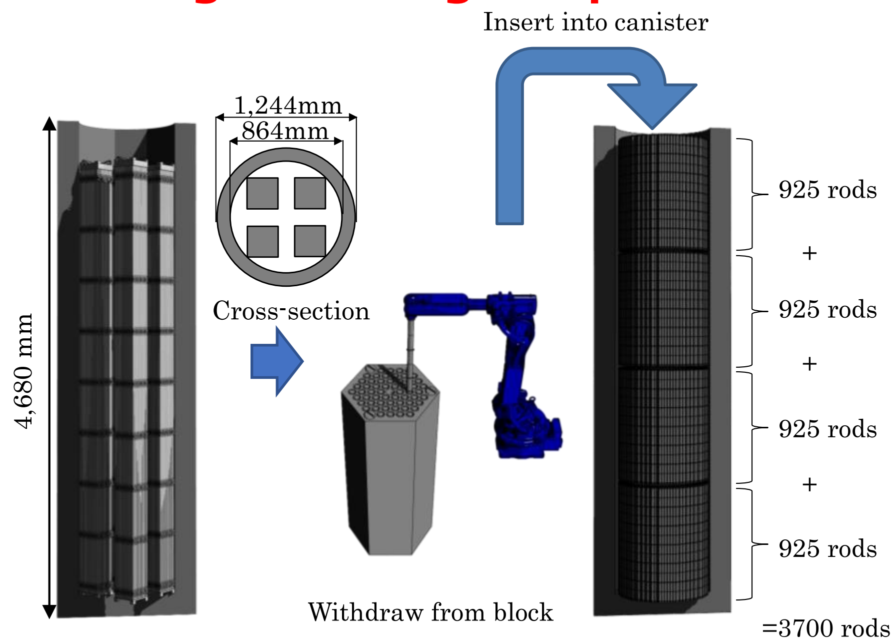
Japan has completed the geological disposal technologies.

For HTGR waste disposal, there is no difference when the vitrified waste is disposed of.

Direct disposal of HTGR Spent Fuel

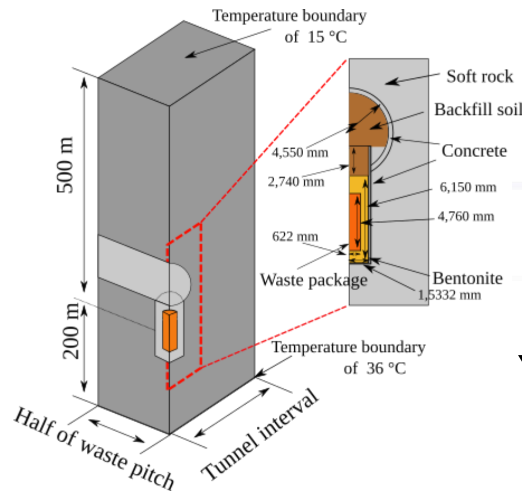
The investigation of direct disposal of LWR spent fuel has been also performed as a option in Japan. Basically, there is no technical gap between the disposal of vitrified waste and spent fuel.

We investigated feasibility study of direct disposal of HTGR spent fuel with **taking advantage of pin-in-block type of fuel**.

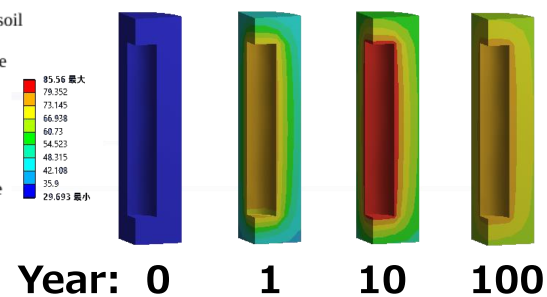


PWR canister **HTGR canister**

The canister number and its footprint per electricity generation can be reduced by 60% compared with an LWR case.



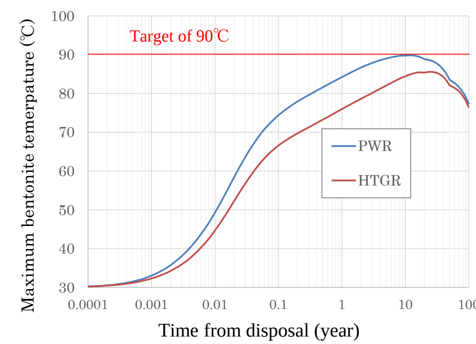
Model of thermal calculation



Bentonite temperature

The bentonite temperature satisfies the limitation of 90℃.

Ref.:Y. Fukaya, T.Nishihara, "Reduction on High Level Radioactive Waste Volume and Geological Repository Footprint with High Burn-up and High Thermal Efficiency of HTGR,"Nuclear Engineering. Design., 307, 188, (2016).



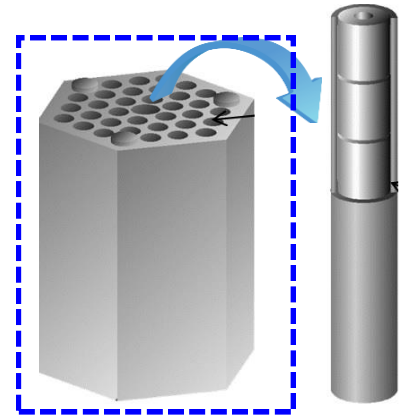
Maximum bentonite temperature

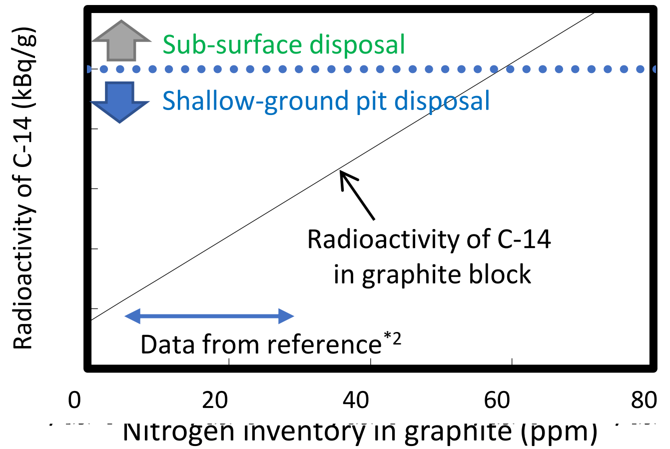
Subject to improve of the specification of fuel cycle scenarios

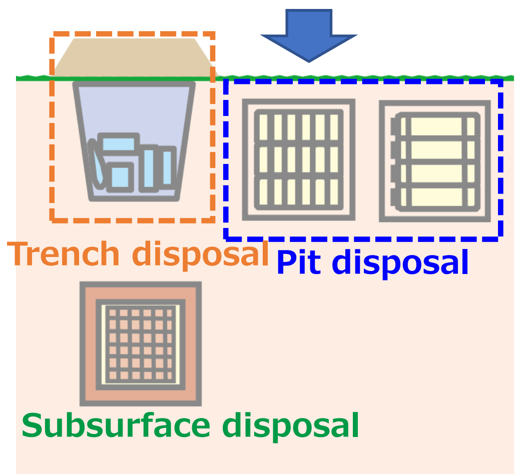
Near Fielded Model for Public Dose Evaluation from Graphite Waste

For all fuel cycle options:

The fuel block whose fuel rod is withdrawn can be disposed of **by shallow-ground pit disposal** Under reactor regulation law.

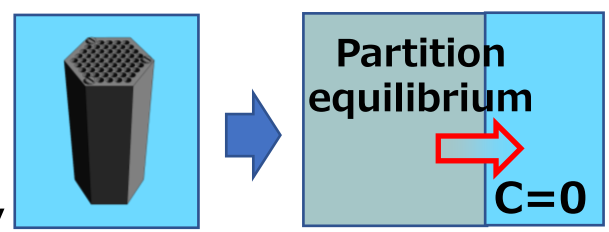






Public dose evaluation

Near field model based on partition equilibrium, in which whole waste is dissolved into ground water, is too conservative for the high water durable graphite.



Near field model

Subject

- ➢ To develop reasonable solubility controlled model.
- ➢ To develop solubility database especially for organic carbon.

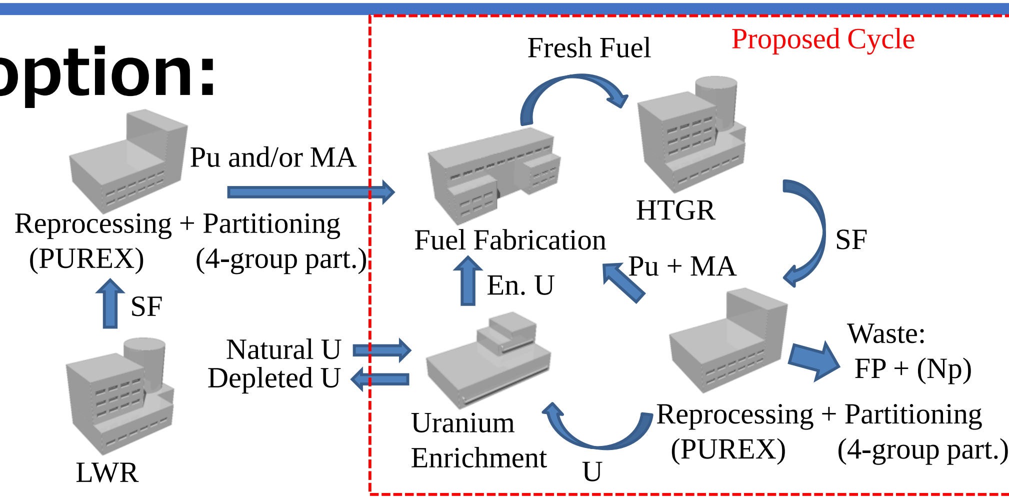
Ref.:Japan Atomic Energy Agency, Safe and Eco-friendly Nuclear Reactor with Meltdown-proof design: High Temperature Gas-cooled Reactor (leaflet), Japan Atomic Energy Agency, (2019).

More reasonable disposal can be applied only by evaluation.

Recovery Ratio Confirmation for Toxicity Reduction

For multi-recycle fuel cycle option:

- Multi-recycle option can minimize the toxicity release from the fuel cycle.
- Even with thermal reactor can establish multi-recycle fuel cycle by feeding fissile material.
- To prevent the toxicity release from the cycle, high recovery ratio more than 99.9%.

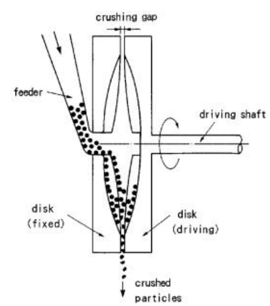


Uranium based multi-recycling

Ref.:Y. Fukaya, M.Goto, H. Ohashi, et al. "Uranium-based TRU multi-recycling with thermal neutron HTGR to reduce environmental burden and threat of nuclear proliferation," J. Nucl. Sci. Technol. 55[11], pp.1275-1290 (2018).

Recovery ratio head end process

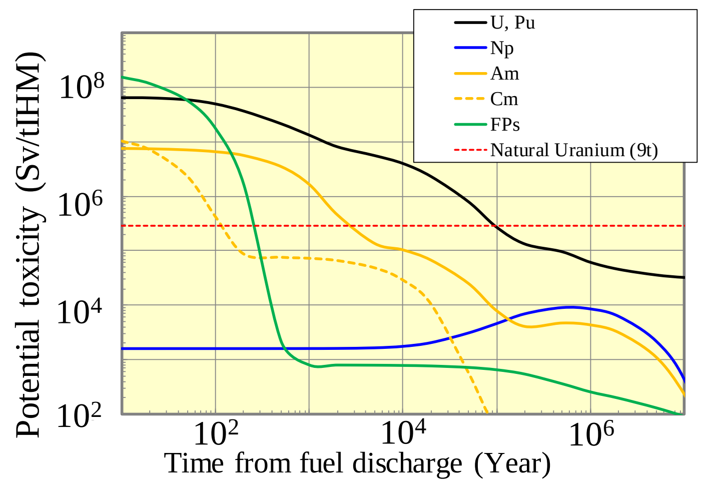
Until the SiC layer crashing of head end-process of HTGR, the recovery ratio approximately 100% is confirmed.



Subject

The recovery ratio more than 99.9% should be proved including clarification process.

The recovery ratio should be confirmed.



Toxicity from spent fuel from LWR

To achieve reducing the toxicity lower than natural uranium level in 300 years, not only P&T but also the recovery ratio more than 99.9% is necessary.

Summary

JAEA introduced the status of R&D of back-end technologies of HTGR and future subject to improve the specification of fuel cycle options.

For R&D of back-end technologies of HTGR:

- Japan had completed the reprocessing and disposal technologies for LWR.
- Head-end process of reprocessing for HTGR had also completed, and applicability to RRP had been also confirmed.
- The disposal technologies for vitrified waste is common for HTGR, and the feasibility for direct disposal of HTGR had been also confirmed.

For subject to improve specification of fuel cycle options:

- Near filed model for graphite waste dose evaluation should be developed to performed reasonable disposal.
- Recovery ration of reprocessing with HTGR head-end process should be confirmed to achieve potential toxicity reduction for multi-recycling option.