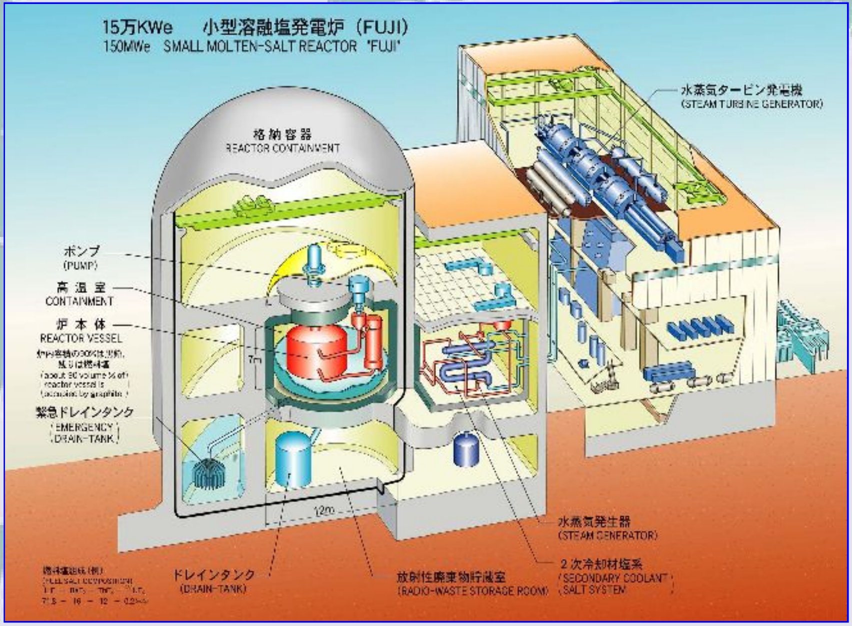
Current Situation of MSR Development in Japan



- Yoichiro SHIMAZU
- Graduate School of Engineering
- Hokkaido University, Japan

Related Organizations

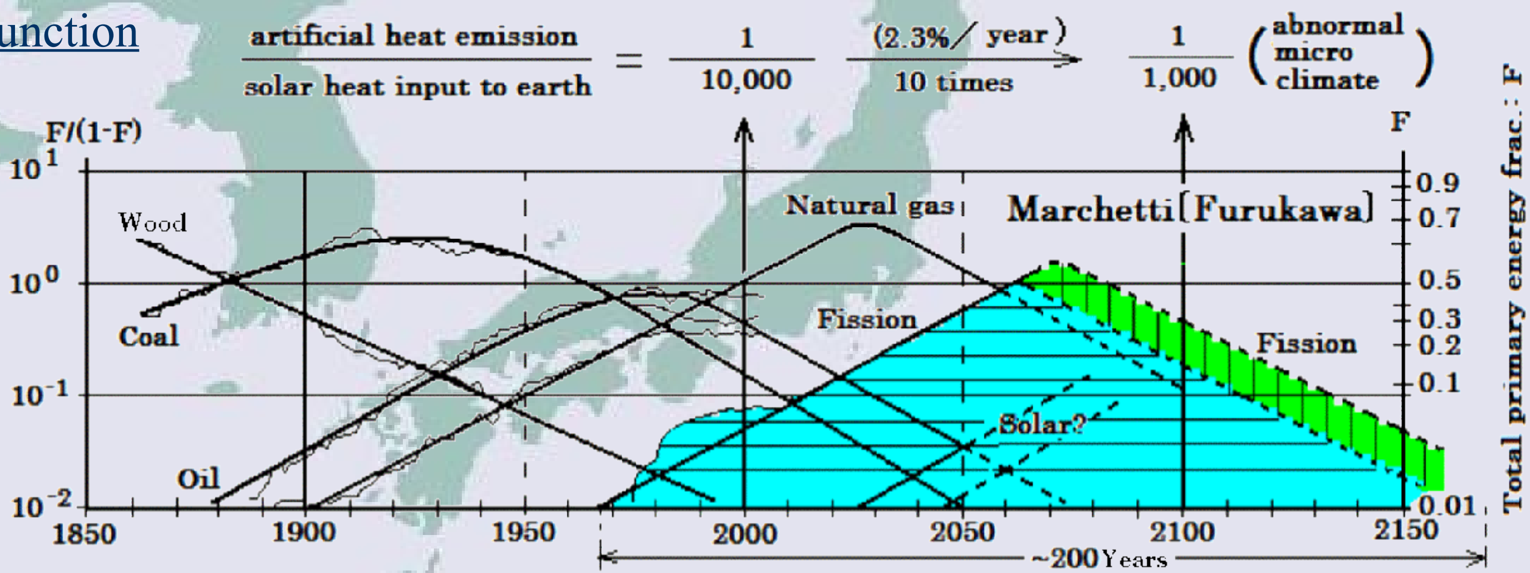
- International Thorium Molten-Salt Forum (ITHMSF)
  - President: Dr. Kazuo FURUKAWA and staffs (Drs. Yoshio KATO, Ritsuo YOSHIOKA, etc.)
- Toyohashi University of Technology (TUT)
  - Laboratory of Prof. Koshi MITACHI
- Hokkaido University (HU)
  - Laboratory of Prof. Yoichiro SHIMAZU
- Kyoto University (KU)
  - Ass. Prof. Takashi KAMEI of Institute of Sustainability Science
- Tohoku University, Osaka university, Tokyo Institute of Technology

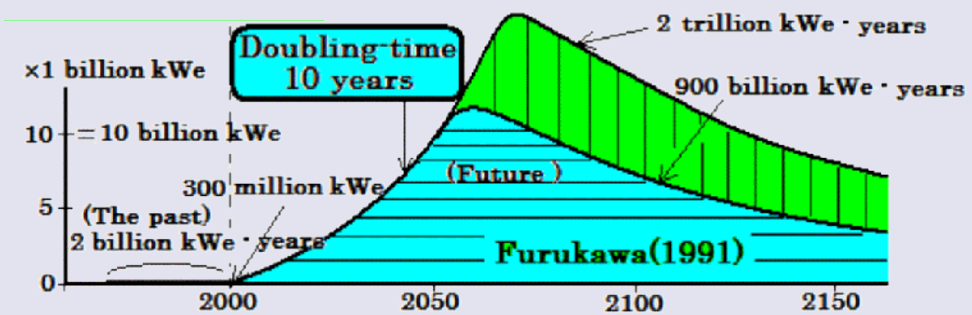
In total, more than 10 scientists are related to MSR research, except foreign coworkers.

Basic Strategy of the MSR Group Activity

Global Future Energy Prediction

Logistic Function





We need a rapid increase of nuclear energy with a doubling-time of 10 years.

Other Requirements for Nuclear Energy

1) Simplicity (structure, operation, maintenance etc.)
2) Excellent Safety (No severe accident)
3) Flexibility in plant size (small to large plant)
4) Nuclear proliferation resistance
5) Economy
6) Flexibility in fuel cycle
   - Th resource: 3-4 times more abundant than U
   - Utilization/Incineration capability of Pu
   - Incineration capability of Minor Actinides, F.P.

↓

One of the best solution is
Thorium-Cycle with Molten Salt Fuel

Research Areas

- ITHMSF: Developmental Strategy of THORIMS-NES composed of MSR ：　FUJI and Accelerator Molten Salt Breeder ：　AMSB
- Toyohashi U.: Thermal and hydraulics analysis and Nuclear design for good breeding capability
- Hokkaido U.: Pu-Th fuel cycle in both thermal and fast MSRs and transient analyses
- Kyoto U.: General investigation of Th usage in view of sustainability

Financial support

- In the present, there are no financial support from the governmental. (Having proposed developmental projects for governmental supports without success.)
- Our basic strategy is to depend on the commercial activity, and to search the financial support of International Industry group under the cooperation with the entrepreneurs' group.

↓

No experiments nor system design have been done in these decades.

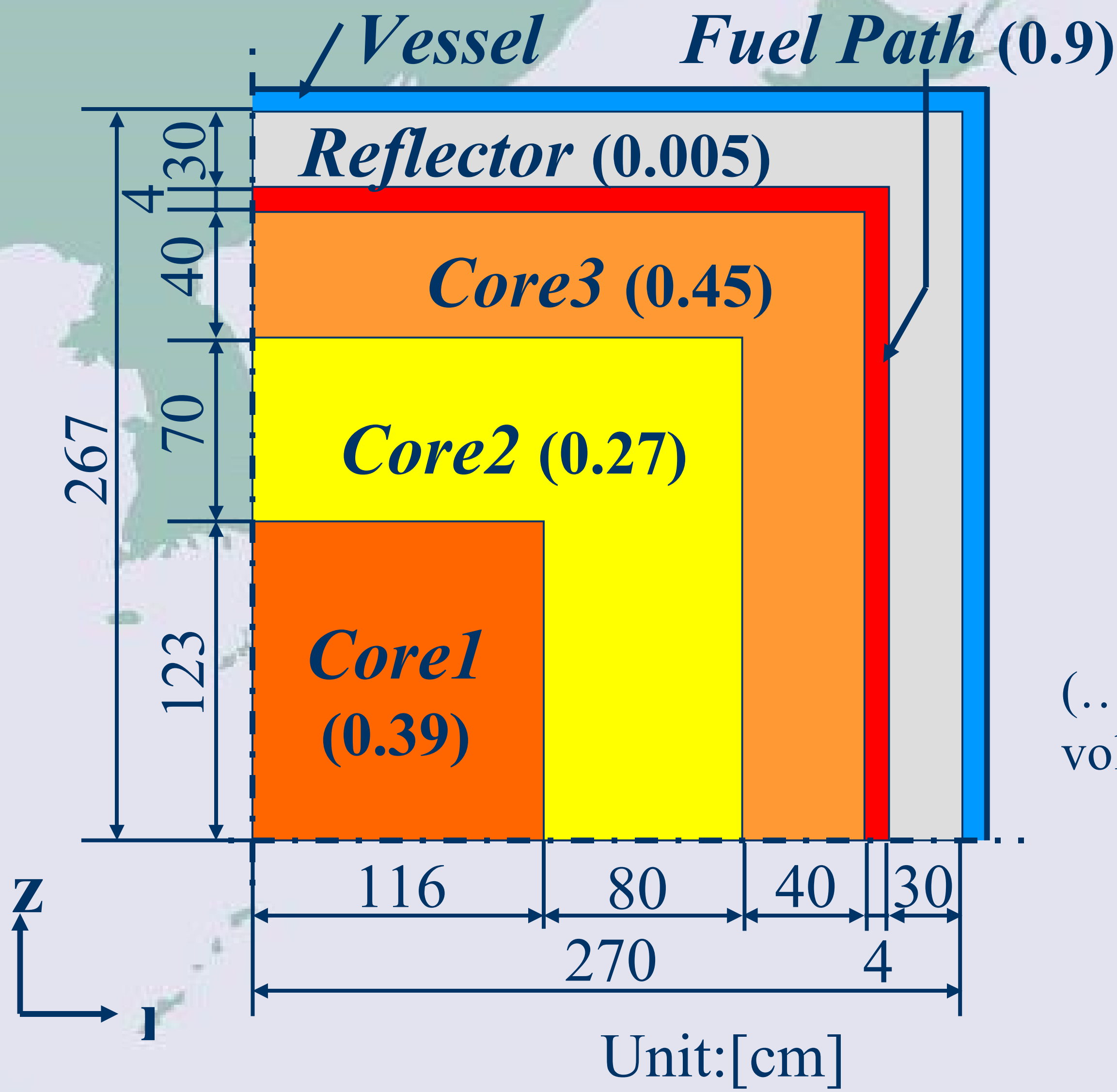
Recent publications-1

ITHMSF	・ K. Furukawa et. al., “Molten-Salt Reactor FUJI,” in “Status of Small Reactor Designs Without On-Site Refueling” IAEA TECDOC-1536(2007). ・ K. Furukawa et. al.,”A Road Map for the Realization of Global-scale Thorium Breeding Fuel Cycle by Single Molten-Fluoride Flow”, Energy Conversion and Management, in print (2008), written by 17 coauthors in the world.
TUT	・ K. Mitachi et al. “Self-sustaining Core Design for 200 MWe Molten-Salt Reactor with Thorium-Uranium Fuel FUJI-U3-(0)” International Workshop on Thorium Utilization for Sustainable Development of Nuclear Energy, TU2007005,Beijing, (2007) ・ Three-region Core Design for 200-MWe Molten-Salt Reactor with Thorium-Uranium Fuel”、 Nuclear Technology, vol.158,No.3,pp348-pp357(2007)
KU	・ K. Furukawa 、 Y.Kato 、 T.Kamei 、 “ Developmental Strategy of THORIMS-NES consisted of Th-MSR “FUJI” and AMSB”, IAEA- TU2007, Beijing, (2007) ・ Statement from the Experts’ Meeting on ”Low Carbon Society Scenarios 2050 and the Roles of China, India and Japan”, Kyoto, Japan, (2007).

Recent publications-2

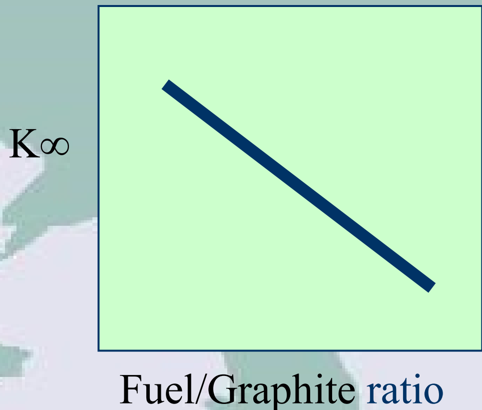
HU	▪ N.Suzuki, Y.Shimazu, ”Preliminary Safety Analysis on Depressurization Accident of a Molten Salt Reactor without Scram”, J.Nucl.Sci.Technol,Vol43,No.7,pp720-730,2006 ▪ Y.Homma, Y. Shimazu, T.Narabayashi, “Flattening of Fast Neutron Flux Distribution in Molten Salt Reactor for Longer Grahpite Moderator lifetime”, Proceedings, PBNC2006, Sydney, CDROM(2006) ▪ Y. Shimazu, N. Suzuki, “Reactivity Initiated Accident Analysis of a Molten Salt Reactor”, Proc. ICENES2007, CD-ROM(2007) ▪ Y. Honma et al, ”Fuel Cycle Study on Pu-Th based Molten Salt Reactors for Sustainable Fuel Supply”, TU2007-003, Beijing, (2007)

FUJI-U3 Core Design (Three region core concept)



(…) is Fuel/Graphite volume ratio.

FUJI-U3 3-region Core Concept



Lower K-infinity by higher Fuel/Graphite ratio, due to lesser neutron moderation.

1) Flux flattening by high F/G ratio(Core1) and low F/G ratio(Core2).

2) Reducing neutron leakage by high F/G ratio(Core3).

	Core1	Core2	Core3
Fuel/Graphite volume ratio	0.39	0.27	0.45

FUJI-U3 Design Conclusion

Assuming 75% capacity factor and chemical processing interval of 7.5 years,

1) Conversion Ratio = 1.0 (for 30 years average)
   ⇒Self sustaining reactor
2) No graphite replacement for 30 years.
3) Scaling FUJI (250 MWe) to 1 GWe plant, and compare with 1 GWe BWR.

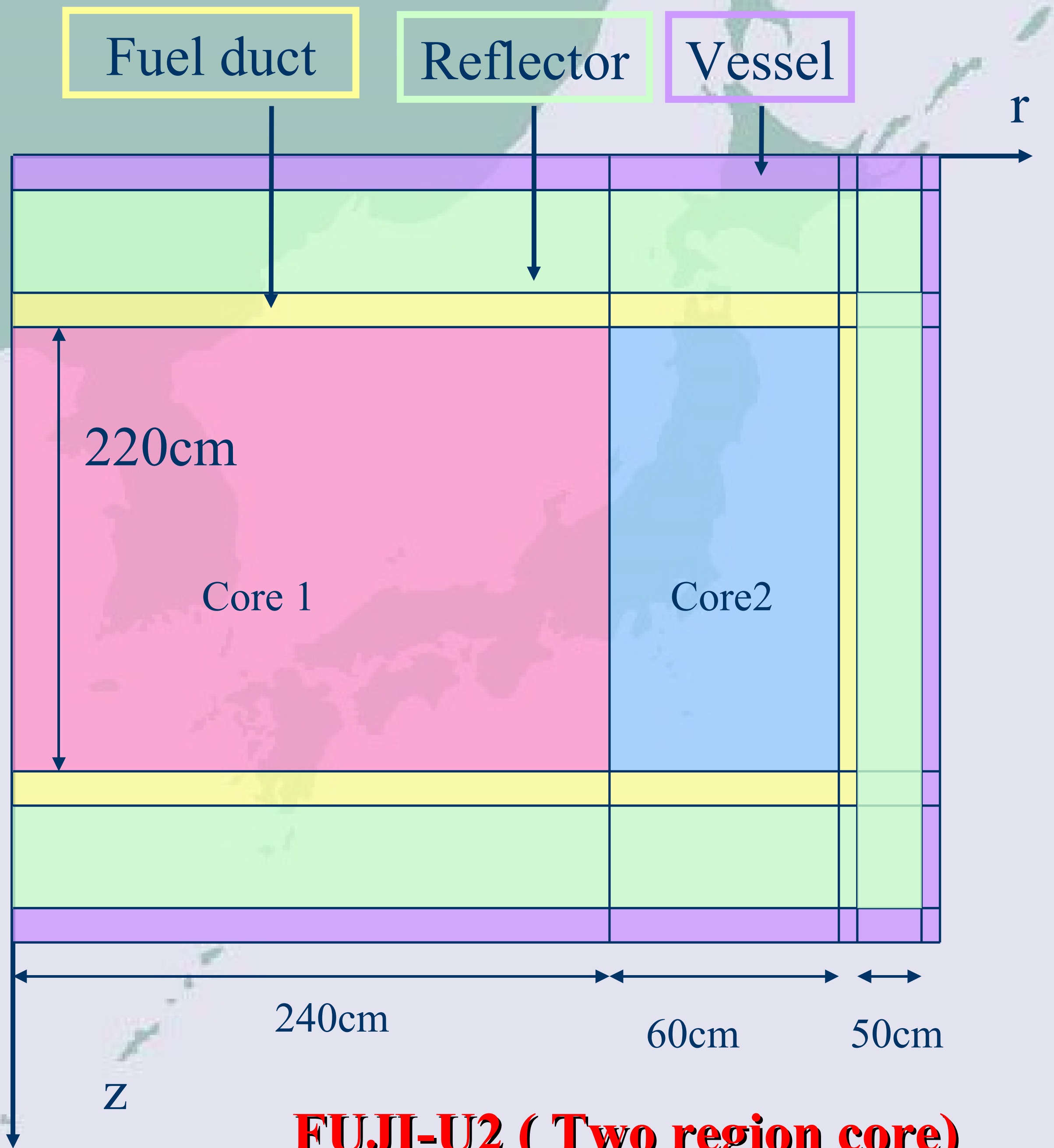
For 30 years total:	FUJI-U3 (1GWe)	Relative to 1GWe BWR
Fissile requirement	7.8 t (★)	32%
Pu production	4 kg	0.1%
MA (Np/Am/Cm) production	23 kg	4 %

★ Since CR is 1.0, the above 7.8 t fissile is discharged at the end of reactor life, and it can be used to the next reactor.

FUJI-U3 Core Parameters

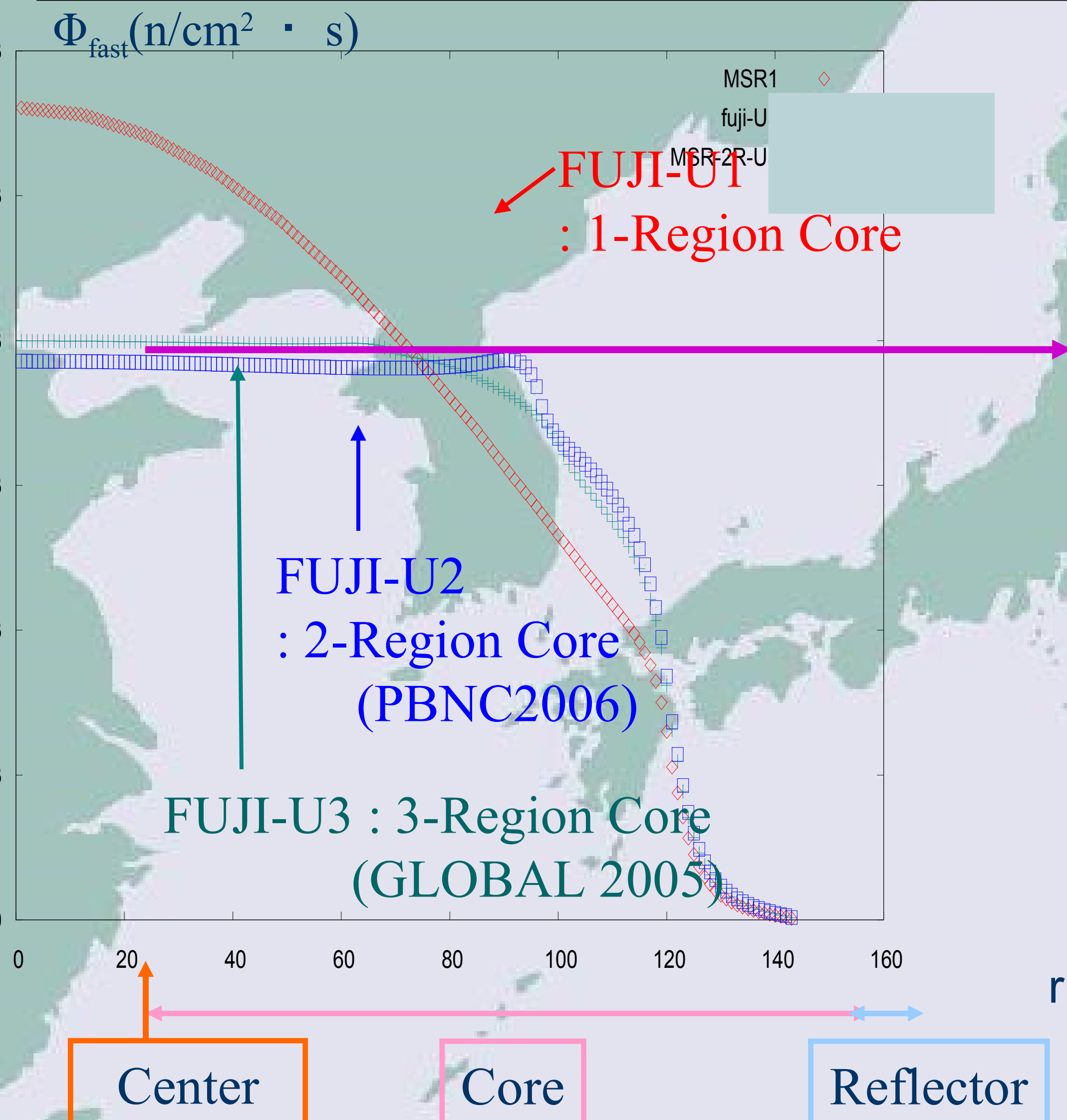
Electric output	200 MWe
Thermal output	450 MWth
Thermal efficiency	44.4%
Reactor vessel Diameter/Height	5.40 m/5.34 m
Core Diameter/Height	4.72 m/4.66m
Structural material	Modified Hastelloy-N
Fuel salt composition	LiF-BeF_2-ThF_4-$^{233}UF_4$.
mol %	71.76, 16, 12, 0.24(initial)
Conversion ratio (mean value)	1.01
Temperature coefficient (dk/K)	-2.7×10^{-5} 1/K (average)

Published at "International Workshop on Thorium Utilization for Sustainable Development of Nuclear Energy", Beijing, 2007/12.



FUJI-U2 (Two region core)

Results of the calculation of ^{233}U-MSR



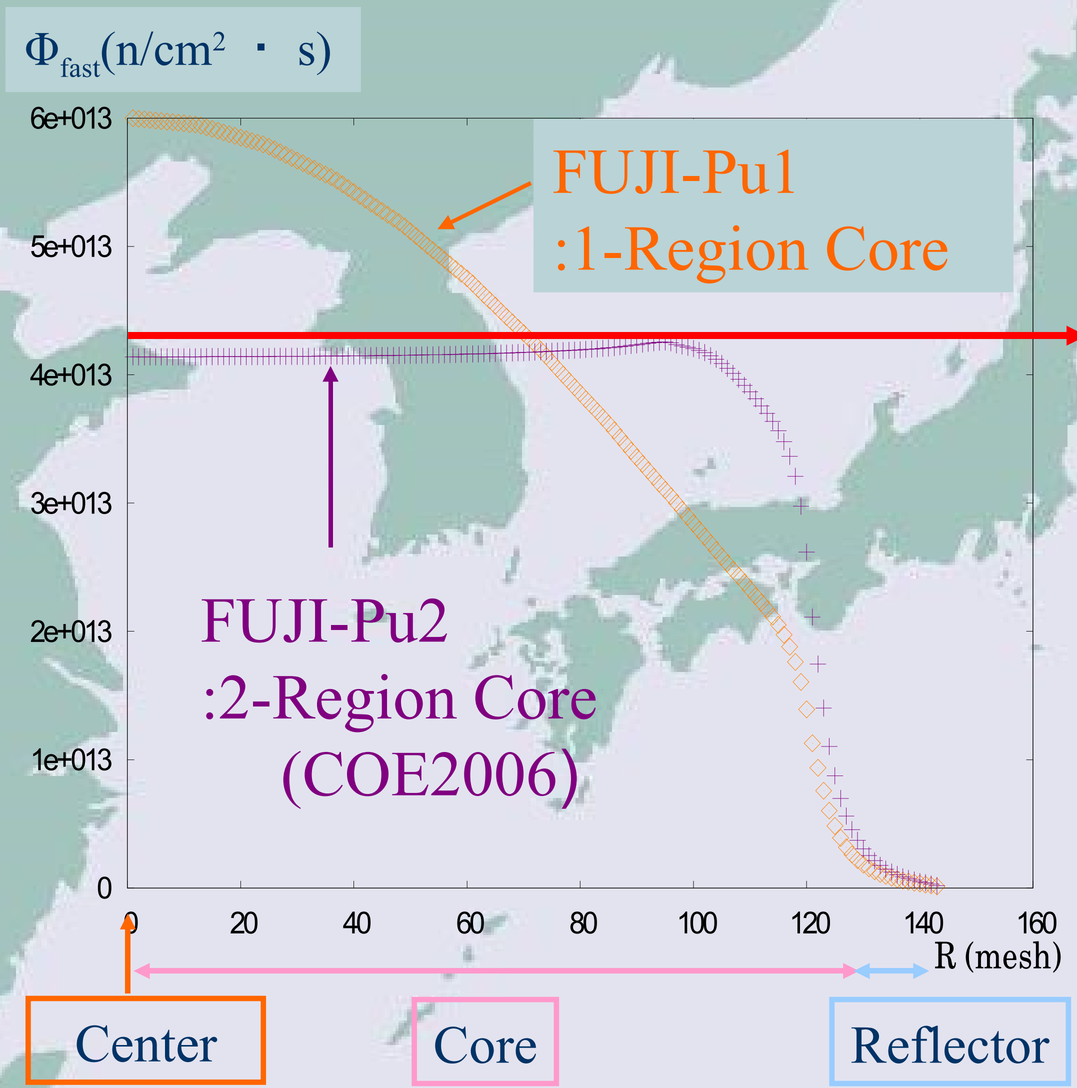
Irradiation limits of graphite moderators for 30 years operation

Moderator life (years)

FUJI-U1	21.7
FUJI-U3	30.7
FUJI-U2	33.2

Radial distribution of fast neutron flux greater than 52keV

Results of the calculation of Pu-MSR



Irradiation limits of graphite moderators for 30 years operation

r (mesh)

Moderator life (years)

FUJI-Pu1	20.2
FUJI-Pu2	30.0

Radial distribution of fast neutron flux greater than 52keV

Major R&D Concerns

1	Neutronic design	No significant concerns about reactor physics model. But, nuclear cross-section measurements for isotopes of the ^{233}U-Th cycle and the corresponding integral experiments are necessary.
2	Fuel chemistry	No serious problems. But, the examination of detailed PuF_3 solubility data in relation to other fission product ions is necessary.
3	Structural materials (Modified Hastelloy-N)	Endurance tests should be performed in the miniFUJI pilot plant. The problem of Te attack could be solved by modified Hastelloy-N (1-2% Nb added), and redox potential control.
4	Core graphite	Irradiation tests should be performed using a powerful reactor such as the MS-4 in Russia. Further development to improve radiation growth of graphite is preferable.

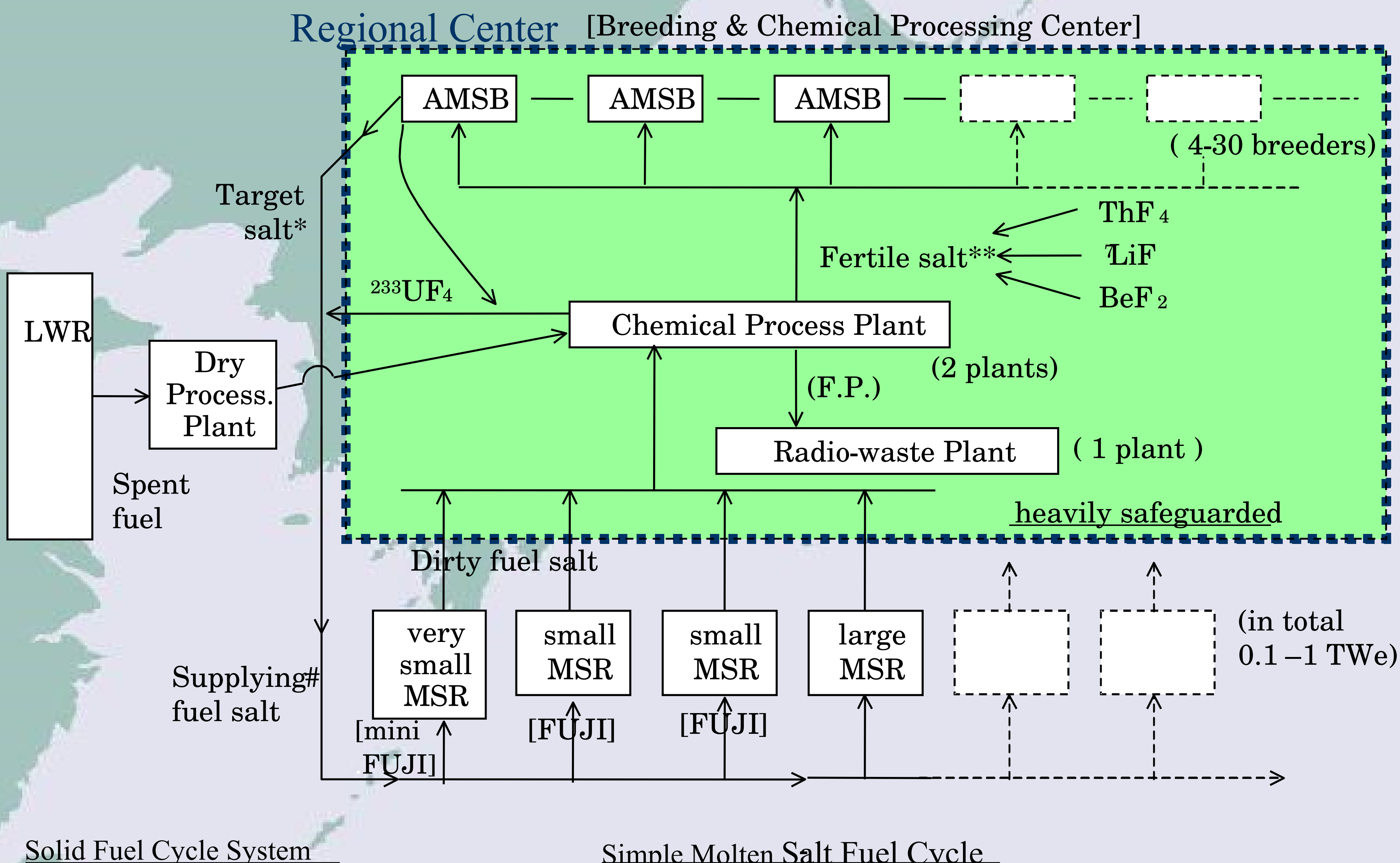
THORIMS-NES (1/2)

THORIum **M**olten-**S**alt **N**uclear **E**nergy **S**ynergetic System

Basic Concept depends on three principles:

[I] Thorium utilization
[II] Application of Molten-Fluoride Fuel technology
[III] Separation of Fissile-Producing Accelerator Breeders
(AMSB) with chemical process plant
& Power Generating Fission-Reactors (FUJI)

THORIMS-NES (2/2)



(*)^7LiF-BeF_2-ThF_4-$^{233}UF_4$ (**)^7LiF-BeF_2-ThF_4 (#)target salt* + additive $^{233}UF_4$

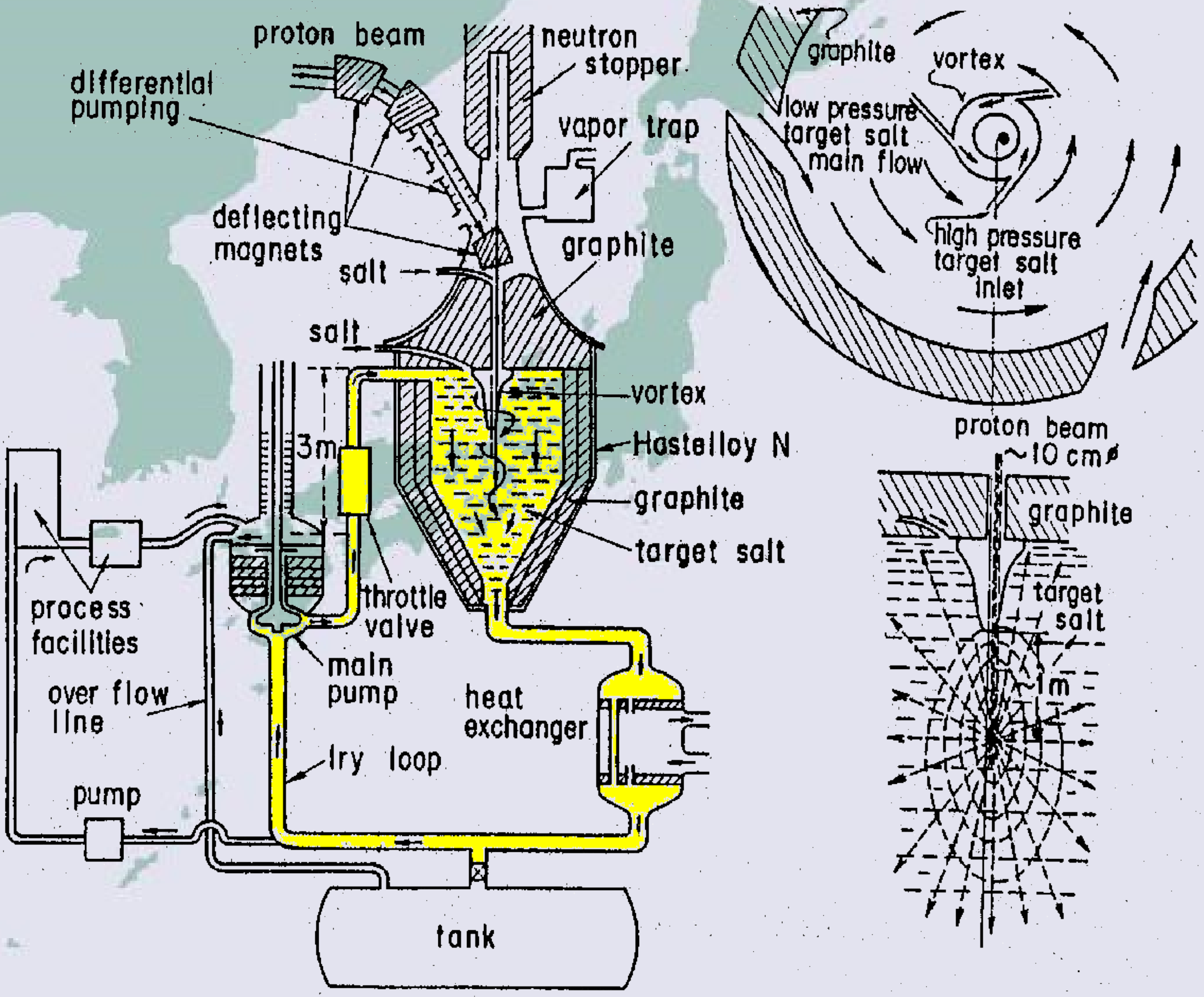
Accelerator Molten-Salt Breeder: AMSB

Composed of three parts:

- 1GeV and 200-300 mA proton accelerator
- Single-fluid molten fluoride target/blanket system
- Heat transfer and electric power recovery system

- ■ sub-critical
- ■ no radiation damage
- ■ easy heat removal
- ■ no target/blanket shuffling
- ■ gas-curtain window
- ■ multi-beam funneling available
- ■ simpler chemical aspects

AMSB Concept



Developmental Strategy of THORIMS-NES

1) Installation/Operation of **miniFUJI** (7-10 MWe) : 7 years later

2) Installation/Operation of **FUJI-Pu** (100-300MWe) : 12 years later

Pu from the existing spent-fuels : using and eliminating Pu

Depending on such MSR-technology development,

3) Development and Installation of **AMSB** : 20-30 years later

Deployment Plans of THORIMS-NES

F-plan: Fission reactor development:

miniFUJI and FUJI in several versions.

FUJI power stations of smaller as well as larger size

D-plan: Dry-processing of spent fuel salt and target/blanket salts

Pu including fuel salt preparation from spent solid fuels of ordinary reactors such as LWR, FBR, HWR etc.

A-plan: Accelerator Molten-Salt Breeder (AMSB) development

Experimental, Prototype, & commercial facilities

Regional Centers Deployment plan:

Chemical processing & Radio-waste management plants

Developmental Schedule of THORIMS-NES

INITIAL STAGE PROGRAM

General R & D
- Fuel-salt loop
- Coolant-salt loop
- Electric generating test loop (200K We)
- Integral test loop (2M We)
- Materials (salts, alloy, graphite)
- Components & Instruments

F1. Pilot-plant (miniFUJI-Pu)
- Reactor design
- Reactor mock-up
- Reactor remote maintenance
- Reactor construction & operation

D1. modified FREGATE

D2. Chemical Processing of Fuel Salts

MIDDLE TERM PROGRAM

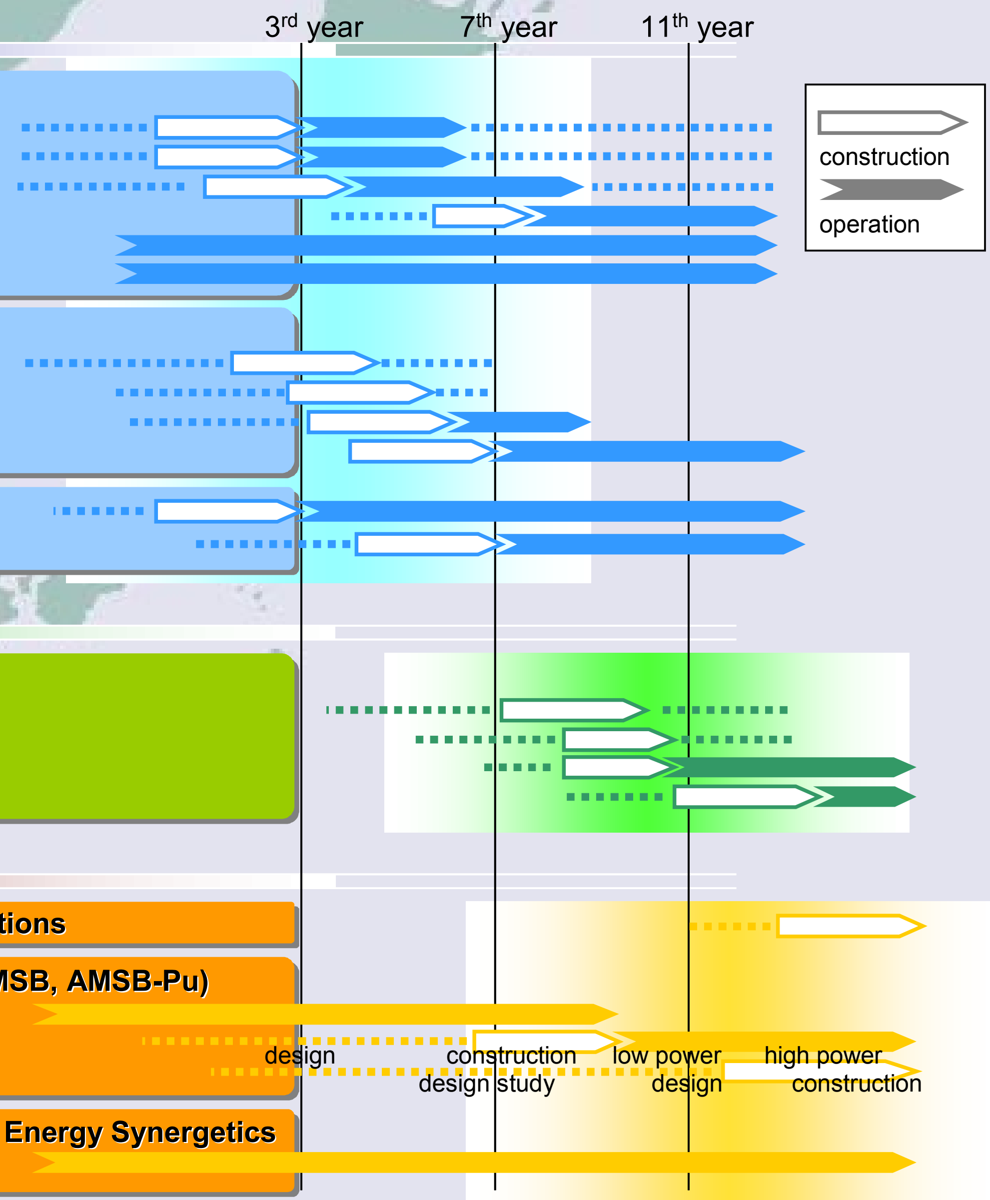
F2. Small Molten-Salt Power Station (FUJI-Pu)
- Reactor design
- Reactor mock-up
- Reactor remote maintenance
- Reactor construction & operation

LONG TERM PROGRAM

F3. Medium-, and Large-Molten-Salt Power Stations

A. Fissile Producing Breeder Development (AMSB, AMSB-Pu)
- Preliminary R & D
- Integral experimental facility (5mA proton beam)
- Prototype facility (50mA proton beam)

Establishment of Thorium Molten-Salt Nuclear Energy Synergetics
- System design study



Future Plan

ITHM SF:	International cooperation with Russia, USA, Europe and other countries. Participation in GIF (Generation IV International Forum)
TUT	Control capability study for MSF-FUJI.
HU	Fuel cycle optimization for Pu and MA burning
KU	Scenario study of energy supply-demand balance at the time of the global use of thorium and a fossil fuel reduction. Scenario study of a smooth shift from the present uranium-LWRs to thorium-MSRs. Safeguard of thorium usage in the countries except the nuclear weapon holders. Strategic competition of thorium usage with the uranium promotion countries (France, Russia etc.) Design of best mixture of energy technologies including thorium nuclear power and renewable energy accepted local circumstances.

Conclusion

1) MSR-FUJI in THORIMS-NES has Excellent Safety / Flexibility in plant size / Nuclear proliferation resistance / Good economy / Flexibility in fuel cycle (Incineration capability of Plutonium and Minor Actinides).

2) Although our activities are based on private and voluntary basis, analytical investigations are being carried out step by step, aiming an early-stage huge-size commercialization of Thorium Energy Industry.