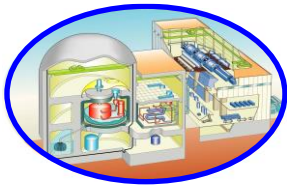


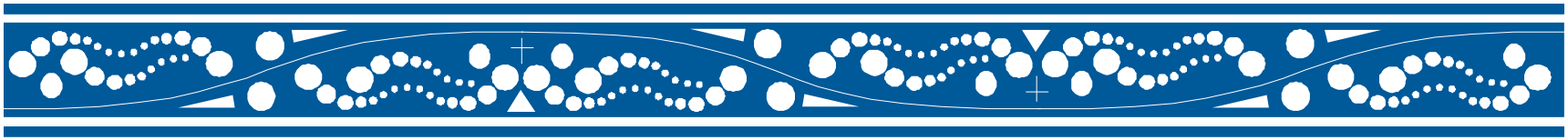
MSR Workshop at ORNL

November 5-7, 2024

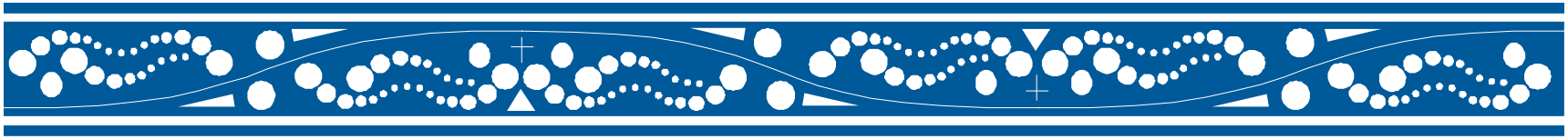
MSR Activity in Japan

1. Introduction
2. Activity for Fluoride salt MSR
3. Activity for Chloride salt MSR
4. Activity in Indonesia
5. Regulatory Guides for MSR Safety, Proliferation Resistance and Physical Protection

Motoyasu Kinoshita, Kazuro Furukawa, Taizo Shibuya
International Thorium Molten-Salt Forum (ITMSF)



1. Introduction



Activity for Fluoride salt MSR

International Thorium Molten-Salt Forum (ITMSF) is a Non-Profit-Organization, established in 2008 for basic study of MSR technology such as conceptual designs and safety analysis. So far, 29 seminars have been held.

This Forum is an observer member of GIF-MSR System Steering Committee since 2005.

Besides that, **Thorium Tech Solution Inc. (TTS)** was established in 2010 for business application.

Both this Forum and TTS were established by Dr. Kazuo Furukawa, and there is an MOU between this Forum and TTS, for MSR-FUJI realization.

Chloride salt fueled fast neutron MSR and related fuel recycling, material compatibility are studied by **BERD** group of Universities and CRIEPI

.

Japanese Government started to support startup companies for MSR development from 2019.

Forum seminar in 2024.

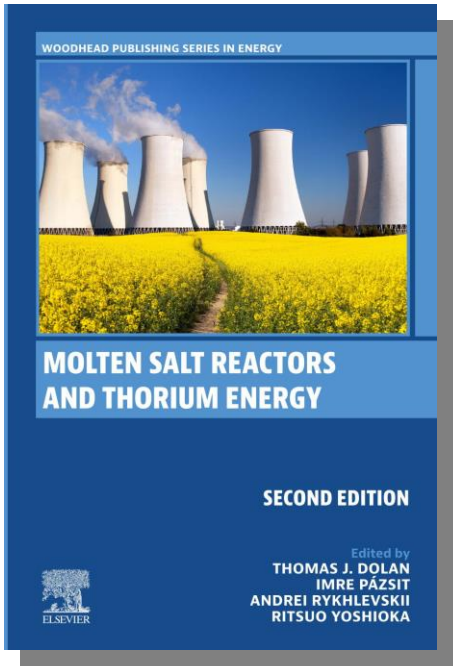
2. Activity for Fluoride salt MSR

MSR-FUJI

MSR-FUJI is based on the MSBR design at ORNL in 1960s to 70s, but there are several improvements.

(1) Small sized plant to deploy widely in the world.
(2) Remove online chemical reprocessing to simplify the plant.
(3) Achieve self-sustaining operation (Conversion Ratio=1.0).
(4) No graphite replacement within 30-years operation.

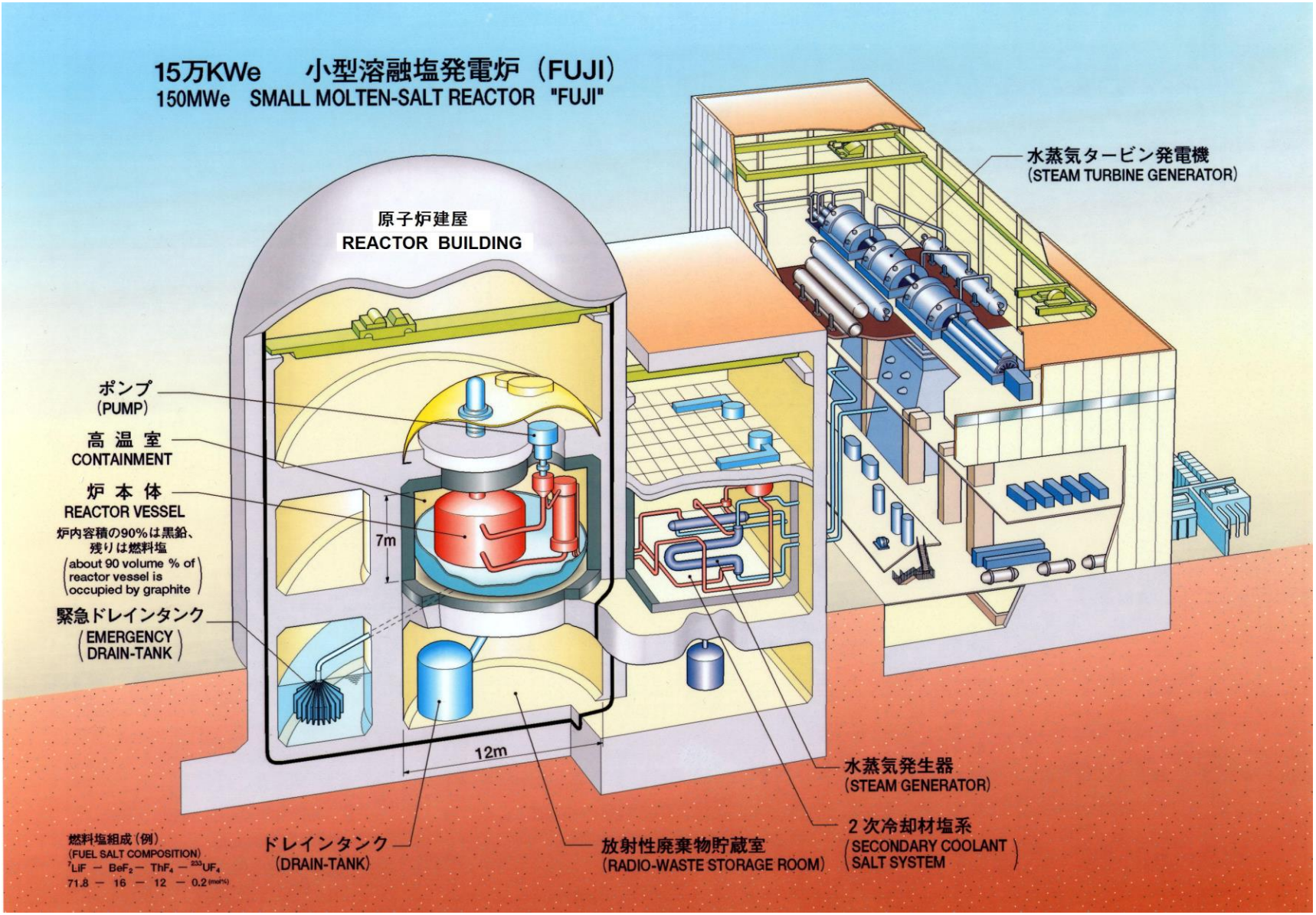
Information on MSR-FUJI is described in the following books [1][2].



[1] "Molten Salt Reactors and Thorium Energy" , by T. Dolan,et al, Elsevier, 2024

[2] "Advances in Small Modular Reactor Technology Development", by IAEA, 2020

Bird-eye View of MSR-FUJI



Molten Salt Loop Technology

● FLiNaK loop (15L/min) is planned to acquire heat transfer data, which will be performed using a molten salt loop at Sukegawa Electric Co..

●FLiNaK (50L/min) loop at the fusion blanket system in NIFS (National Institute for Fusion Science) was used for freeze valve tests. (See Section.5.)

Graphite and Hastelloy-N

● Graphite for MSR can be provided by a Japanese maker, which was already provided to HTGRs both in Japan and China.

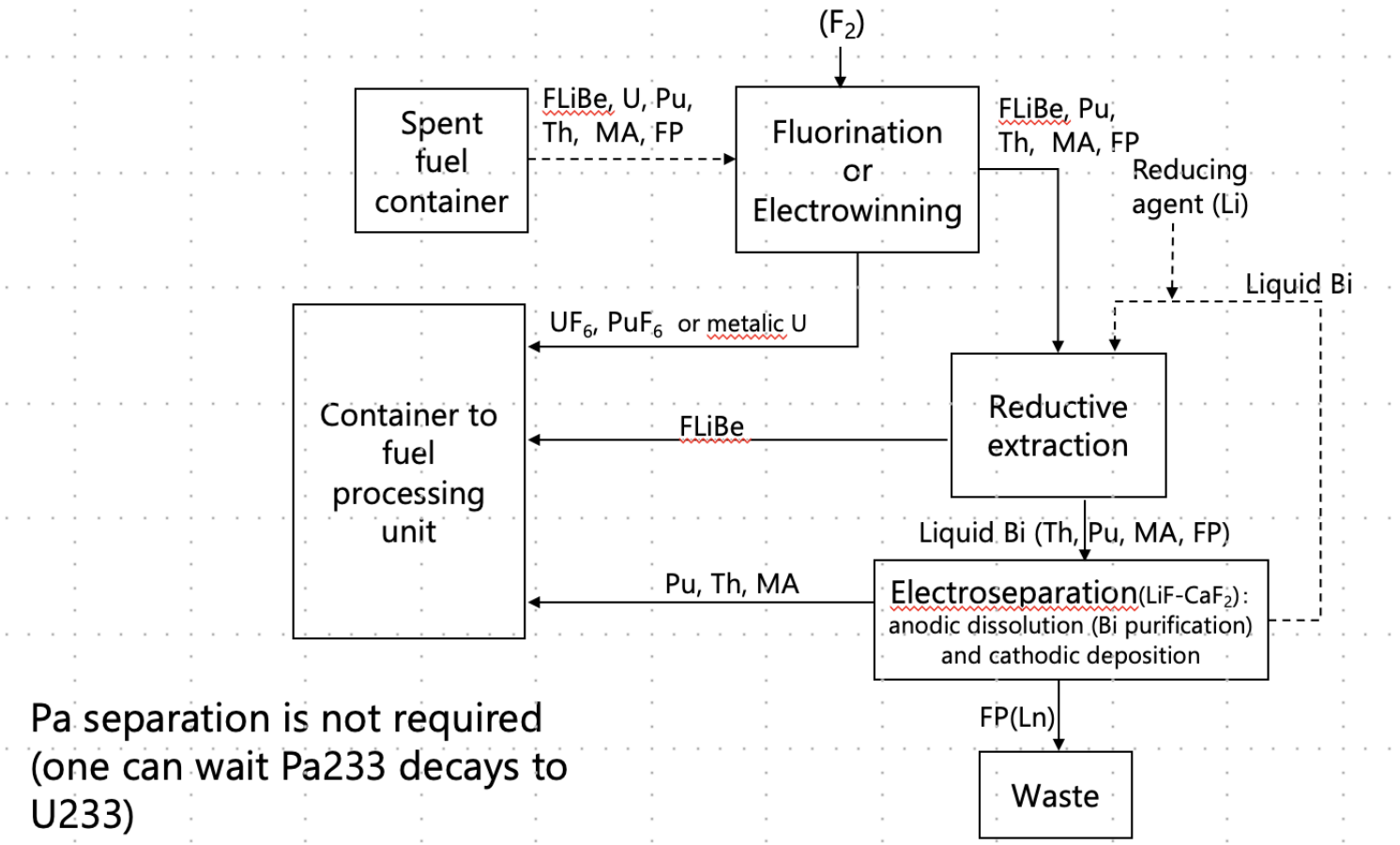
●Hastelloy-N is provided to industries by a Japanese maker, and there will be no concern to supply large amount.

Graphite for HTGR

Hastelloy-N sample

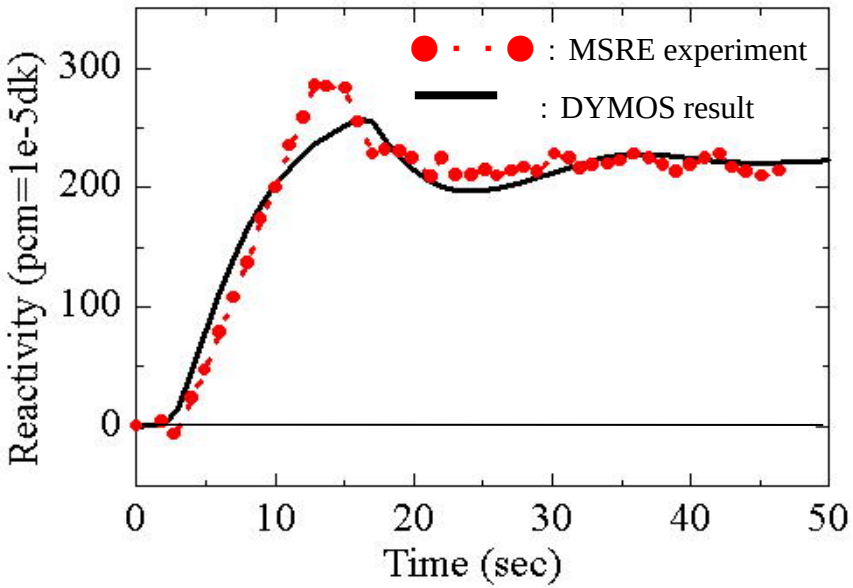
Fuel Cycle for MSR

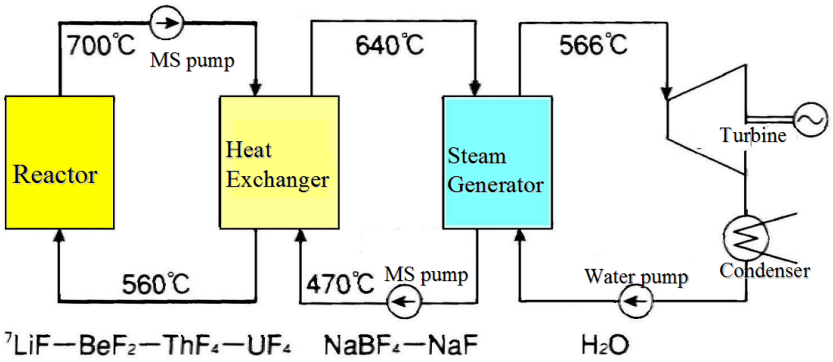
We have started a joint study with CVR in Czech, in order to establish off-line reprocessing of spent fuel salt from MSR.
Online reprocessing was studied at ORNL in 1970s, but not demonstrated.
The following off-line reprocessing is under consideration, and considered feasible.

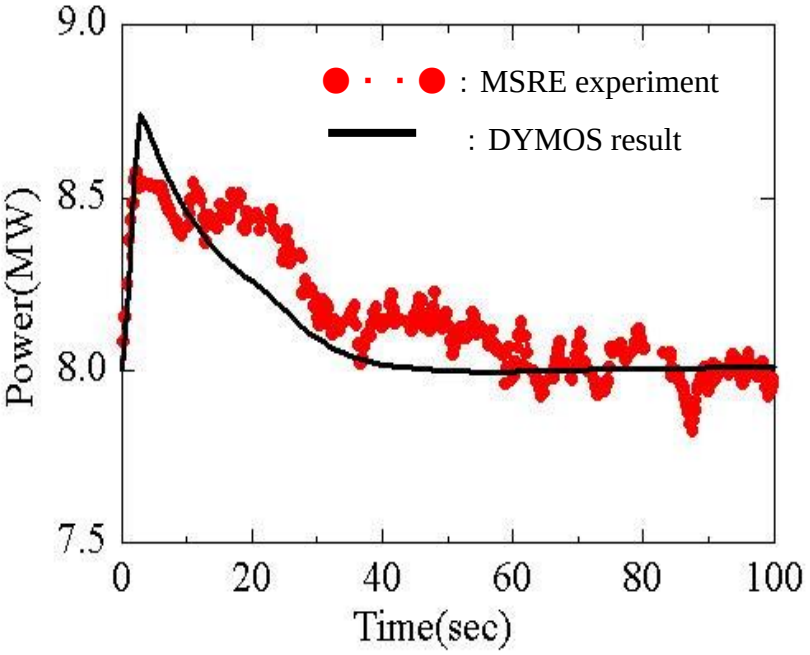


Safety Analysis Code “DYMOS”

We have performed verification study of a safety analysis code for MSR.
It can be used for transient & accident analysis, such as reactivity insertion accident, or pump trip accident, and so on.





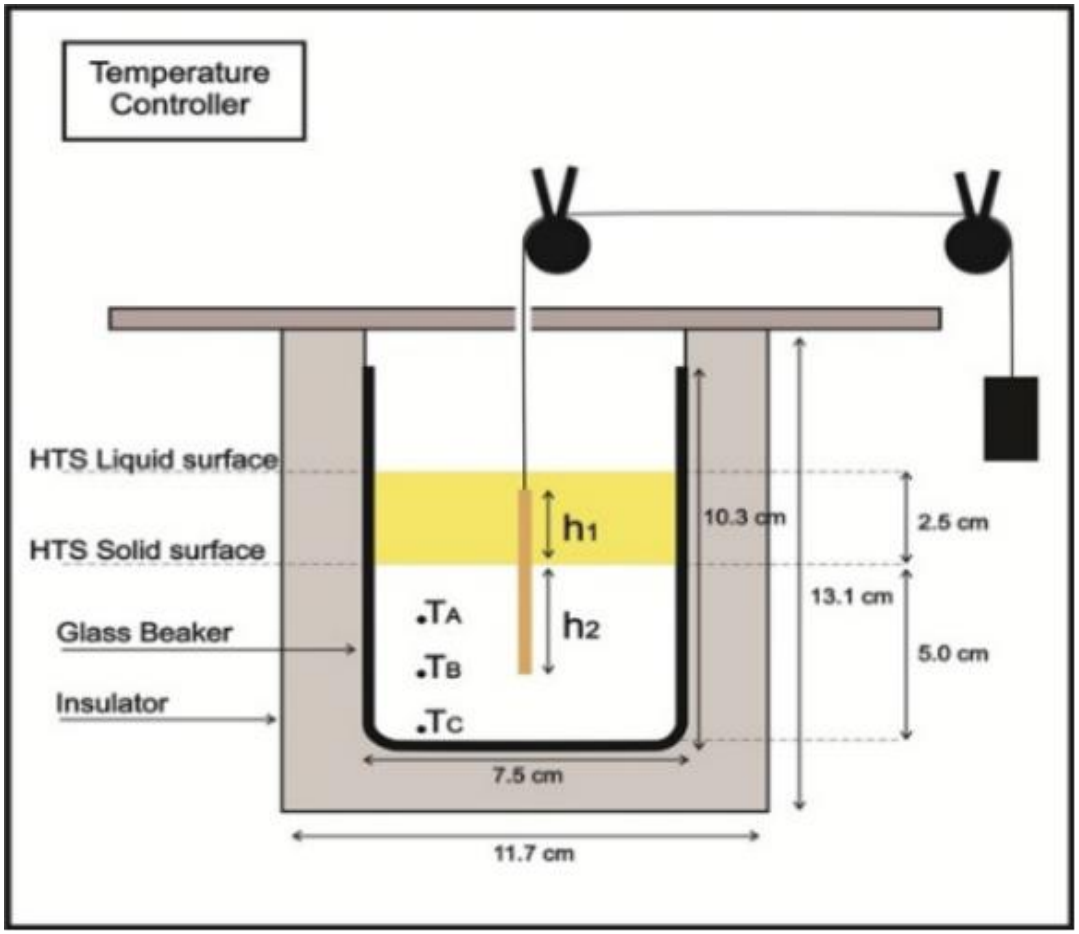


Verification of DYMOS code for MSRE experiments shows very good agreement.

Y. Shimazu, R. Yoshioka, K. Ogasawara, “Proposal of Application of a Simple Analysis Code DYMOS for Accident Analyses of Molten Salt Reactors”, Journal of Energy Research and Reviews, Vol.15, No. 4, 2023

Basic Freeze Valve Experiment

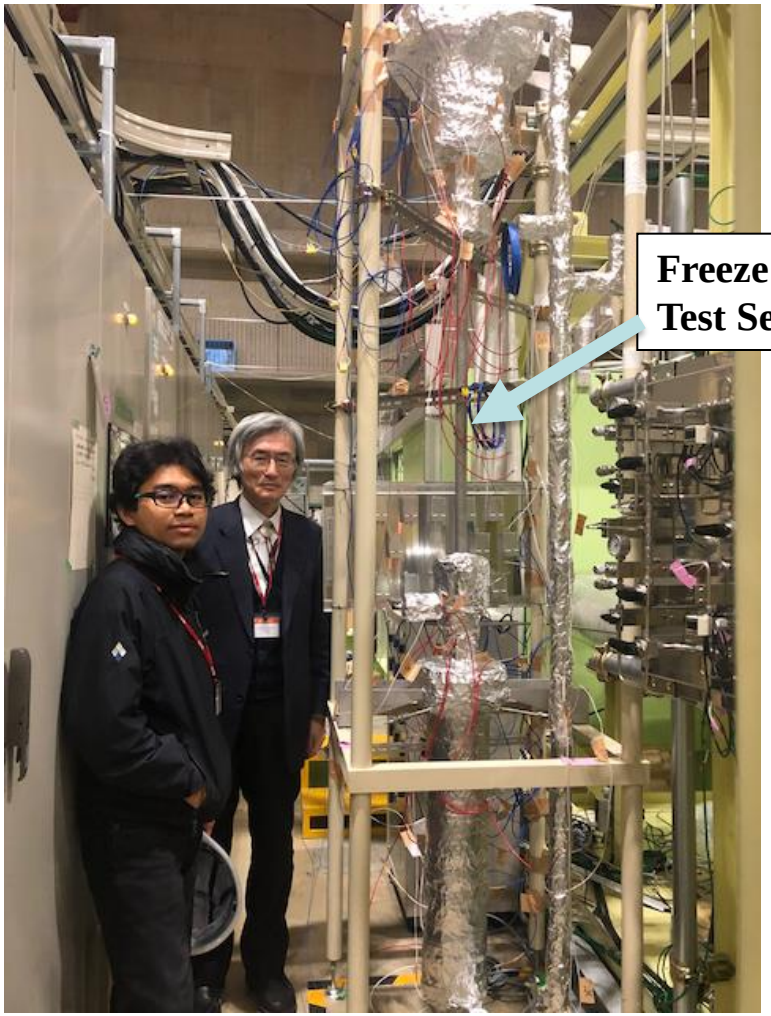
Using two-layered (molten salt over frozen salt) geometry, several parameters are investigated, such as salt temperatures, wall thickness, wall material, etc..



Freeze Valve Testing at NIFS

Based on experimental studies, UEC (Univ. Elec. Comm) patented freeze valve with thick copper blanket which gives shorter opening time

We prepared freeze valve testing system at FLiNaK molten salt loop at National Institute of Fusion Science (NIFS).



3. Activity for Chloride salt MSR

Chloride salt MSR, BERD activity

BERD is Japanese domestic group for MSR R&D. （次世代 R&D 機構）.

Member: Tojyo Inst. Tech., Fukui Univ. Doshisha Univ. CRIEPI

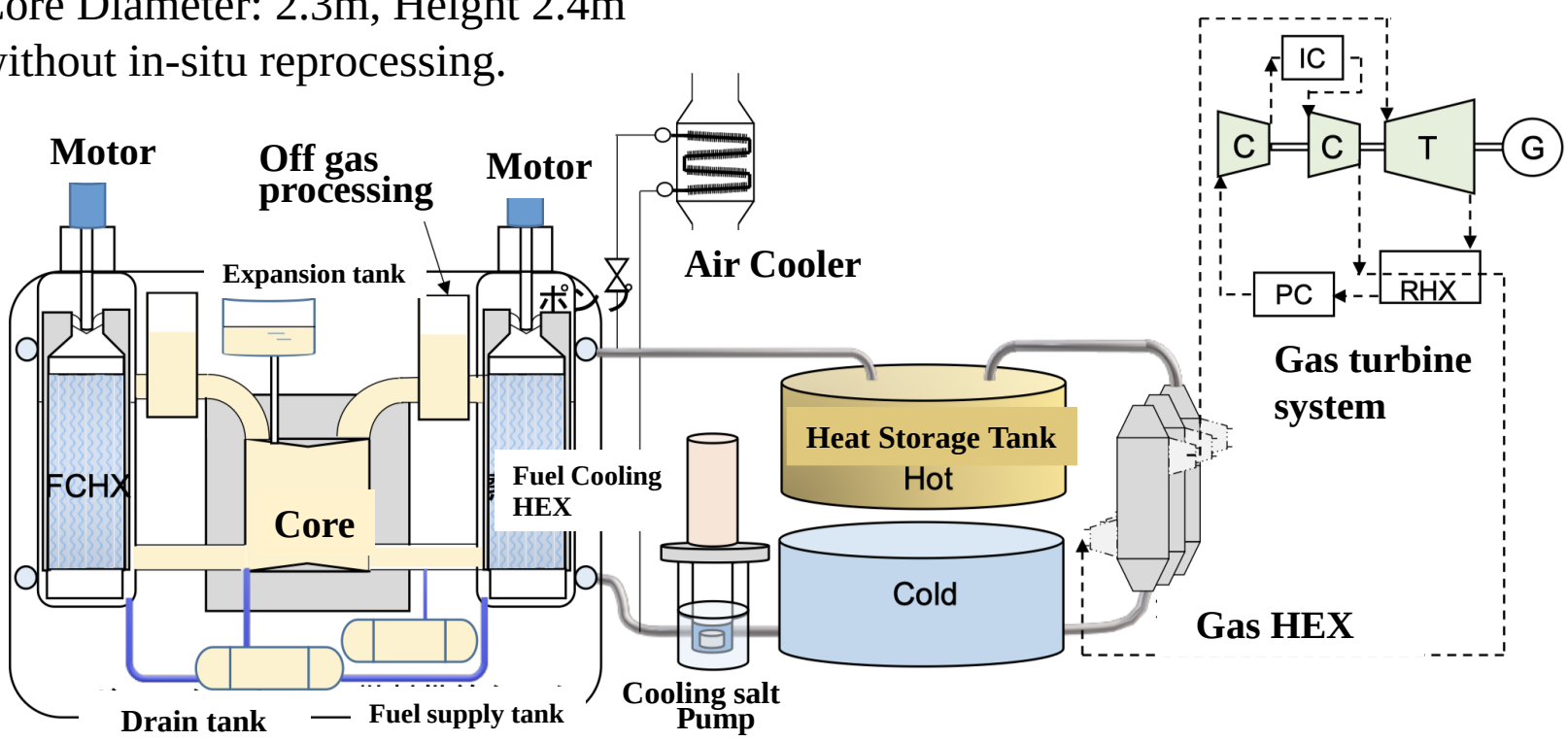
From 2019, 2011 till now supported by NEXIP program of METI.

IMSFR (Integral Molten Salt Fast Reactor)

Power: 700MWt

Core Diameter: 2.3m, Height 2.4m

without in-situ reprocessing.

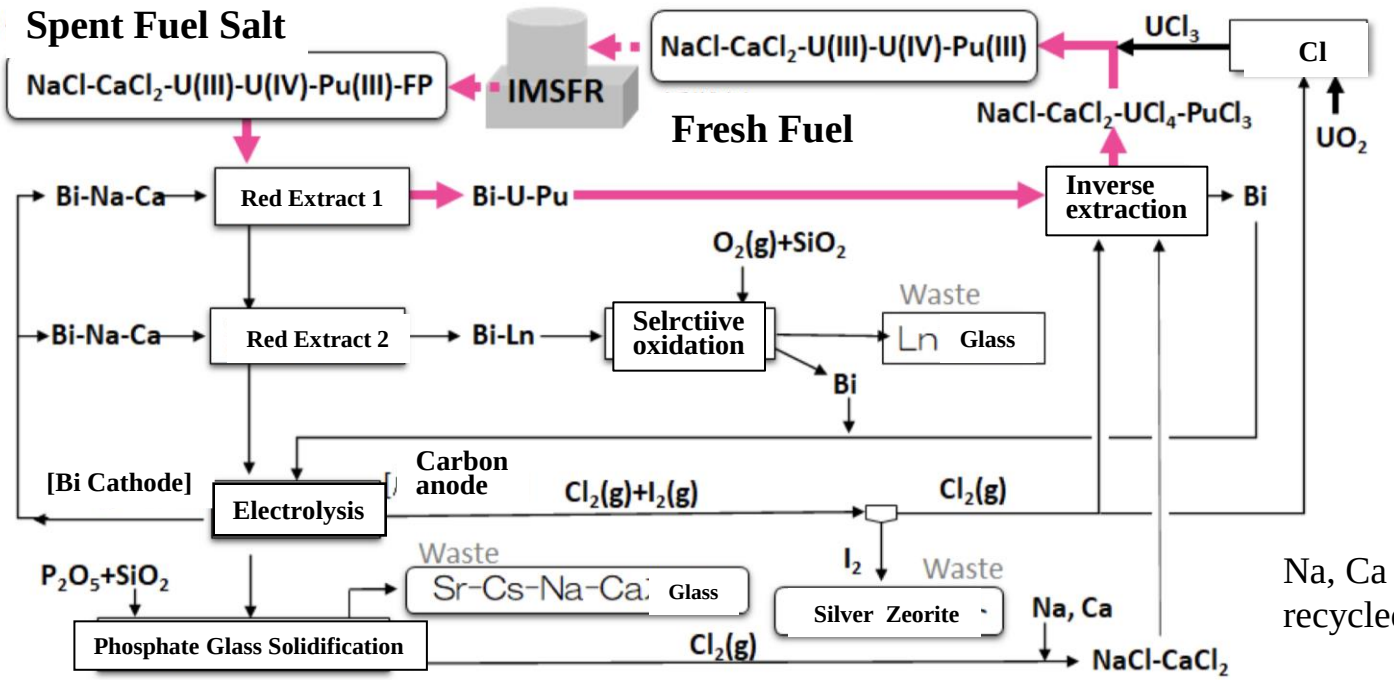


H. Mochizuki; Nucl. Eng. Design, 2024 Vol 428, November 2024, 113472

Fuel Cycling of Chloride salt MSR

BERD Group

IMSFR Fuel: (MA, LWR grade Pu, depleted U)
Power: 700MWt
28.62 ton MS Fuel/40year (10 Batches in year)
94kg to RE Glass, 23kg to Phosphate Glass



Na, Ca will be recycled

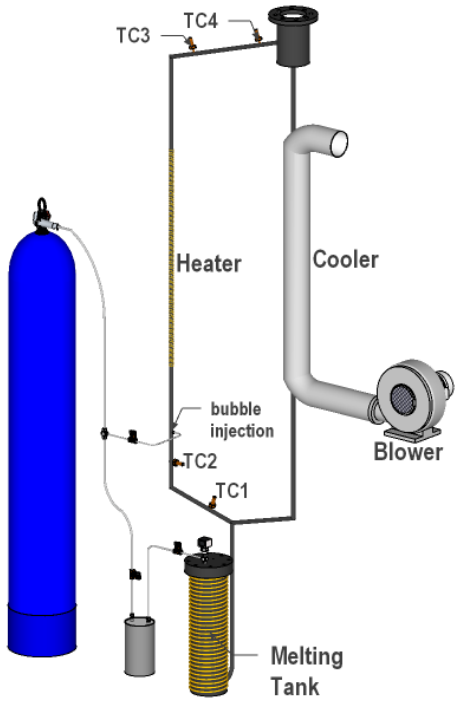
Mitachi, K., Shimazu, Y.,, J. Nuc. Sci. and Tech., 59, 10, 1297 -1303, (2022).

Yamawaki, M., Koyama; J. Nuc. and Radiochemical. Sci., 16, 1(2016)

4. Activity in Indonesia

Activity in Indonesia (ITB)

Natural circulation testing loop was assembled in Inst. Tech. Bandung .(ITB) as one of basic experimental activities for MSR R&D by graduate students.



Duwi Hariyanto, Sidik Permana et.al, Nuc. Eng. Design, Vol 416, 2024, 112753

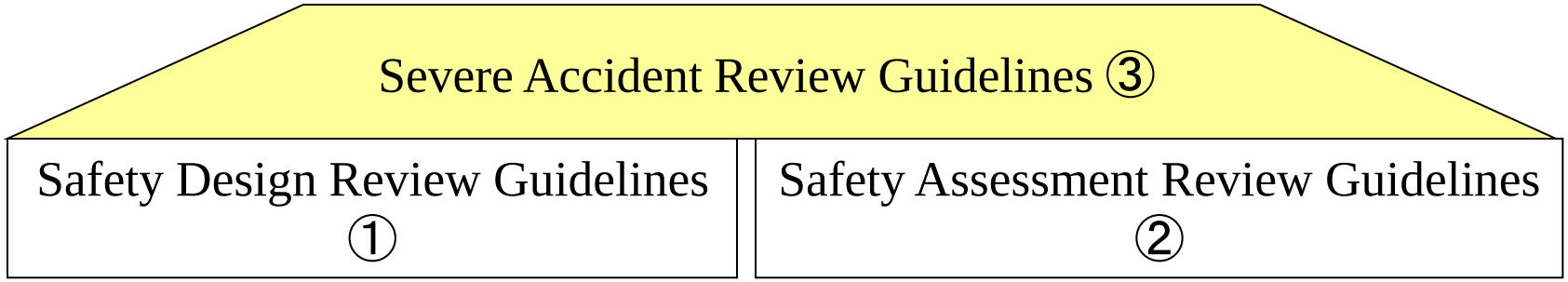
Fukushima Diichi (2011)

5. Regulatory Guides for MSR Safety and Proliferation Resistance

Physical Protection

Proposed Safety Review Guidelines for MSRs

Two-tiered structure:



No. 1 is **basic safety design guidelines** covering normal operations, Anticipated Operational Occurrences (AOO), and Design Basis Accidents (DBA) proposed by the authors [1], which is equivalent to ANSI/ANS-20.2-2023 [4].

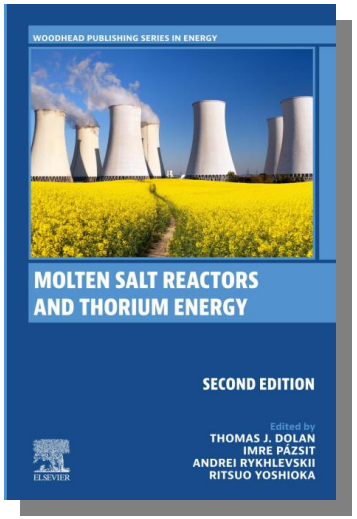
No.2 is **guidelines for safety analysis for AOO and DBA**, proposed by the authors [2], with reference to Japanese guidelines for light water reactors (LWRs).

No.3 is **Guidelines for events beyond DBA (severe accidents)**, also proposed by the authors [3], with reference to Japanese guidelines for LWRs.

Sources of MSR Safety Review Guidelines

[1] R. Yoshioka, M. Kinoshita, "Regulatory guide for MSR safety design", Section 11.6 in the book: "*Molten Salt Reactors and Thorium Energy*", Elsevier, 2024

[2] R. Yoshioka, M. Kinoshita, "Regulatory guide for MSR safety assessment", Section 11.7 of the book: "*Molten Salt Reactors and Thorium Energy*", Elsevier, 2024



[3] R. Yoshioka, T. Morita, K. Ogasawara, M. Kinoshita, Y. Shimazu, M. Furukawa, "Regulatory Guide for MSR Severe Accident", IAEA Technical Meeting on Severe Accident Analysis and Management for Non-Water Cooled Reactors", 14-17 October 2024

[4] ANS, "Nuclear Safety Design Criteria and Functional Performance Requirements for Liquid-Fuel Molten Salt Reactor Nuclear Power Plants", ANSI/ANS-20.2-2023, January 2024

Study for Severe Accident (1/2)

●In US, there is a Code of Federal Regulation for DBAs [5], but it is generic regulations and not specific to severe accidents.
Besides that, there is a safety review guidelines for experimental MSRs [6], but it is not specific to severe accidents.

●Also,IAEA's safety design standard for LWRs "SSR-2/1" [7] has only one requirement for severe accidents,and it is considered insufficient.

●In Japan, based on the Fukushima accident, review guidelines for LWR severe accidents are submitted [8].
Based on these guidelines, new guidelines for MSR severe accidents are proposed by the authors as "Regulatory Guide for MSR Severe Accident" [3], considering differences between LWR and MSR.

Fukushima 2011

Study for Severe Accident (2/2)

References:

[5] NRC, 10CFR50.155, “Mitigation of Beyond-Design-Basis Events”, 2019.

[6] R.J. Belles, et al., “Proposed Guidance for Preparing and Reviewing a Molten Salt Non-Power Reactor Application”, ORNL/TM-2020/1478, 2020.

[7] IAEA, “Safety of Nuclear Power Plants: Design”, IAEA Safety Standards Series No. SSR-2/1, IAEA, Vienna, 2012, and IAEA, “Safety of Nuclear Power Plants: Design, Specific Safety Requirements”, SSR-2/1(Rev.1), 2016

[8] Nuclear Regulation Authority, Japan “Review Guide on the Effectiveness Evaluation of Fuel Salt Boundary Damage Prevention Measures and Containment Damage Prevention Measures” (in Japanese), 2013.

Proliferation Resistance:

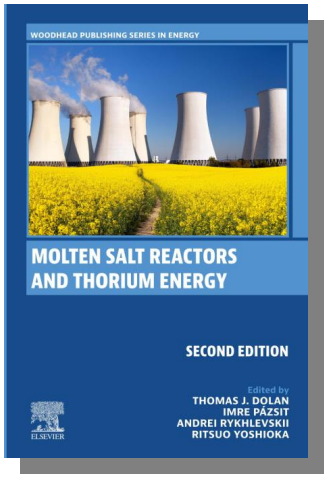
Mostly diversion of nuclear material to weapon by the country.

Physical Protection:

Mostly theft of nuclear material or reactor attack by terrorists.

Proliferation Resistance and Physical Protection

A comprehensive report is included in the following book;
A. Erickson, R. Yoshioka, "Proliferation resistance and physical protection of MSR", Section 10 in the book: "*Molten Salt Reactors and Thorium Energy*", Elsevier, 2024



As for **Proliferation Resistance**, various MSR technologies are discussed, such as, Fuel type, Coolant type, Neutron spectrum, Fuel salt type, Fuel feeding after startup, Reprocessing type, Fissile & Fertile material, Blanket loop, Addition of Minor actinide, Purpose of MSR, and Core structure.

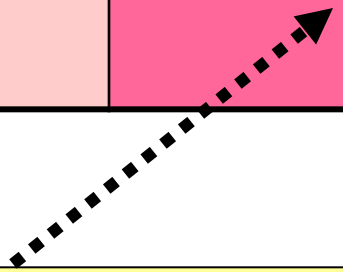
As a result, MSR fuel cycle has potential Proliferation Resistance, because of U-232 gamma radiation.

As for **Physical Protection**, design basis threat (DBT) for LWR is discussed at first. Then, DBT for MSR is proposed here, where loss of AC and DC power sources is already considered in designs.

It is concluded that MSR is appropriately protected against DBT.

Beyond-DBT Issue

	LWR safety	Physical Protection
Design basis	DBA (Design Basis Accident)	DBT (Design Basis Threat)
Beyond design basis	Beyond-DBA (Sever accident)	Beyond-DBT

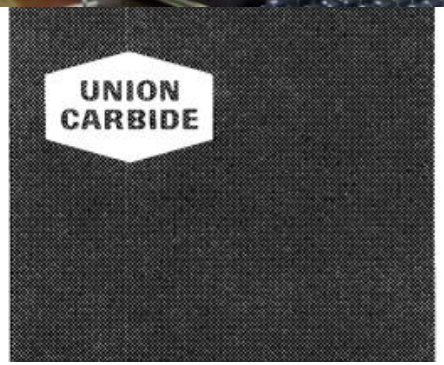


Safety or accident in LWR or MSR are required both in DBA and Beyond-DBA (Severe accident) scenarios.

Current common understanding of DBT is that invasion to reactor area can be avoided, and Beyond-DBT is not discussed so far.

But it actually occurred, Beyond-DBT has to be discussed.

2012/1/23 @ORNL



Conceptual Design Characteristics of a Denatured Molten-Salt Reactor with Once-Through Fueling

J. R. Engel
H. F. Bauman
J. F. Dearing
W. R. Grimes
E. H. McCoy
W. A. Rhoades

ORNL-TM-7207

Thank you for your attention!

Any questions/comments?