資料　４－１

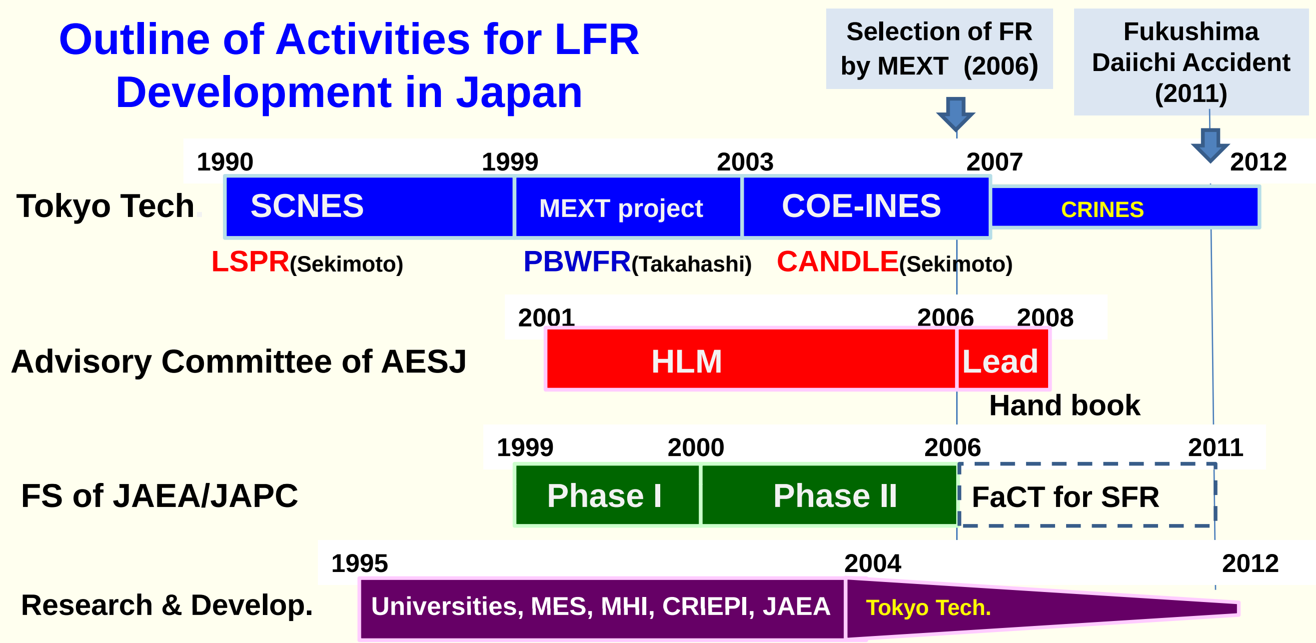
第11回GIF-LFR pSSC
（イタリア、ピサ、2012年4月16日）
日本側発表資料　高橋　実

11th LFR Prov. SSC Meeting
Pisa, Italy, 16 April, 2012

National Status on LFR Development in Japan

Minoru Takahashi
CRINES, Tokyo Institute of Technology

Outline of Activities for LFR Development in Japan



Tokyo Tech.: Tokyo Inst. of Tech.
AESJ: Atomic Ener. Soc. of Japan
JNC: Japan Nucl. Cycle Dev. Inst.
JAEA: Japan Atomic Ener. Agency
JAPC: The Japan Atomic Pow. Company
MEXT: Min. of Edu.,Cul.,Sports, Sci. Tech.
MES: Mitsui Eng. & Shipbuild.
MHI: Mitsubishi Heavy Indus.
CRIEPI: Central Res.Inst. of Elec.Pow. Indus.

SCNES: Self-Consistent Nucl. Ener. Sys.
COE-INES: 21st Cen. Center of Excel. Program "Inno. Nucl. Ener. Sys. for Sustainable Dev. of the World
CRINES: Center for Res. into Inno. Nucl. Sys.
FS: Feasibility Study on Commer. FR Cycle Sys.
FaCT: FR Cycle Sys. Tech. Dev. Project

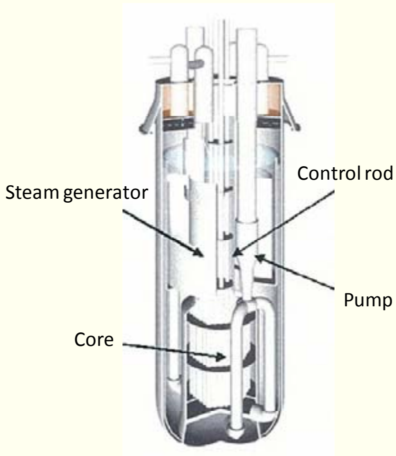
Proposal of LFR concepts in Tokyo Tech.

➢A concept of long-life small safe reactor, potential of small nuclear reactors for future clean and safe energy sources was studied from 1990, and LSPR was proposed by Prof. Sekimoto in 2001.

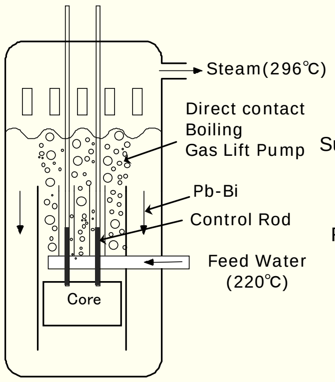
➢As a more simplified and economical LFR, PBWFR was proposed by Prof. Takahashi in 2003.

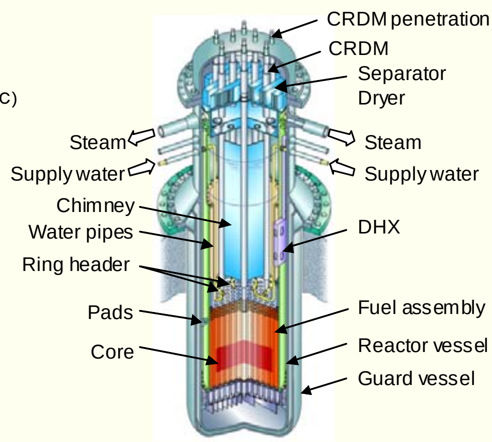
➢Basic studies for the LFRs have been continued by CRINES of Tokyo Tech. Innovative burning scheme named CANDLE is under investigation.

LSPR -50



PBWFR-



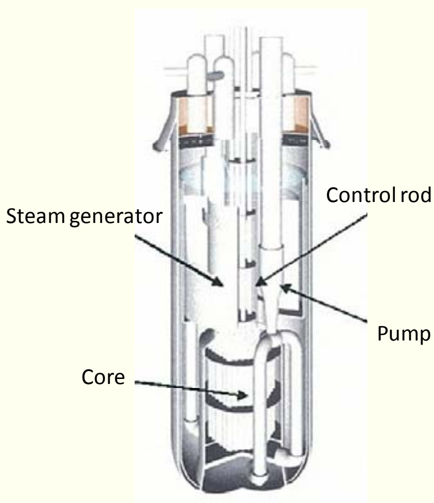


Proposal of LFR concepts in Tokyo Institute of Technology

◆**LSPR**-Tokyo Tech (Sekimoto)

As a small reactor with long life core, the concept of **LSPR (LBE-cooled long-life Safe Simple Small Portable Proliferation resistant Reactor)** was proposed. Small reactors will be constructed in factories of the nuclear energy park, transported to the site, and deployed. The reactor vessel is sealed without being opened at the site. for refueling, which is excellent for proliferation resistance. At the end of the reactor life, it is replaced by a new one. The old one is shipped to the nuclear energy park. There is no radioactive waste left at the site. In other words, the site is free from the waste problems.

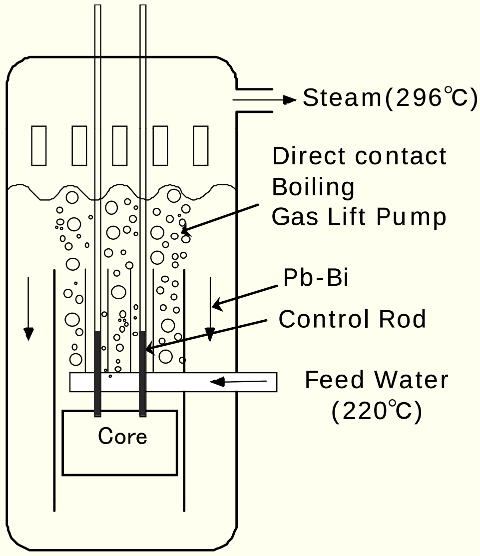
LSPR



Proposal of LFR concepts in Tokyo Institute of Technology (cont'd)

◆**PBWFR**-Tokyo Tech (Takahashi)

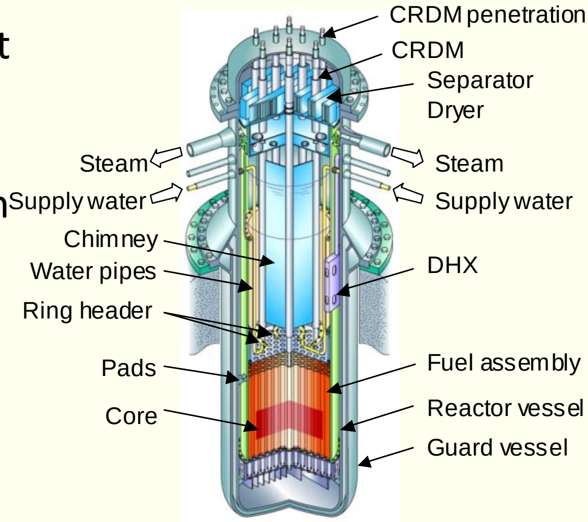
Lead alloy is corrosive, which causes erosion on the surfaces of structural materials in certain conditions. To avoid the corrosion and erosion problem, the components that contact lead alloy should be eliminated as much as possible. Particularly, the concern is corrosion on tube surfaces of steam generators (SG) exposed to high temperature coolant, and erosion on the surfaces of impellers of primary pumps exposed to high velocity flow.).



Proposal of LFR concepts in Tokyo Institute of Technology (cont'd)

◆**PBWFR (cont'd)**

Thus, the feasibility of the elimination of the SGs and the primary pumps by direct injection of a feed water into hot LBE above the core has been studied. The injected feed water boils in a chimney and steam bubbles go up with buoyancy force. The bubble motion serves as a driving force of coolant circulation in the use of the heavy coolant. This design concept of LFR is called **PBWFR (Pb-Bi-cooled direct contact boiling Water Fast Reactor).**



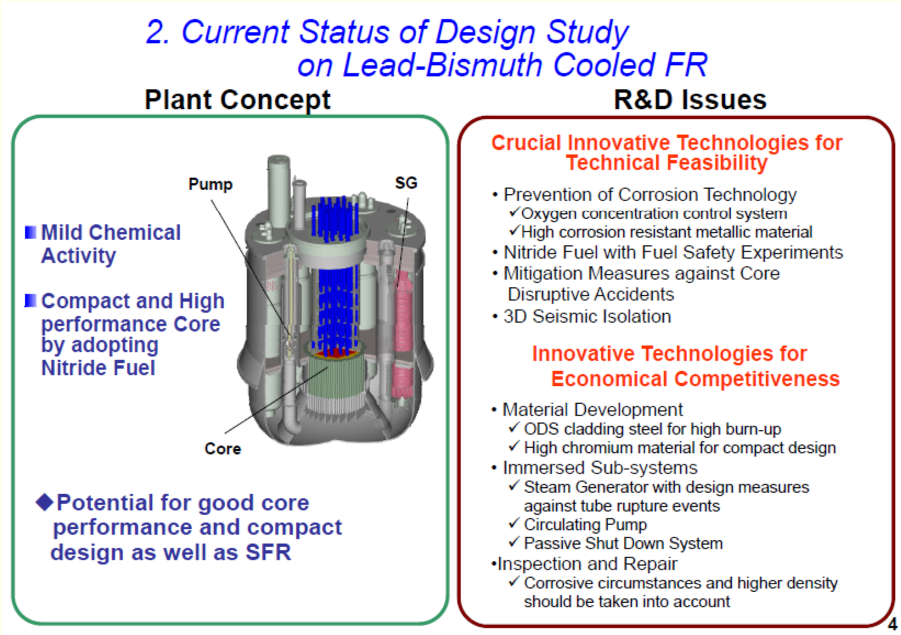
Main parameters of LSPR and PBWFR (Tokyo Tech.)

	LSPR-50	PBWFR-150
Power, Thermal/Electric, MW	**150/53**	**450/150**
Thermal efficiency, %	35	33
Core diameter/height, m	1.652/1.08	2.78/0.75
Fuel	**U-Pu-10%Zr mettalic or U-Pu nitride**	**U-Pu itride**
Fuel pin diameter, mm	10	12
P/D, Inner core/Outer core	1.12/1.18	1.3/1.3
Linear power density, W/cm	51.9 (Average)	363 (max.)
Pump type/unit number	Mechanical / 2	**Gas lift /1**
Temperature, inlet /outlet, ˚C	360/510	310/460
Coolant flow rate, t/h	12,300	73,970
Steam generator, Type/Unit number	Serpentine tube/2	Direct contact/1
Temperature, Feed water/Steam, ˚C	210/280	220/296
Steam pressure, MPa	6.47	7.0
Reactor vessel, diameter/height, m	5.2/15.2	4.69/19.8
Refueling interval, y	**12**	**10**

Proposal of LFR concepts in Japan

Best possible performance of LFR concepts, for improvement of economic and other performance for comparison and selection

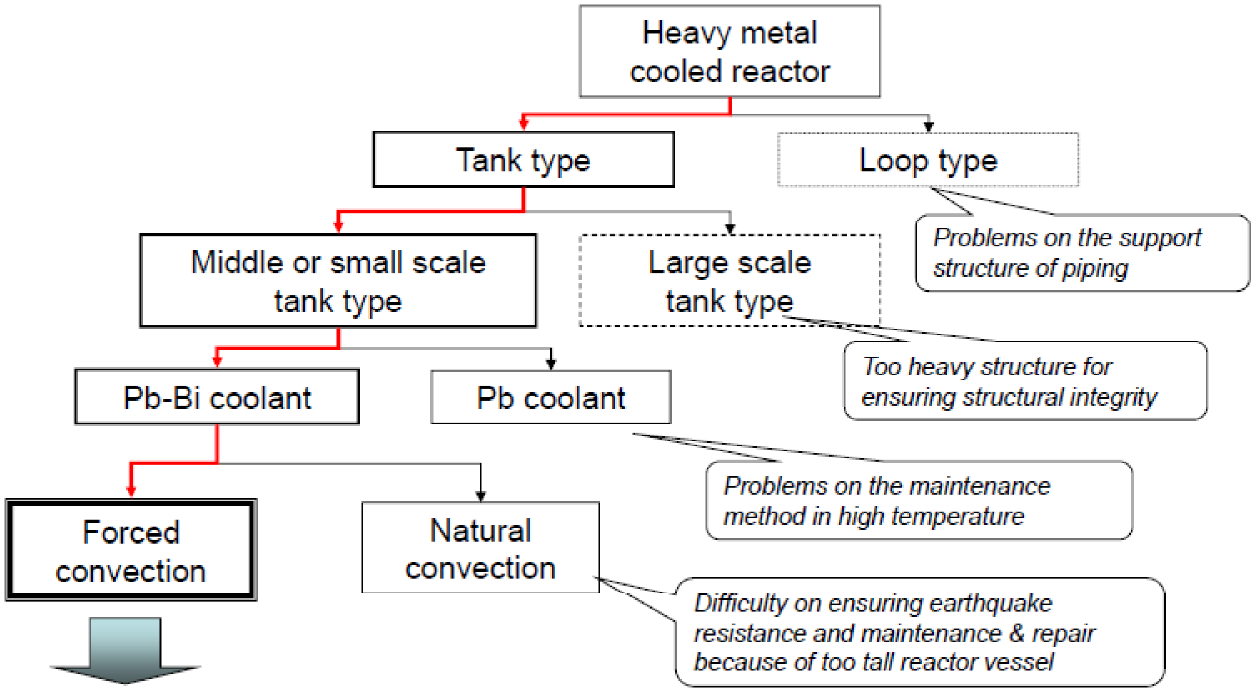
Feasibility Study on Commercialized Fast Reactor Cycle Systems by JAEA/JAPC



Technical explanation will be provided later again.

S. Kotake, et al. GLOBAL 2005, Oct. 9-13, 2005, Tsukuba, JAPAN

2. Current Status of Design Study on Heavy Metal Cooled FR



Pb-Bi cooled middle scale tank type modular reactor (forced convection) has been selected as the most promising heavy metal cooled FR concept

Requirement		SFR (1500MWe)		LBE-cooled FR (750MWe)	
		Breeder core	Fuel economy	Breeder core	Fuel economy
Safety		Experiment for passive safety and measure for avoid of re-criticality		Avoid of re-criticality by fuel floating	
Utilization of nuclear resource	BR	1.1	1.03	1.1	1.04
	Fissile inventory (t/GWe)	5.7	5.8	5.9	5.9
	Replacement time for FR (y)	60	-	70	-
Environmental burden	MA burn (%)	5 from LWR			
	FP transmutation	LLFP (I-120, Tc-90)			
Economy	In-core aver. (>150) (GWd/t)	147	150	154	155
	Whole-core aver. (>60) (GWd/t)	90	115	105	128
	Oper. Period (month)	26	26	18	18
	Availability (%)	95	95	93	
	Outlet temp. (℃)	550		445	
	Thermal effic./outside load factor	42.5/4		38/3	
	Unit construction cost (<200kJPY/kWe) (%)	90		100	

Political Decision for Development of FBR Cycle System in Japan

- Jul. 1999 - JFY2006, **JAEA/JAPC** : Feasibility Study on **Commer. FR** Cycle Sys.

  Phase I (Jul. 1999-JFY2000): Extraction of **typical FR system concepts**

  Phase II (JFY2001-2006): Investigation of the concepts to bring out **attractive properties**
- 2 Nov. 2006, **MEXT**: Research and development **policy** of FR Cycle System
- 26 Dec.2006, **AEC**:

  Basic Policy on Research and Development of FBR Cycle Technologies over the Next Decade ----- **Selection of SFR and GFR**
- 2006, **JAEA/JAPC**: Start of Fast Reactor Cycle Technology Development Project (FaCT Project); July 2007 **MFBR**(MHI); June **2011**, Phase I Report
- JFY2011, Postpone of conceptual design; currently **strengthening of safety system**

AEC: Japan Atomic Energy Commission

MEXT: Ministry of Education, Culture, Sports, Sci. and Tech.-Japan

JAEA: Japan Atomic Energy Agency

JAPC: The Japan Atomic Pow. Company

Activities in Tokyo Institute of Technology

- Systematic research toward "**Construction of Self-Consistent Nuclear Energy Systems**".

  Design concepts of **small LFR** proposed in the early 1990s, and related feasibility studies performed.
- JFY 2003-2007 21st Century Center of Excellence (COE) Program "*Innovative Nuclear Energy Systems for Sustainable Development of the World (**COE-INES**)*" (integrating research with education)
- From 1 Jan. 2006 till Present, Center for Research into innovative nuclear Energy Systems (**CRINES**) , (promoting the innovative nuclear energy systems)
- **GIF MOU** for collaboration between our center and EU started in 2010, and Rosatom joined it this year **without support of Japanese government (MEXT)**

Budget: MEXT Education Program

21st Century Center of Excellence (COE) Program (COE-INES) in Tokyo Tech.

- The purpose was to reinforce university education and research functions for study at a higher level and cultivation of creative, internationally competitive talent.
- The proposal, **"Innovative Nuclear Energy Systems for Sustainable Development of the World (COE-INES)"**, is the only chosen one for the Nuclear Engineering Category.
- CANDLE burning was proposed by Prof. Sekimoto

MEXT: Japanese Ministry of Education, Culture, Sports, Sci. and Tech.

Budget: MEXT Development Program

Innovative Nuclear R&D Program

(From JFY 2005 till Present)

JPY: Japanese yen

FY	Approved	FY	Approved
2005	7	2009	9 (Total 5.8 B JPY)
2006	13	2010	6 (Total 4.1 B JPY)
2007	3	2011	0
2008	2	2012	-

FY 2012		
Title	Budget	Number of program approved
Nuclear Energy System (4 year)	10M-100M JPY/y	10-15
Basic Strategy Research Initiative	5M-35M JPY/y	12

Budget: MEXT Development Program

Innovative Nuclear R&D Program for LFR

(Approved programs related to LFR)

JFY	Researcher	Title	Budget
2002	**ADS Gr. of JAERI**	Development of **ADS** Technology	
2002-2004 (3y),	**Takahashi (Tokyo Tech.)**,	Development of **Pb-Bi-cooled** Direct Contact Boiling Water Small Reactor	Total 395M JPY
2005	**A. Kimura (Kyoto Univ.)**	, Development of **Super ODS** Steels R&D for Fuel Cladding	1.426B JPY for 5y
2006	**M. Sato (Tohoku Univ.)**	Adhesion Strength of Corrosion-resistant Film for **LFR**	

Current Status of Nuclear Energy in Japan

26 Aug. 2010, Trouble in prototype SFR Monju

11 Mar. 2011, Fukushima Diichi NP accident

May 2011, Operation of Hamaoka NPP suspended

2011, Conceptual design of SFR postponed in FaCT program

Apr. 2012, Oii units 3 & 4 judged to be safe by Government

5 May 2012, Operation of Tomari Unit 3 to be stopped for inspection, resulting in no operation of NP in Japan.

Apr. 2012, Reorganization of Nuclear Regulatory System

Period of more than 40 years for decommissioning of Fukushima Daiichi NP units 1-4 in the future

Prototype SFR, Monju

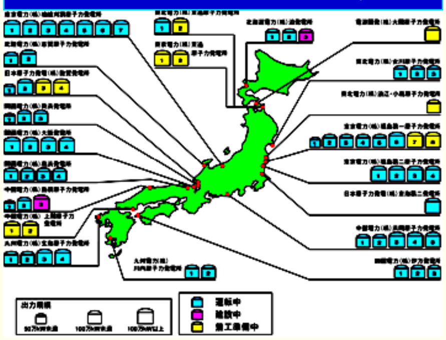
Hihg chances of a powerful quake striking the Hamaoka region

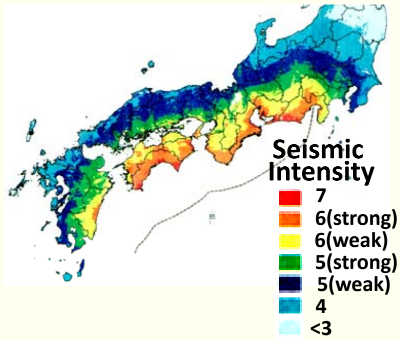
M9.1-class Earthquake in Nankai Trough

New Prediction of Tsunami (Tidal Wave) in Mar. 2012

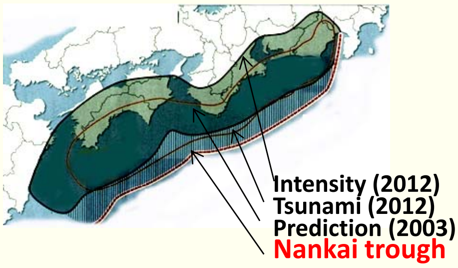
Earthquake	Area (km²)	Mag.
Nankai trough (Intensity)	110 M	9.0
Nankai trough (Magnitude)	140 M	9.1
North-east Japan (2011)	100 M	9.0
Sumatra (2004)	180 M	9.0
Chile (2010)	60 M	8.8
Prediction (2003)	61 M	8.7

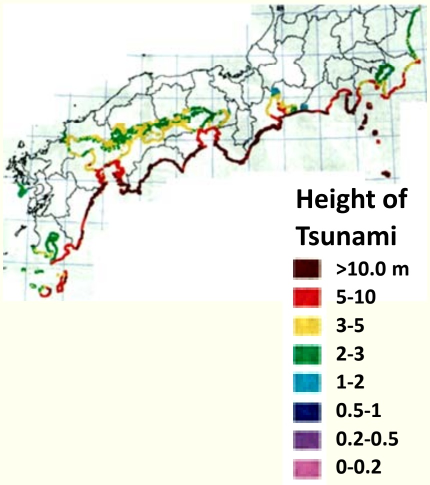
Nuclear Power Plants in Japan

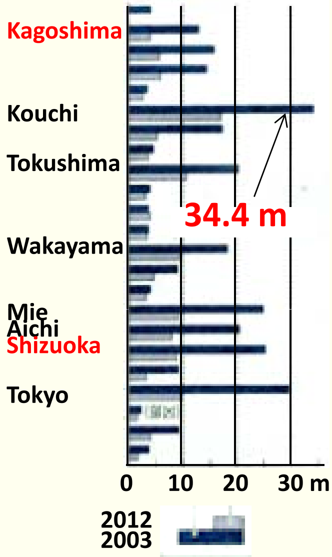




Hypocenter







Review of Energy Policy in Japan

- Mar. 2012 Ministry of Economy , Trade and Industry (METI)

Candidates of desirable electric energy mixture (%)

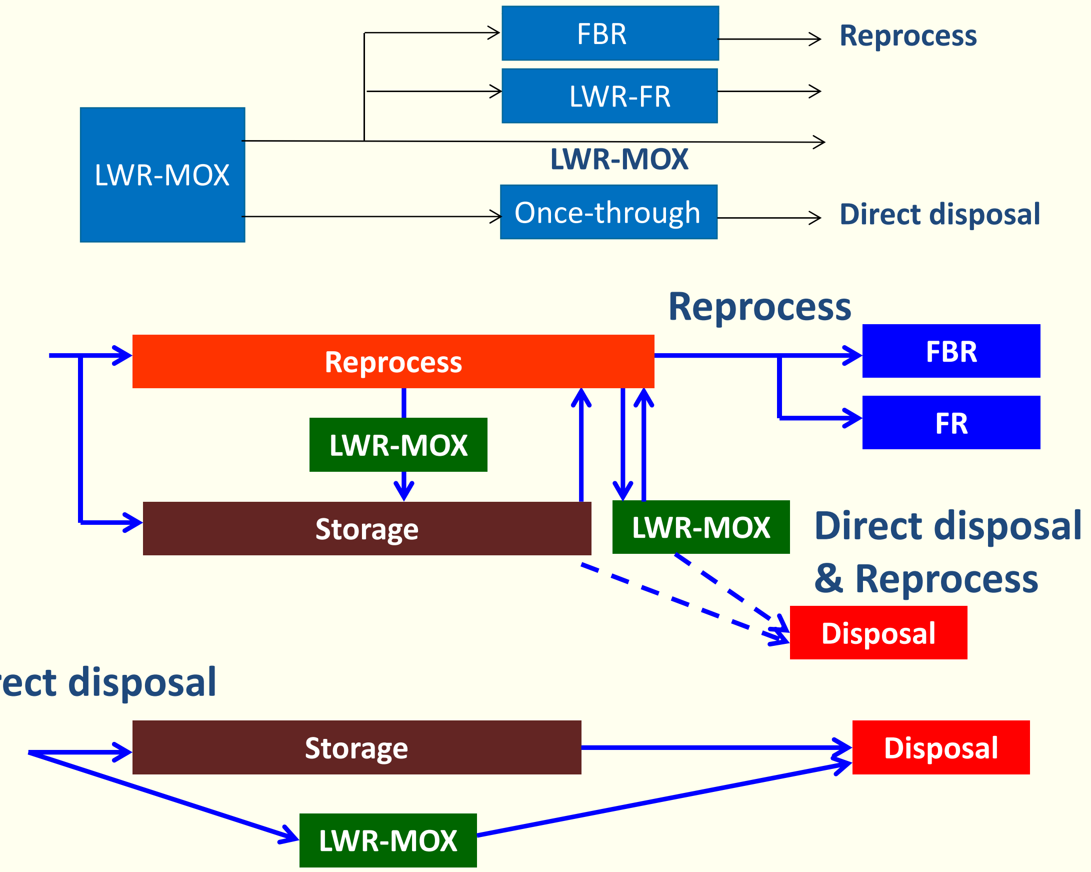
(Final decision in May 2012)

Nuclear (LWR)	Renewable	Thermal	Co-gen./Ind.
0	35	50	15
20	30, 25	35, 40	15
25	25, 20	35, 40	15
35	20	30	15

- 2012, **AEC**: Revision of “Framework for Nuclear Energy Policy”

Mar. 2012 AEC: Japan Atomic Energy Commission

Present Options in Nuclear Energy Policy in Japan



Why was the LFR concept excluded?

Phase II Final Report of Feasibility Study on Commercialized Fast Reactor Cycle Systems by JAEA/JAPC

2.1 Technical summary of FR systems

2.1.3 Lead-bismuth-cooled reactor

- By applying nitride fuel, LFR has the potential to achieve core performance equivalent to SFR and meet all the design requirements.
- Essential issues include the **corrosion of steel** such as the fuel cladding in addition to the development of the **nitride fuel**.
- Fundamental R&D is needed to develop corrosion prevention technology and corrosion resistant material. It is quite difficult to prepare alternative technologies for these issues at this stage.
- Although **LFR** was also selected as one of the candidate reactor types at the GIF project, **no country has taken leadership in its development thus far, and, hence, a breakthrough in the fundamental issues by international cooperation is unlikely.**

Phase II Final Report
March, 2006, JAEA/JAPC

2.1.5 Promising concepts for the FR system

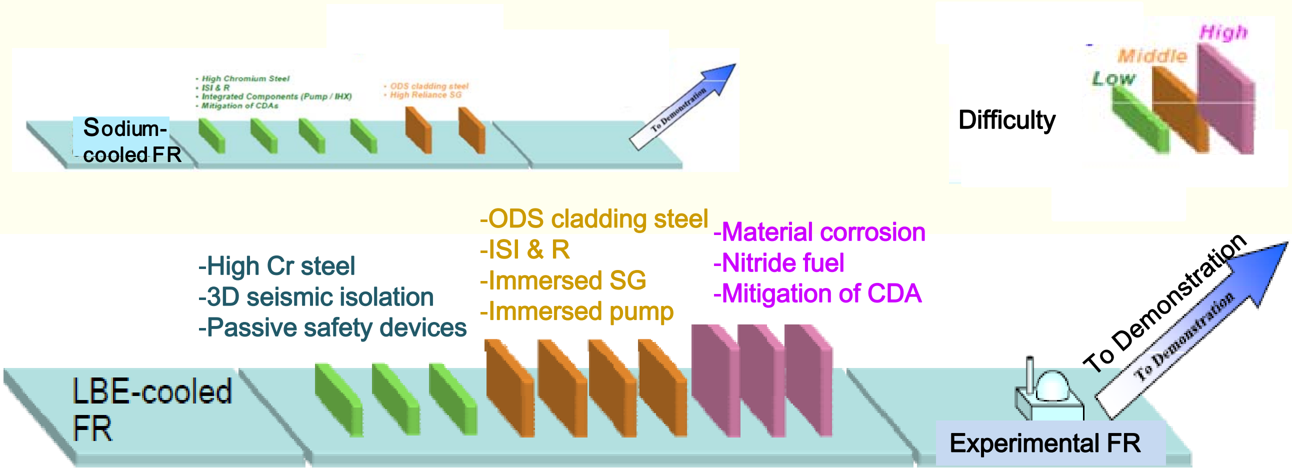
- **SFR** is superior to other reactor types from the perspective of both potential conformity to the design requirements and technical feasibility.
- Furthermore, since it has the potential to be adopted as an **international standard concept**, which may help to enhance technical feasibility, it is evaluated as the most promising FR system concept.
- **The other FR concepts cannot become superior to the above-mentioned promising ones (SFR & GFR) from the perspective of either the potential conformity to design requirements or technical feasibi**lity.

S. Kotake, et al. GLOBAL 2005, Oct. 9-13, 2005, Tsukuba, JAPAN

4. Summary of Suitability to Design Requirements

LFR has a good potential for core performance as well as SFR by adopting nitride fuels. But core performance may be reduced by reflecting safety experiment issues and lead-bismuth corrosion test in phase II study.

5. Technical Feasibility of Each FR Concept



2.3 Discussion on the principle for prioritization

2.3.1 Evaluation of the entire FR cycle system

□In selecting promising FR cycle concepts, it is appropriate to evaluate potential conformity to the development goals, technical feasibility and other factors of not only the FR system and the fuel cycle system, respectively, but also the entire FR cycle system that is the combination of the two systems.

□It is concluded that **SFR is the most promising concept and GFR (Helium gas-cooled reactor) is a promising concept**.

2.3.2 Principle for prioritization

□In order to prioritize R&D, the above-mentioned concept (a) is selected as "the concept to be developed with a focus on (principal concept)" because it is judged to be the most comprehensively superior concept by the technical summary.

□In addition, it is decided to designate those concepts having more attractiveness than the principal concept as "concepts to be developed in a complementary manner (complementary concept)" from the perspective of assuring diverse alternatives to uncertainties, including future needs, and the above-mentioned concepts (b) and (c) are selected as the complementary concepts.

□**The main R&D investment should be focused on the principal concept** in consideration of efficient utilization of the limited research resources.

□Concerning the complementary concepts, R&D should be conducted with a focus on concerns that are judged as essential for technical feasibility and other aspects.

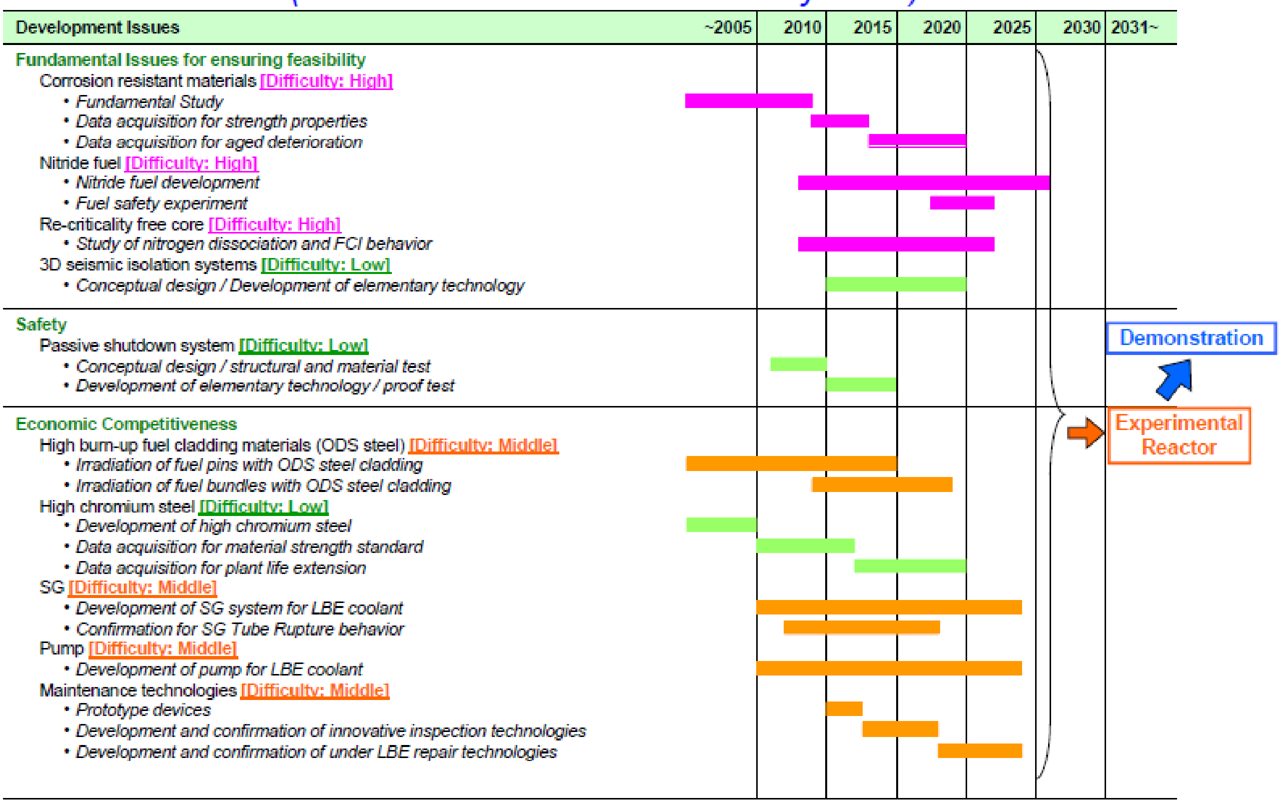
3. R&D Strategy in Phase III and beyond

3.1 R&D Prospects until approximately 2015 (Figure 3)

☐ In the Phase II study, selection of promising candidate concepts for commercialization, **establishment of the principle for prioritizing R&D concerns and development of the R&D program until approximately 2015** have been conducted.

☐ In parallel, concerning the **prioritized concepts**, perspectives on fundamental applicability have been obtained by elemental experiments and research on each of innovative technologies.

6. Draft Roadmap of key Technologies Development (Lead-Bismuth Cooled FR System)



Ref. S. Kotake, Y. Sakamoto, M. Ando, T. Tanaka "Feasibility Study on Commercialized Fast Reactor Cycle Systems Current Status of the FR System Design," GLOBAL 2005, Oct. 9-13, 2005, Tsukuba, JAPAN

7. Summary of Technical Feasibility

- Lead-bismuth cooled FR and helium gas cooled FR have several fundamental R&D issues and they must, first of all, be solved to clarify their technical feasibility. Eventually, the R&D approach by construction of a experimental reactor would be needed for integration and demonstration of developed technologies.

8. Concluding Summary

- The most promising FR concept would be selected mainly by technical evaluations, which are consisted of suitability to the design targets and of their technical feasibilities, with taking account of the combination of the related fuel cycle system, until the end of the coming March
- The alternative FR concept would be selected to make the development plan be flexible, which means different type of performance and of development issues, with taking account of utility opinions and also the status of the international collaborations
- The rest of FR concepts would be addressed as the fundamental development concept, where only crucial issues would be developed as the basic research for the possibility of the breakthrough, with tanking account of international research tendency

Feasibility Study on LFR (JAEA)[1][2][3]

[1] JAEA Technical Report NO.12 Separate Volume 9/2001
[2] JAEA Technical Report NO.24 Separate Volume 11/2004
[3] JAEA Feasibility Study on Commercialized Fast Reactor Phase Ⅱ Report 4/2006

(1) Schedule

Phase Ⅰ Oct.1999～Mar.2001

Phase Ⅱ Apr.2001～Mar.2006

(2) Parameter of Reactor Concept

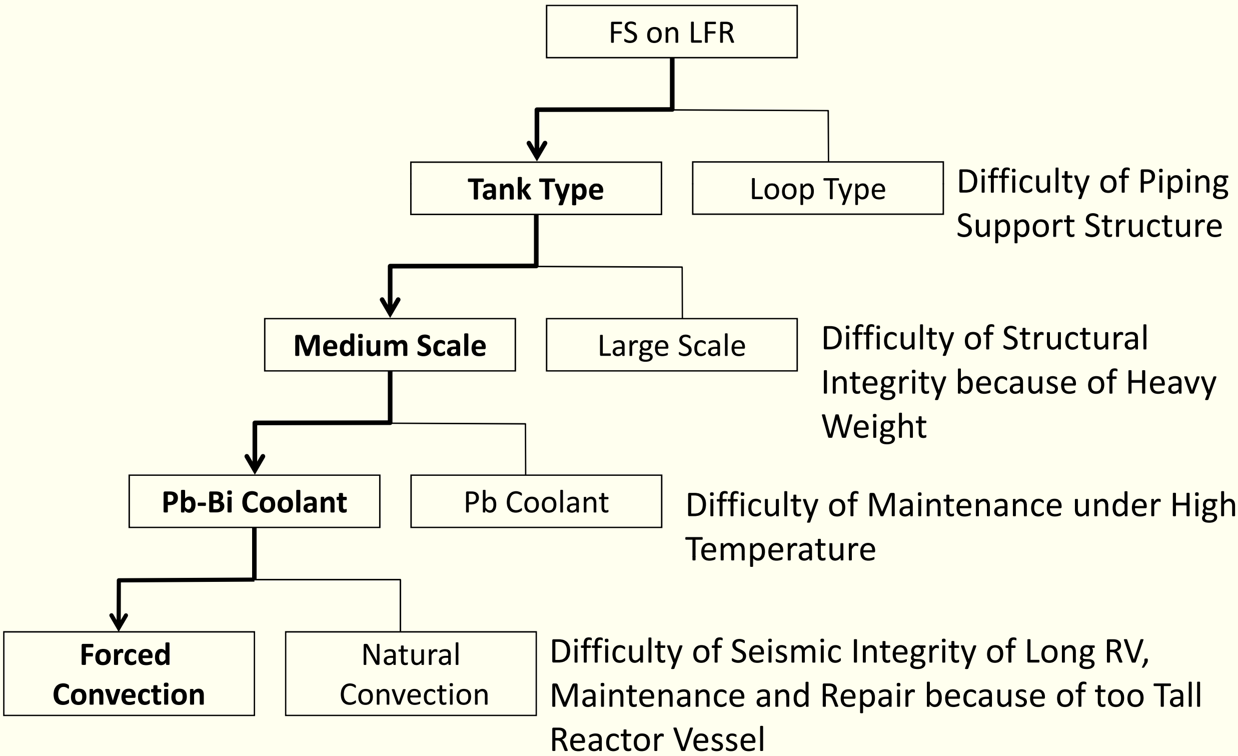
(a) Coolant Pb, Pb-Bi

(b) Reactor Scale Large, Medium, Small

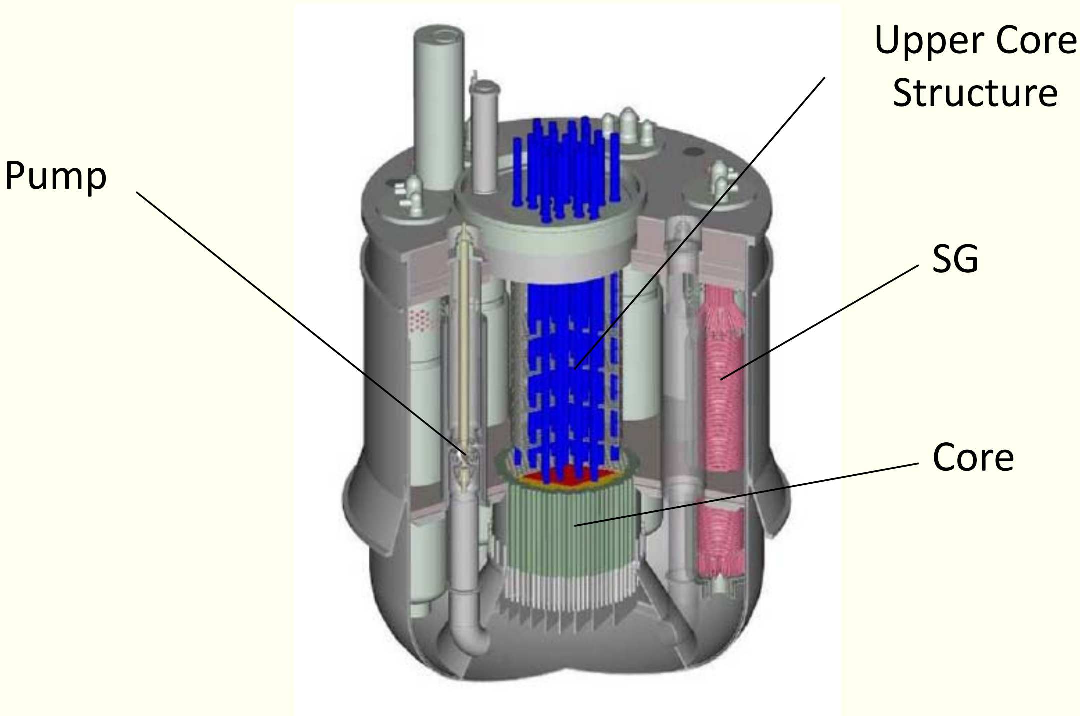
(c) Reactor Type Tank, Loop

(d) Convection NC, FC

(3) Selection Process of LFR Reactor Concept



(4) Selected Concept of LFR



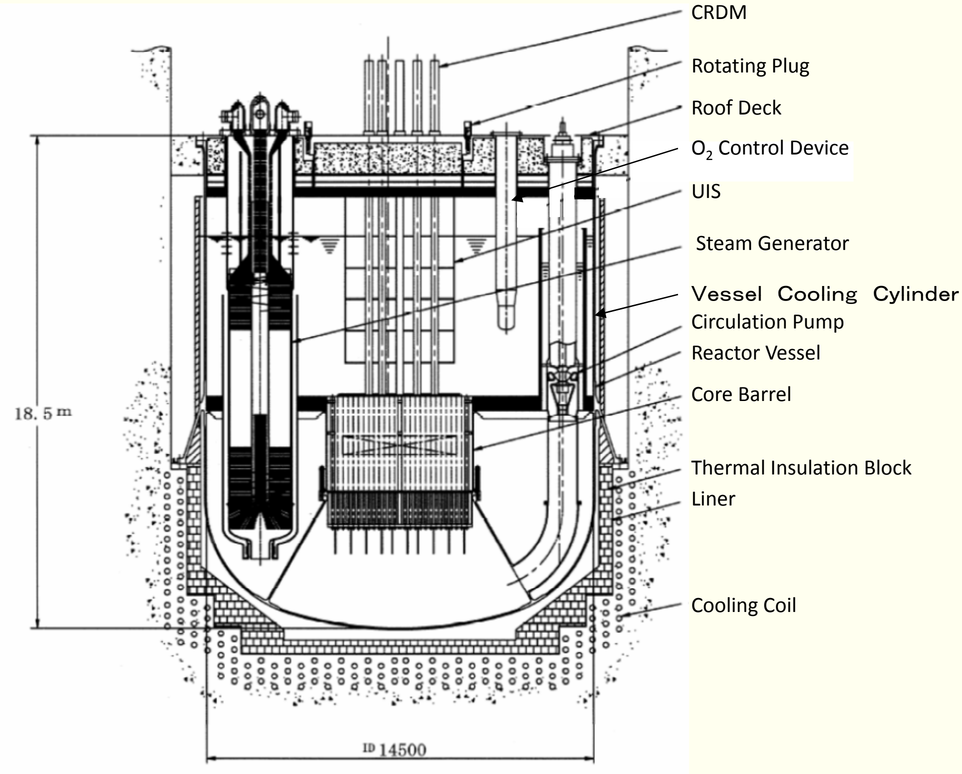
750MWe Medium Scale LFR

Main Plant Specification of LFR

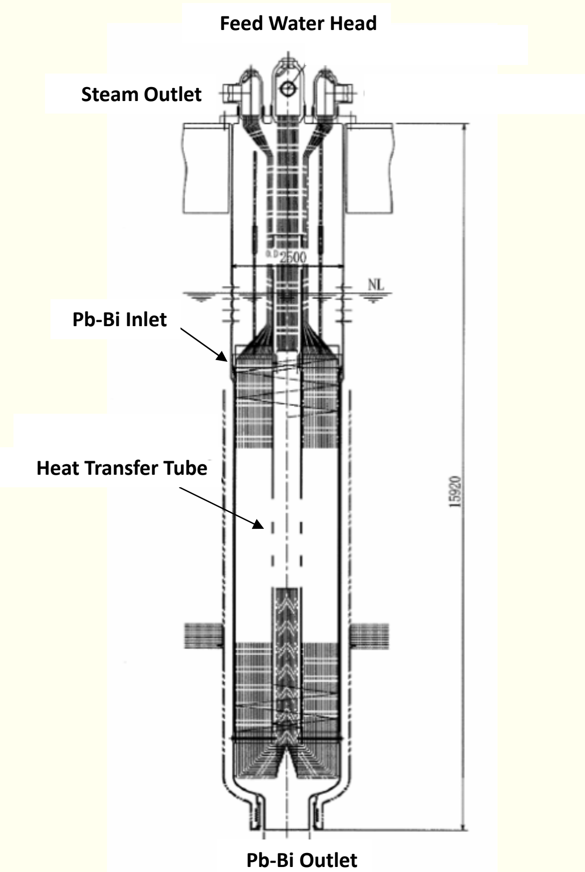
Item	Spec
Reactor Type	Forced Convection LFR
Electric Power	750MWe
Thermal Power	1,980MWt
Primary Coolant Temperature	445℃/285℃
Primary Coolant Flow Rate	3.06×10^5Ton/h
Steam Temperature/Pressure	400℃/6MPa
Feed Water Temperature/Flow Rate	210℃/3,126Ton/h
Cycle Efficiency	～38%
Burn Up (Average)	150000MWd/t
Breeding Ratio	1.19 (Nitride Fuel)
Decay Heat Removal System	DRACS×3 (NC)

Core Design Specification

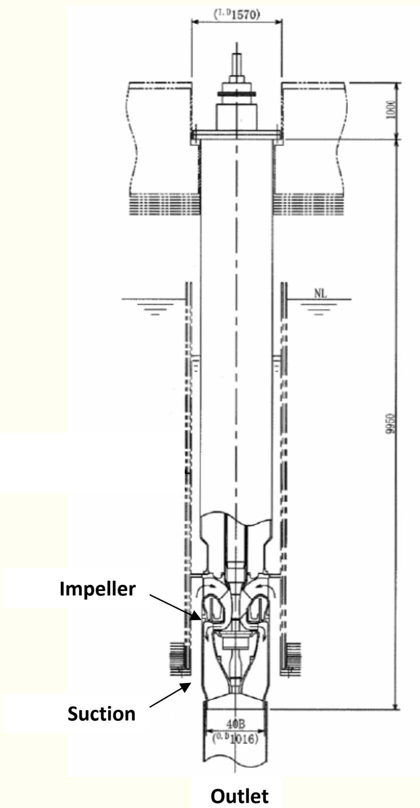
Item	Specification
Reactor Thermal Power	1980MWt
Electric Power	750MWe
Core Type	2-Region Homogeneous Core
Refueling Interval	18Months
Number of Batches	6
Core Height	70cm
Axial Blanket (Upper/Lower)	0/18cm
Equivalent Core Diameter	443cm
Number of Fuel Assemblies (Inner/Outer)	252/192
Radial Blanket	—
Number of Control Rods (Main/Backup)	24/7
Number of Radial Shielding materials	Pb-Bi 84 Zr-H 90



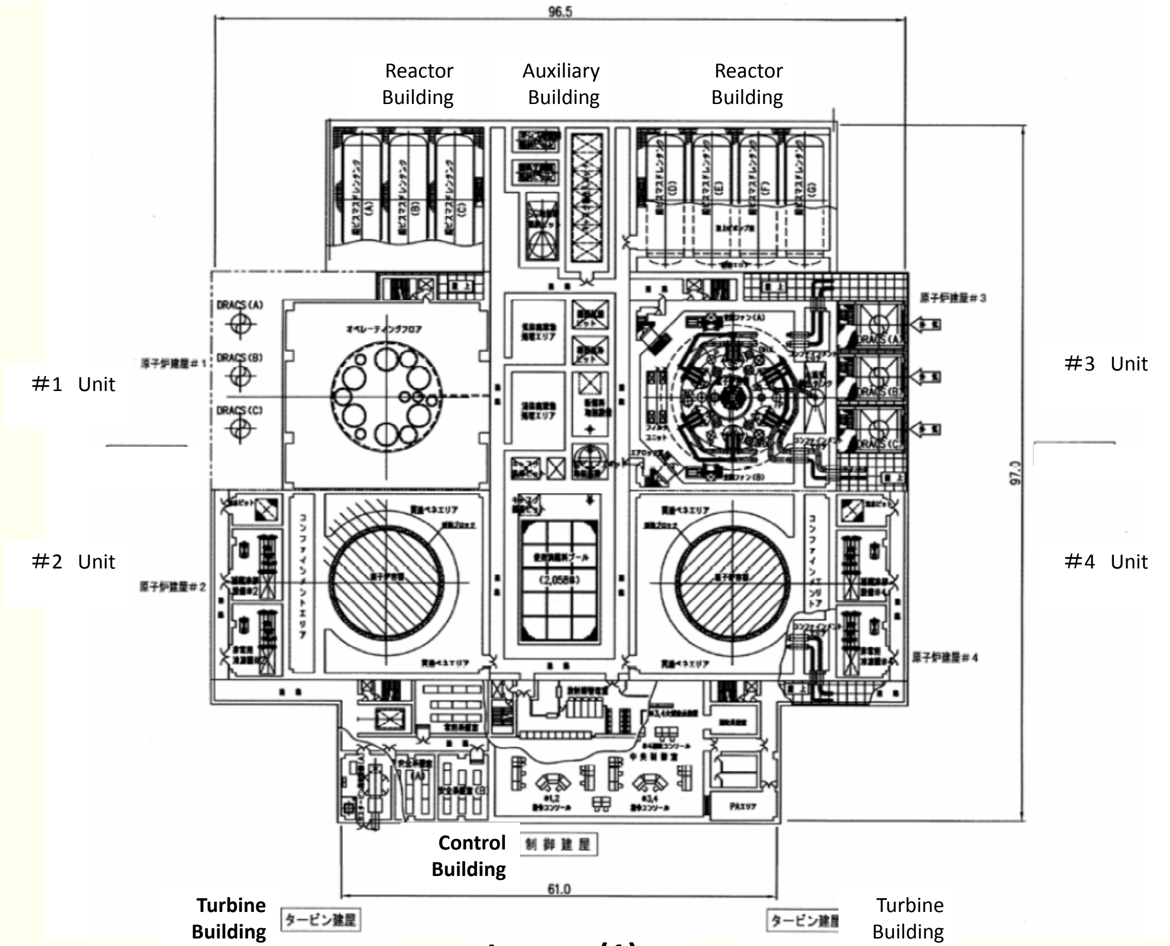
Reactor Vessel



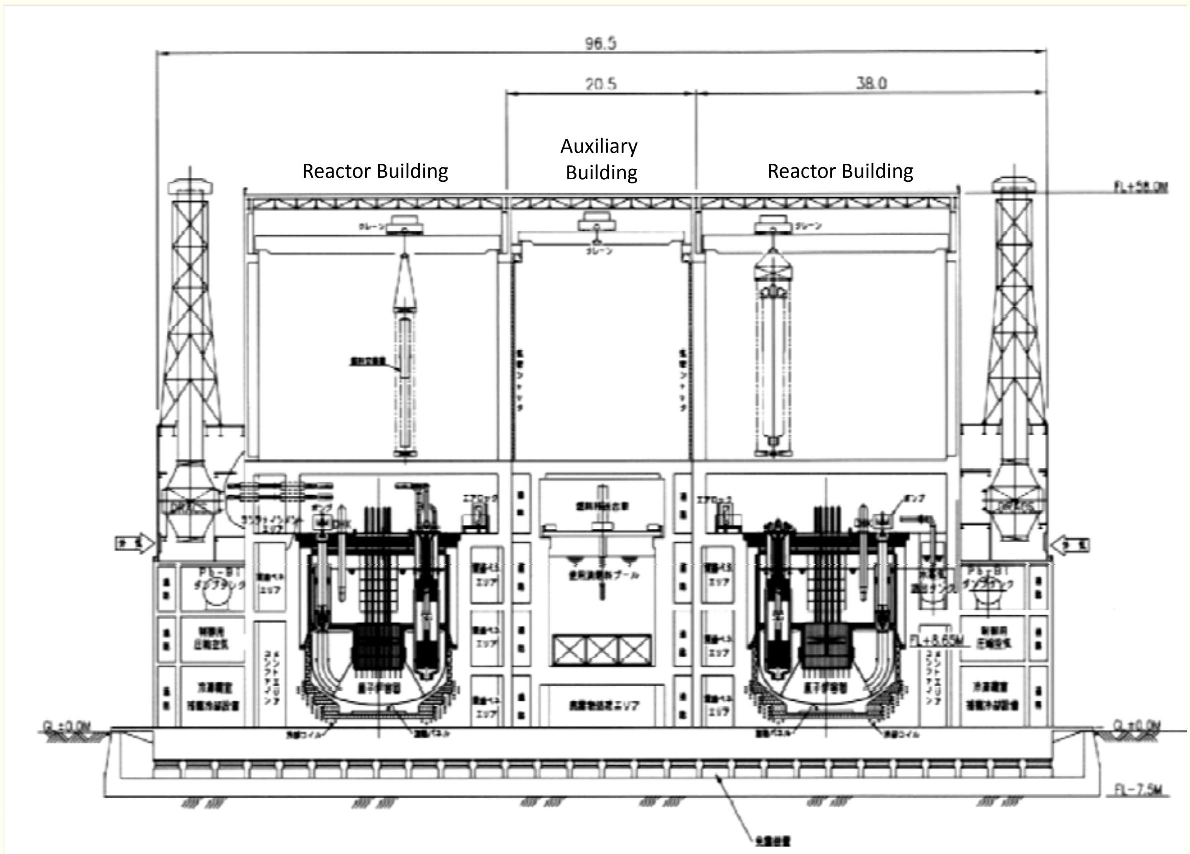
Steam Generator



Circulation Pump



Layout (1)



Layout (2)

Concluding Remarks

1. Based on the final report of the feasibility study (FS), SFR has been selected as the most promising concept for future commercialization in Japan since 2006.
2. In the final report of FS, the superiority of SFR with proposed innovative technologies and GIF activity was emphasized. On the other hand, the issue of corrosion and no activity in GIF was pointed out as the problem of LFR in spite that LFR has various superiority.
3. The FaCT project was performed for development of commercialized SFR for five year. However, the operation of the prototype FBR Monju has been stopped since Aug. 2010 due to a trouble.
4. After the accident of Fukushima Daiichi Nuclear Power Plants, the energy policy in Japan is under review. Following the result of the review, the Framework for Nuclear Energy Policy will be revised in 2012.
5. The revision of the policy may be influenced by various factors including GIF-LFR activity.

Thank you
for your kind attention!