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第 14 回加速器駆動システムおよび核変換技術に関する アジアネットワークワークショップ報告書

Proceedings of 14th International Workshop on Asian Network for Accelerator-Driven System and Nuclear Transmutation Technology (ADS-NTT 2016)

編集：卞　哲浩

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Preface

The proceedings describe the current status on research and development (R&D) of accelerator-driven system (ADS) and nuclear transmutation techniques (NTT), including nuclear data, accelerator techniques, Pb-Bi target, fuel technologies and reactor physics, in East Asian countries: China, Korea and Japan.

The proceedings also include all presentation materials presented in “the 14th International Workshop on Asian Network for ADS and NTT (ADS-NTT2016)” held at Mito, Japan on 5th September, 2016. The objective of this workshop is to make actual progress of ADS R&D especially in East Asian countries, as well as in European countries, through sharing mutual interests and conducting the information exchange each other.

The report is composed of these following items:

- Presentation materials: ADS-NTT 2016

Cheol Ho Pyeon

September 2016

Keywords:
Status report, ADS, NTT, Asian countries

Contents

The 14th International Workshop on Asian Network for Accelerator-Driven System (ADS) and Nuclear Transmutation Technology (NTT) (ADS-NTT2016), 5th September, 2016, at Mito, Japan

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Activities in JAEA induced 1st Technical Meeting (Sep., 2015) for ADS-NTT 2015

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14th International Workshop (General Meeting) on Asian Network for Accelerator-Driven System (ADS) and Nuclear Transmutation Technology (NTT) in 2016 (ADS-NTT 2016)

- Agenda-

organized by Research Reactor Institute, Kyoto University
sponsored by J-PARC, Japan Atomic Energy Agency

5th September, 2016, at Hotel Terrace Garden Mito

September 5th (Monday)

13:30	Registration
13:55 - 14:00	Opening remarks **(Prof. Cheolho Pyeon, Kyoto Univ., Japan)**

Progress and Status on ADS in Asian countries
(Chairman: Dr. Kazufumi Tsujimoto, JAEA)

14:00 – 14:40	“Activities in JAEA induced 1st Technical Meeting (Sep., 2015) for ADS-NTT 2015” (Dr. Toshinobu Sasa, JAEA, Japan)
14:40 – 15:20	“Status on Gen-IV research activities in Korea” (Prof. Seung-Woo Hong, SSKU, Korea)
15:20 – 15:40	Break
15:40 – 16:20	“Current Status of Subcritical Reactor Technology for ADS in China” (Prof. Yunqing Bai, INEST, CAS)
16:20 – 17:00	“Current Status on ADS Experiments at KUCA” (Prof. Cheolho Pyeon)
17:00 – 17:20	Break
17:20 – 17:50	Round Table by Speakers **(Chairman: Prof. Cheolho Pyeon)**
17:50 – 18:00	Closing remarks **(Chairman: Dr. Toshinobu Sasa)**
18:30 – 21:00	Dinner with information exchange hosted by JAEA and KURRI

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Activities in JAEA
inducing 1st Topical Meeting for ADS-NTT 2015

14th International Workshop on Asian Network for ADS-NTT 2016
5th Sep. 2016, Mito Japan

Toshinobu Sasa

J-PARC Center, Japan Atomic Energy Agency

Contents

- Activities for ADS development in JAEA
  - National Policy for Energy Supply
  - Future ADS Design
  - Status of J-PARC Facility Design

- Topics in 1st topical meeting

- Summary

National Policy for Energy Supply

Nuclear Energy Situation in Japan

- Nuclear Power in Latest Strategic Energy Plan -

2. Principles of Energy Policy and Viewpoints for Reform Nuclear Power

- Important base-load power source as a low carbon and quasi-domestic energy source, contributing to stability of energy supply-demand structure, on the major premise of ensuring of its safety, because of the perspectives; 1) superiority in stability of energy supply and efficiency, 2) low and stable operational cost and 3) free from GHG emissions during operation.

- Dependency on nuclear power generation will be lowered as much as possible by energy saving and introducing renewable energy as well as improving the efficiency of thermal power generation, etc.

- Under this policy, we will carefully examine a volume of electricity to be secured by nuclear power generation, taking Japan's energy constraints into consideration from the viewpoint of stable energy supply, cost reduction, global warming and maintaining nuclear technologies and human resources.

Nuclear Energy Situation in Japan

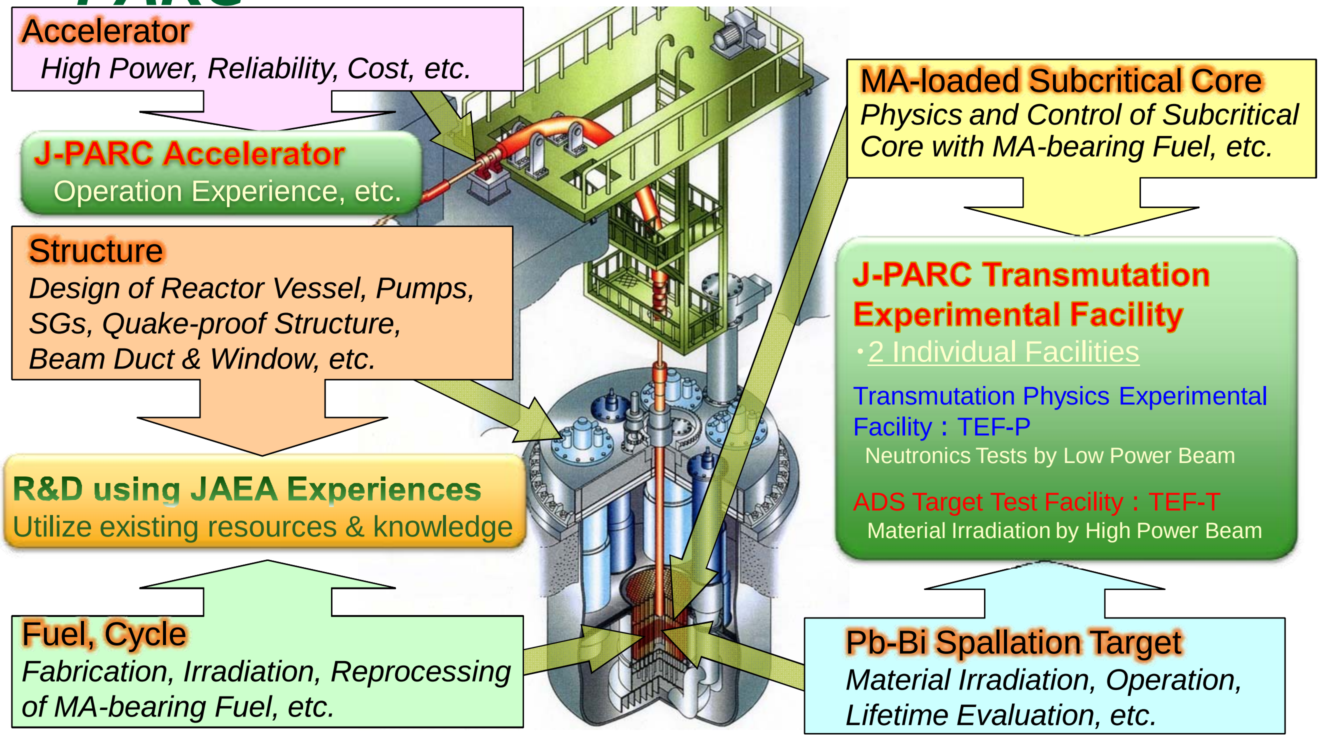
- Radioactive Waste Issues -

Chapter 3, Section 4 Re-establishment of the nuclear energy policy

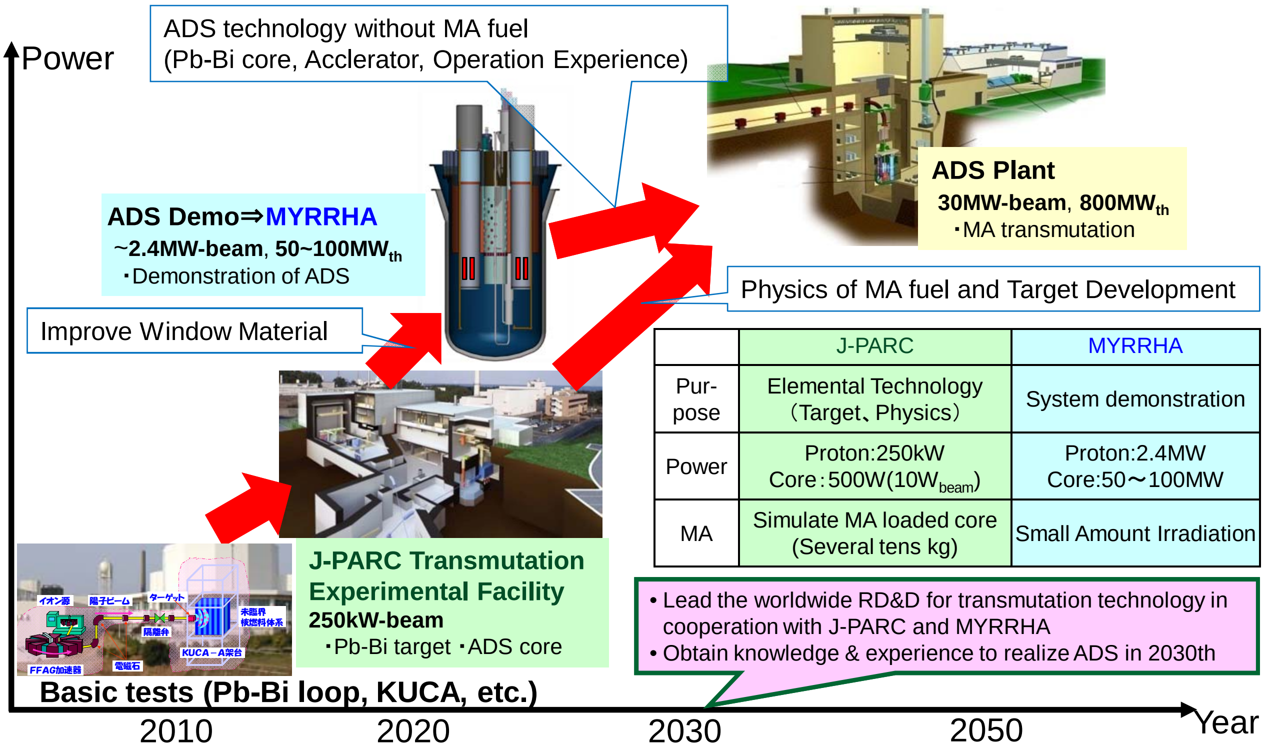
- Government Of Japan (GOJ) will promote technology development on volume reduction and mitigation of degree of harmfulness of radioactive waste. Specifically, development of technologies for decreasing the radiation dose remaining in radioactive waste over a long period of time and enhancing the safety of processing and disposal of radioactive waste, including nuclear transmutation technology using fast reactors and accelerators, will be promoted by utilizing global networks for cooperation. Also, while GOJ examines the situation of study and progress in terms of final disposal, it studies the feasibility of integrated implementation of the R&D for final disposal and reduction of volume, international research cooperation and a researcher resource development related to them.

Future ADS Design

Issues and R&Ds for ADS using J-PARC



TEF-MYRRHA Joint Roadmap to Accelerate Establishment of ADS Transmutation

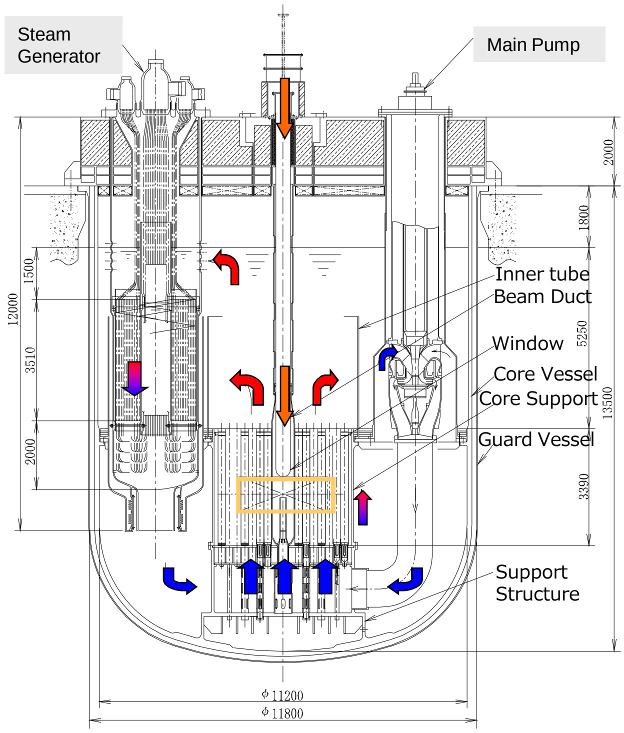


	J-PARC	MYRRHA
Pur-pose	Elemental Technology (Target、Physics)	System demonstration
Power	Proton:250kW Core：500W(10W$_{beam}$)	Proton:2.4MW Core:50～100MW
MA	Simulate MA loaded core (Several tens kg)	Small Amount Irradiation

- Lead the worldwide RD&D for transmutation technology in cooperation with J-PARC and MYRRHA
- Obtain knowledge & experience to realize ADS in 2030th

ADS Proposed by JAEA *- LBE Target/Cooled Concept -*

- Proton beam : 1.5GeV ~30MW
- Spallation target : Pb-Bi
- Coolant : Pb-Bi
- Subcriticality : k_{eff} = 0.97
- Thermal output : 800MWt
- Core height : 1000mm
- MA initial inventory : 2.5t
- Fuel composition :
  (60%MA + 40%Pu) Mono-nitride
- Transmutation rate :
  10%MA / Year (**10 units of LWR**)
- Burn-up reactivity swing : 1.8%Δk/k



Grant-In-Aid for Nuclear

Research and development to solve the engineering issues for transmutation system using accelerator-driven system

3 years
5M$ $_{max}$

1. MA partitioning process development using actual waste solution

Spent fuel → Rough separation of U → U
→ Separation of U, Pu, Np → U, Pu, Np
→ Separation of An(III), Ln → Separation of An(III) / Ln → Am, Cm; Ln
→ Separation of Cs, Sr → Cs, Sr
→ Separation of PGM → PGM; The other FP

An(III): Trivalent actinide
Ln: Lanthanide
FP: Fission product
PGM: Platinum group metal

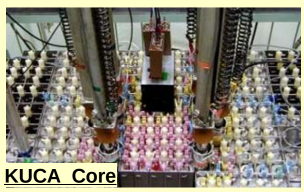
MA partitioning process experiments from actual waste solution of used nuclear fuel

Separation of An(III) and lanthanide from HLLW:
New extractants based on "CHON principle": **TDdDGA**

Separation of An(III) from lanthanide:
Invention of new extractants

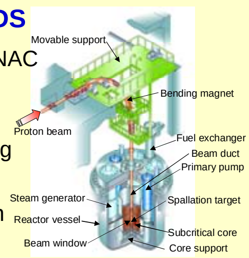
2. Feasibility design study of ADS

2.1 Reactor physics experiments to simulate ADS using Kyoto University Critical Assembly (KUCA) with FFAG proton accelerator

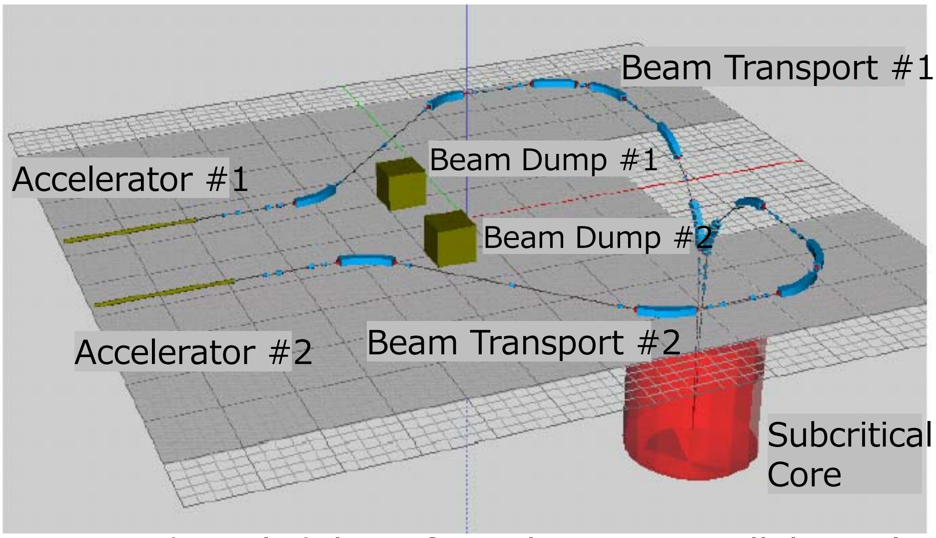


2.2 Research and development for engineering issues of ADS

- ✓ Improved reliability of proton LINAC for ADS
- ✓ Enhanced feasibility of beam window of ADS by compensating the burnup reactivity change
- ✓ Robust safety aspects based on detailed plant dynamic analysis



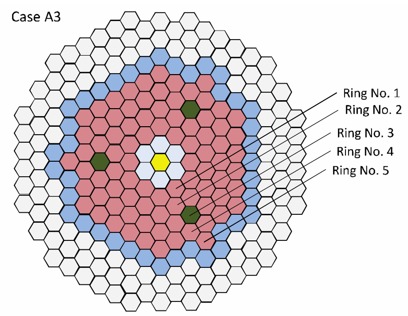
Increase Beam Reliability



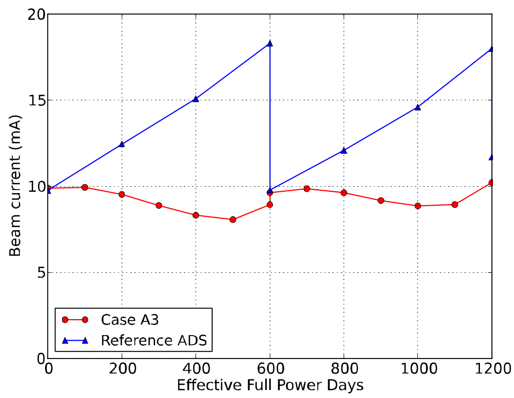
- To improve the reliability of accelerator, parallel accelerator layout is an ultimate solution
- By running two accelerators by 50% of rated power each, reliability requirement for ADS can be satisfied
- Optimum layout of parallel accelerator should be determined

k_{eff} adjustment by control rod

- ADS with Control Rods for k_{eff} adjustment
  - Install Three B_4C CRs (Total Worth:1.5%dk/k)
  - Possible to keep proton beam current around **10mA** during the burnup cycle



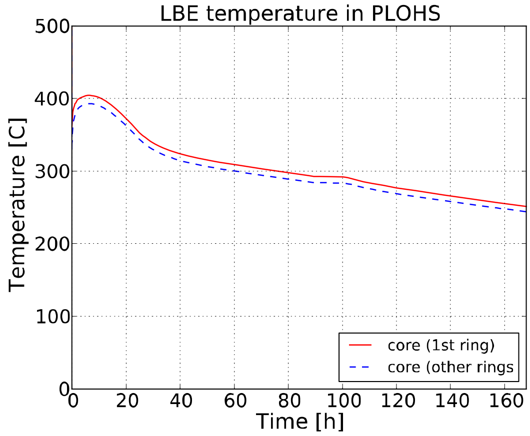
CR Layout (Green)



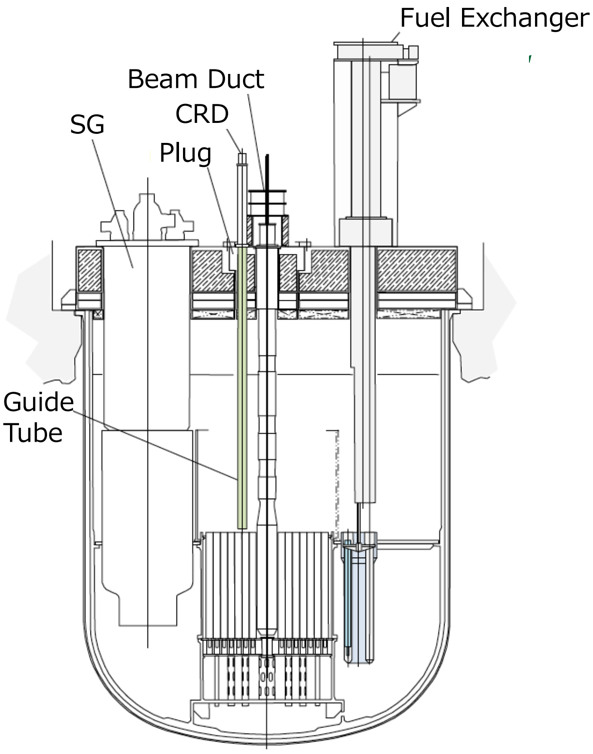
Beam Current Change during burnup

Improvement of passive safety

- Reflecting the Fukushima Accident, addition of PRACS (Primary Reactor Auxiliary Cooling System) is studied
- PLOHS with PRACS was analyzed by RELAP5-Mod3
- Confirm the coolant temperature can be kept below 400 … on Black Out



Subcritical core



- Layout of reactor components including newly added equipment was performed
- The scheme to replace beam window and fuel is confirmed

Status of J-PARC Facility Design

Transmutation Experimental Facility

ADS Target Test Facility (TEF-T)

Investigate engineering characteristics of LBE spallation target

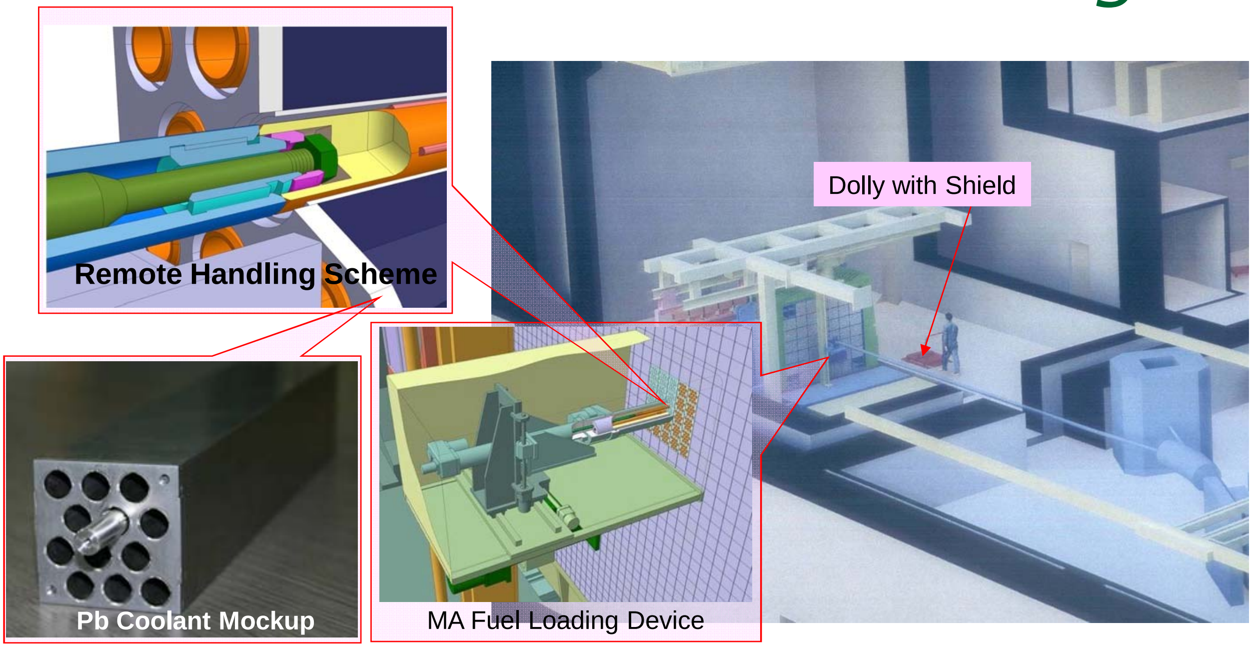
- *400MeV-250kW Proton Beam*
- *LBE Temperature 500℃$_{max}$*
- *Oxygen Potential Controlled*
- *Hot Cell for PIE samples preparation*

Transmutation Physics Experimental Facility (TEF-P)

Explore neutronic performances of ADS and/or MA-loaded core

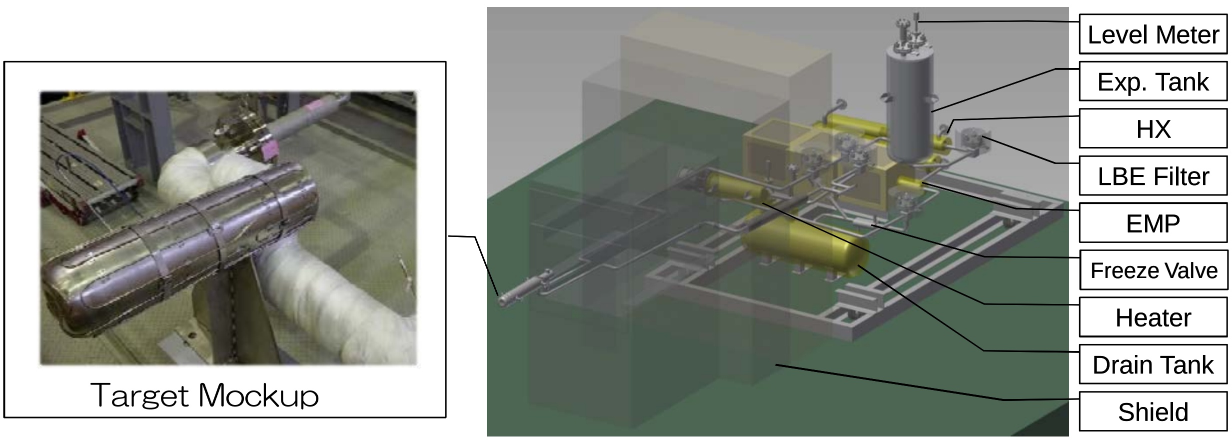
- *400MeV-10W Proton Beam*
- *Table-split type Critical Assembly*
- *MA-bearing pin type fuel for experiments*

Minor Actinide Fuel Handling



- Requires remote handling device to storage/transport/loading of MA fuel
- Basic functional tests for MA fuel loading device is performed and confirmed the operation
- Heat removal test in Pb Coolant mockup is underway
- To improve accuracy of experiments, fuel rod identification methods is under consideration

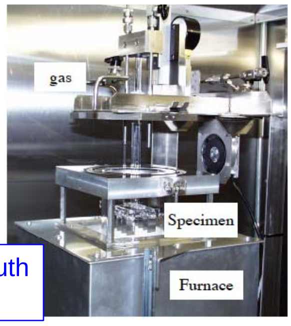
Design of Target Trolley



- Base layout was finished considering the drain route and maintainability through shield window.
- Further design harmonized with remote operation by MSM and PM will be performed.

Lessons Learned in past 10 years

- To realize TEF-T and ADS, JAEA built a static corrosion experimental equipment (**JLBS**), four experimental lead-bismuth loops (**JLBL-1, 2, 3 and 4**)
- The equipment were installed for corrosion/erosion examination (**JLBS**, **JLBL-1**), measurement device development (**JLBL-2, 4**) and thermal-hydraulic experiments around beam window(**JLBL-3**).



JLBS (JAEA Lead-Bismuth Static corrosion facility)

JLBL (JAEA Lead-Bismuth flow Loop)

New Test Equipment for TEF-T Design

OLLOCHI Oxygen-controlled Lbe LOop for Corrosion tests in HIgh temperature

- Material corrosion database for various temperature, oxygen potential, LBE flow rate will be collected
- The loop will be operated from next April
- Addition of corrosion test section with mechanical stress are planned

IMMORTAL Integrated Multi-functional MOckup for TEF-T Real-scale TArget Loop

- Demonstration of safe operation of LBE loop by reflecting operation condition of J-PARC LBE Spallation target
- Tests for dynamic behavior of heat removal, functional tests of sensors, loop components are underway

Oxygen Sensor Calibration Device

- To prevent corrosion by flowing LBE, oxygen potential in LBE should be controlled in appropriate potential range (10^{-5} to 10^{-7} %)
- Development of oxygen potential sensor and loop tests for oxygen potential control mechanism are underway

Outline of "OLLOCHI"

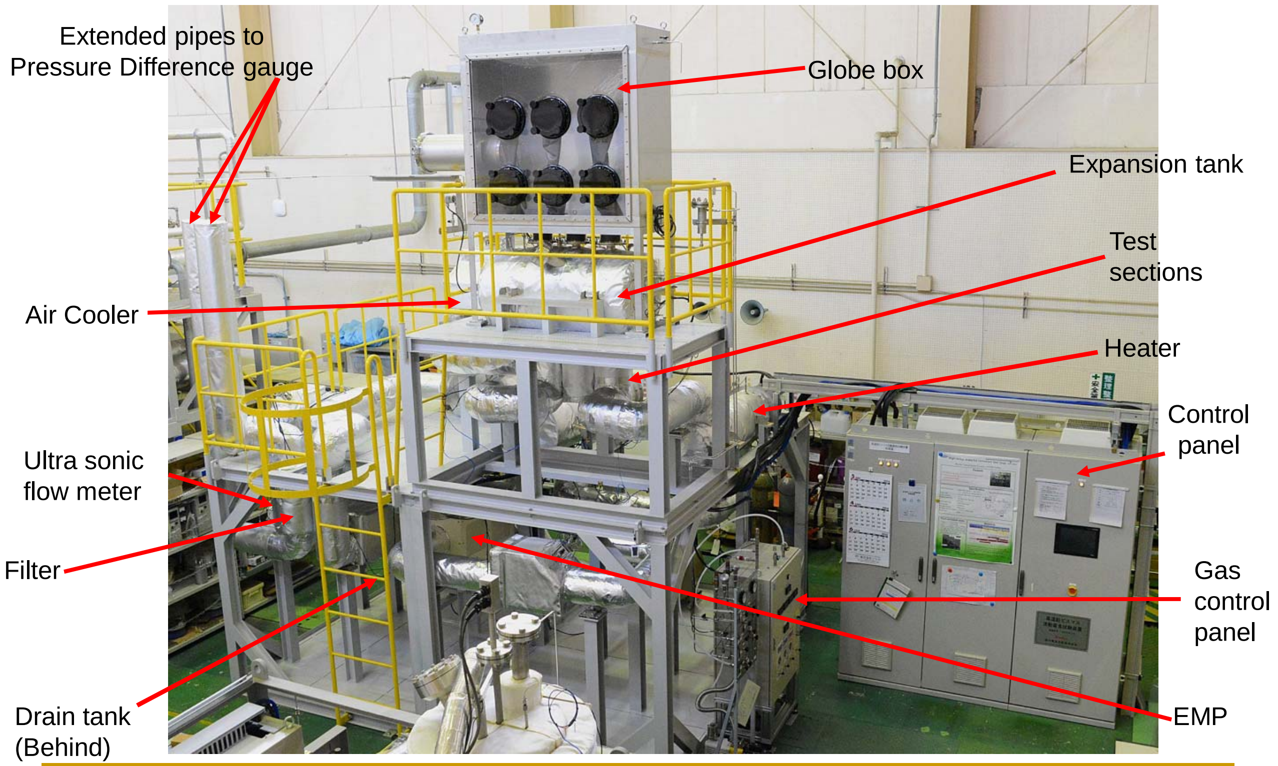
Purpose

- Fundamental study for future ADS development
- Corrosion data collection for PIE on TEF-T irradiated materials.
- Development of filtering system

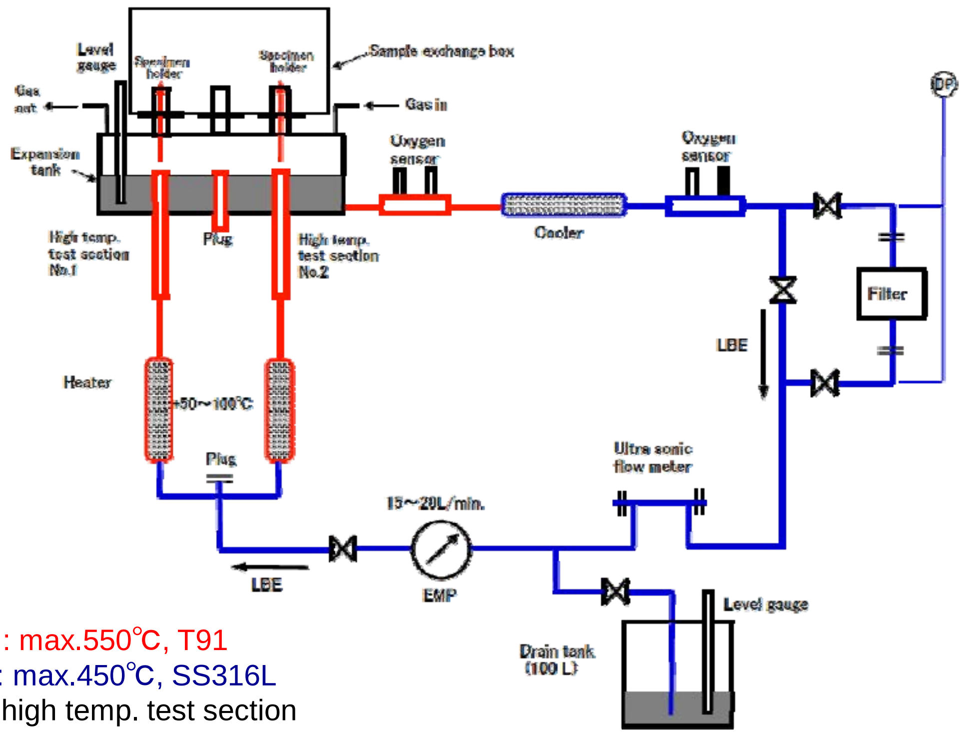
Design concept

- High temperature (>500℃) corrosion test
- Multi test section
- Non-contact type flow meter
- Oxygen sensor, oxygen concentration control system
- Purification system of LBE
- Exchange test-piece without drain (to keep oxygen concentration)
- Decrease flange connection to prevent LBE leakage

Appearance of OLLOCHI



Schematic flow diagram of OLLOCHI



High temp. section : max.550℃, T91
Low temp. section : max.450℃, SS316L
Flow rate : 1m/s at high temp. test section

Tentative Corrosion Test Program

		2016	2017		2018		2019		2020		2021		2022	
Phase		1 (Proof test)	2 (Corrosion test, benchmark)		3 (Corrosion test)		4 (Corrosion test, reproducibility)		5 (Corrosion test, long run test))		6 (Corrosion test)		7 (Corrosion test, reproducibility)	
Oxygen concentration (wt.%)		10^{-5} – 10^{-7}	←	←	←	←	←	←	←	←	←	←	←	←
LBE flow rate		1m/s	←	←	←	←	←	←	←	←	←	←	←	←
ΔT (℃)		100	←	←	←	←	←	←	←	←	←	←	←	←
Test section No.1	Temp. (℃)	450	450	450	500		500	500	500		550	550	550	
	Time	3,000h	1,000h	3,000h	5,000h		1,000h	3,000h	5,000h(10,000h)		1,000h	3,000h	5,000h	
Test section No.2	Temp. (℃)	450	450		500	500	500		500	500	550		550	550
	Time	3,000h	5,000h		1,000h	3,000h	5,000h		1,000h	3,000h	5,000h		1,000h	3,000h
Specimen		Austenitic F/M steel	Austenitic, F/M steel, welds, coating, ODS, etc.		←		←		←		F/M steel, welds, coating, ODS, etc.		←	

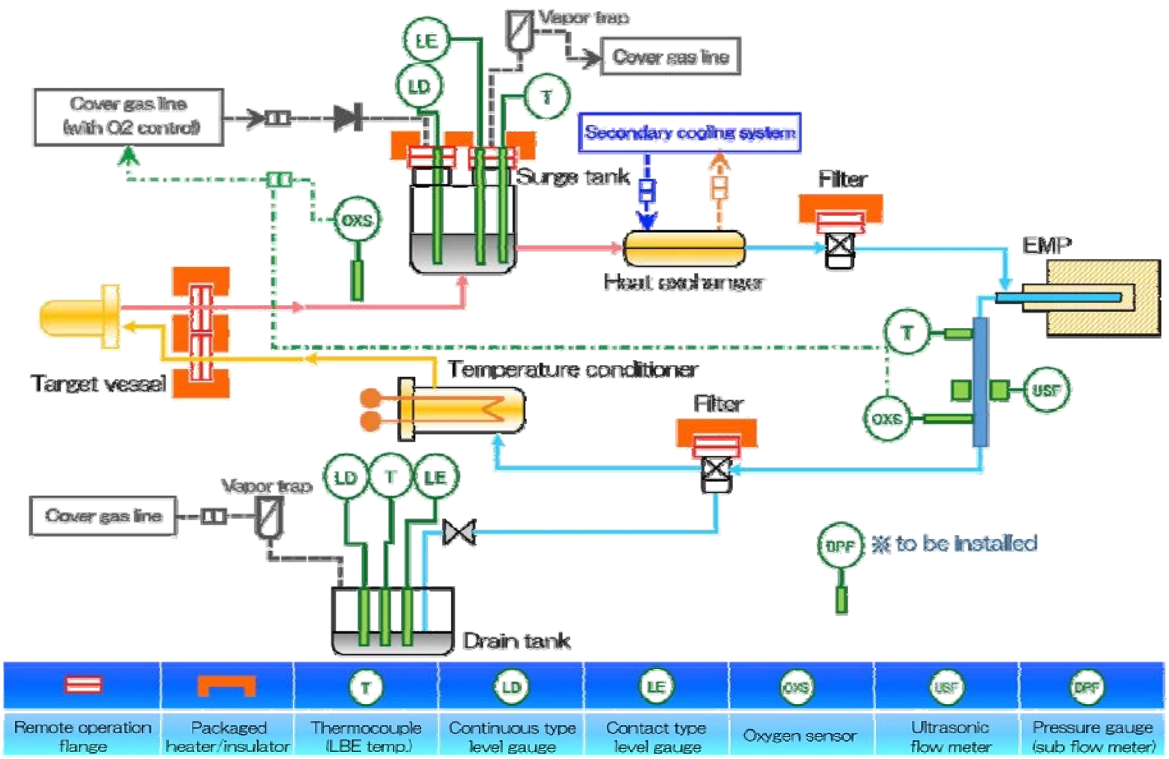
Outline of "IMMORTAL"

- Target Mock-Up loop "IMMORTAL" is a demonstration test loop with most of same configuration/components of the primary cooling system of TEF –T target
- Most of component are actual scales, except a temperature conditioner simulating heat generation by the incidence of proton beam.

Purpose of IMMORTAL

1. Dynamic behavior of heat removal
2. Confirmation of operation procedure
3. Integral test of individually developed components of LBE technologies (including EMP & HX)
4. Production of control sample for PIE of TEF-T irradiation sample

Schematic Flow Diagram of IMMORTAL



Major Specifications of IMMORTAL/TEF-T

Specifications	IMMORTAL	TEF-T
Max. temperature	500 ˚C	500 ˚C
Temperature difference ΔT	100 ˚C	100 ˚C
Max. Flow rate	120 liter/min	120 liter/min
Heat deposition by proton beam	n/a	200 kW
Power of temperature conditioner	67 kW :to simulate heat generation (about 1/3 of heat deposition)	< 10 kW :to control inlet temp. only
Amount of heat exchanger	Design 200 kW Working 67 kW	200 kW
Inventory of LBE	≈ 290 liter	≈ 290 liter
Main piping	i.d. 69.3 mm	i.d. 69.3 mm ⇒ i.d. 42.6 mm
Main material	316 SS	316 SS / T91
Flow monitoring system	Ultrasonic flowmeter	Ultrasonic flowmeter
Oxygen Concentration (OC) control system	Available (Pt/Air type sensor)	Available (Pt/Air type sensor)
Liquid pressure gauge	To be installed	Available
Freeze seal type of drain valve	To be installed	Available

Full Scale TEF-T Target Modckup

Purpose

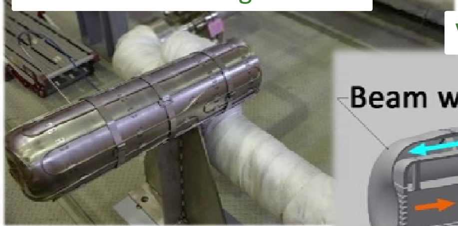
A) Confirmation of manufacturing method
B) Confirmation of the residual LBE after drain operation
C) Structural durability in non-irradiation condition (erosion/corrosion)
D) Confirmation of dynamic behavior
(LBE flow, heat transfer, flow vibration)

Confirmed by long-run test & flow visualization (B–D)

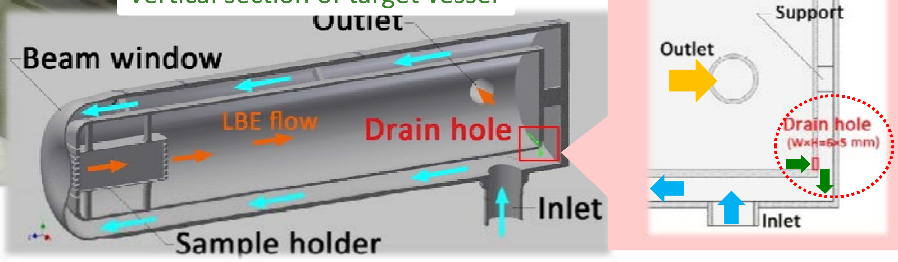
Result of A) & present design of B)

A) BW(2mm thick) part was made by shaving from ingot, and successfully manufactured.
B) To reduce residual LBE, drain hole (6(W)×5(H)mm) was provided at the end of inner pipe.

Manufactured target vessel



Vertical section of target vessel

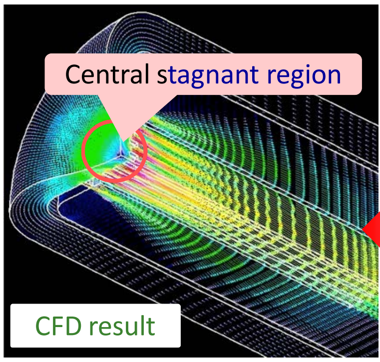


LBE Flow visualization in Target

Purpose of flow visualization experiment

- To verify the simulated LBE flow (In particular instability of central stagnant region)
- Confirmation of the effect of planned guide fin (to remove the central stagnant region)
- Experimental data acquisition to verify the fluid analysis result for upgrade of target vessel

Estimation of the instability of central stagnant region is important issue for TEF-T target.

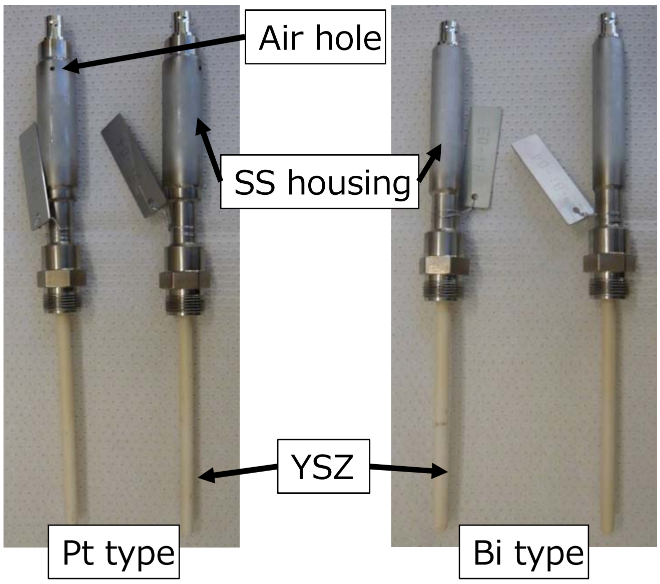


Full-scale transparent acrylic model of target vessel

Fabrication of Oxygen Sensor

- Pt type: Air hole is prepared. To prevent LBE leakage by YSZ failure, freeze seal design was employed in housing.
- Bi type: No air hole

Length of sensor	240mm
Diameter of YSZ	6/4 mm (O/I)
Length of housing	140mm
For Pt type	Pt paste /SUS304 wire
For Bi type	Bi/Bi_2O_3=95:5 /Mo wire



Control of Co in flowing LBE condition

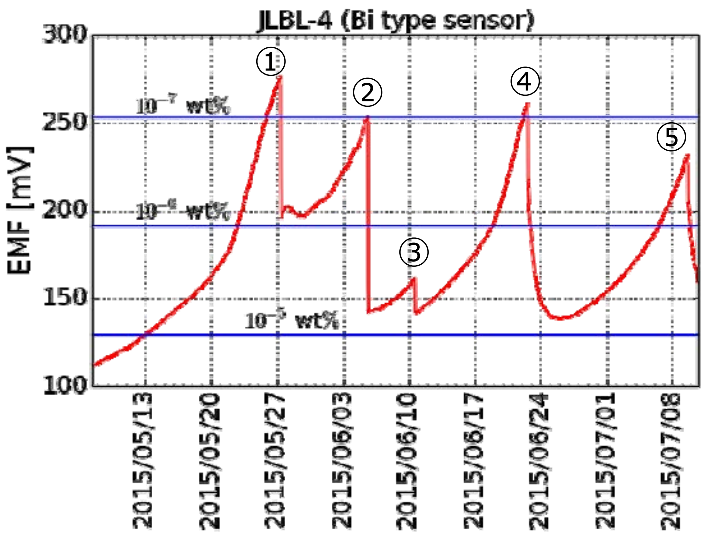
- Outline of JLBL-4

Specifications of JLBL-4	
Main material	316SS
Inventory	20 L
Max. pressure	6 bar
Max. electrical power	7 kW heaters
Max. design temperature	500 ℃
Flow rate of LBE	Max. 40 L/min
Flow rate of observation	EMF

O2 sensor	Bi type sensor (made by SCK･CEN)
LBE temperature	350℃
LBE flowrate	26L/min

Control of Co in flowing LBE condition

- Result



①	Ar continuous (2days)
②	Ar+O_2*1 150cc (50sccm×3min)
③	Ar+H_2*2 500cc (100sccm×5min)
④	Ar+O_2 150cc (50sccm×3min)
⑤	Ar+O_2 75 c c (50sccm×1.5min)

*1: 20vol% O_2
*2: 4.5vol% H_2

- Basic oxidation operation was performed
- It is required to comprehend the relationship between change of Co and input of oxygen.
- #③ will be also the effect of residual oxygen.

Topics in 1st Topical Meeting on Asian ADS-NTT Meeting

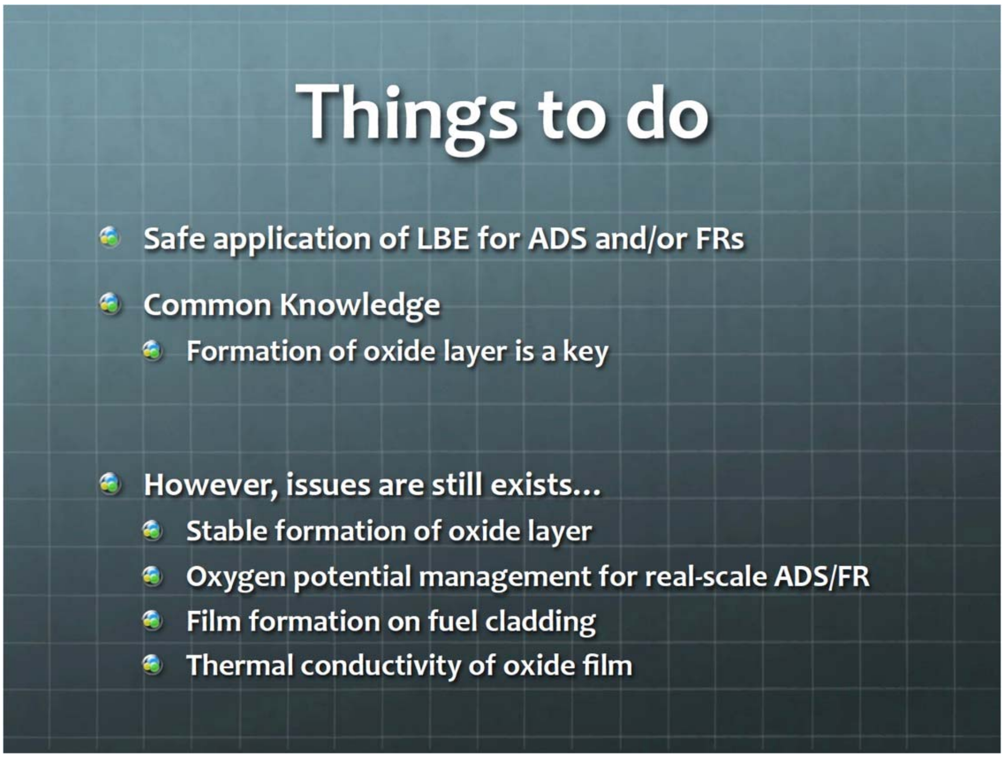
Topical Meeting for LBE Application

- To increase professional information exchange, topical meeting was held in-between the regular ADS-NTT meeting
- LBE handling technology was selected as a specific topic
- Prof. J. Konys (KIT) gave an invited talk
- 14 presentations from China, Korea and Japan were discussed

Group Photo

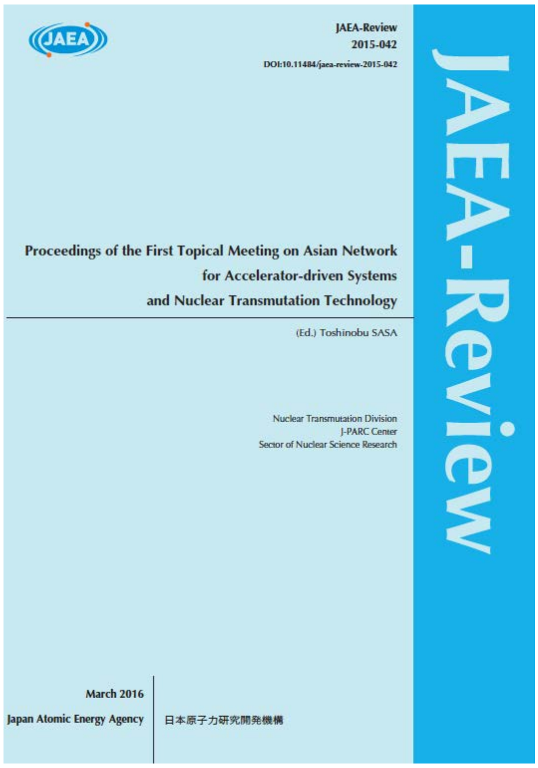
Topical Meeting on Asian Network for ADS & NTT
(Oct. 2015, J-PARC/JAEA, Japan)

Slide in Final Discussion



Proceedings is available online!

- All presentations during 2 days were collected in a report
- You can find the digital document on JAEA website



Summary

- P&T is specified as an option of Japanese energy policy
- JAEA proceeds P&T using ADS and TEF design works
- Future ADS Design is performed
  - Studies to improve reliability of intense proton beam
  - Researches to increase k-eff stability and safety of MA-core
- Design study of TEF-T have been performed
  - Apply existing knowledge from J-PARC Mercury Target
  - Design optimization to prepare irradiation database for ADS
- 1st topical meeting for Asian ADS-NTT network

Status of SNF, GEN IV & ADS in Korea

The 14th Workshop on Asian Network for ADS-NTT
Mito, Japan
September 5, 2016

Seung-Woo Hong, SKKU
Il-Soon Hwang, SNU
Jueun Lee, SNU
Yong-Hoon Shin, SNU
Myung Jae Song, HYU

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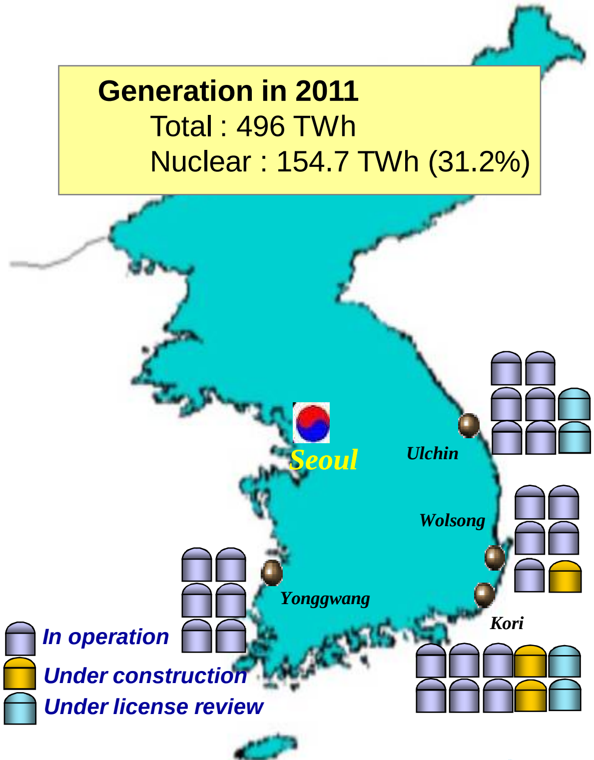
II. Status of GEN IV in Korea
III. ADS research in SKKU
IV. TORIA
V. Summary

I. Status of NPP and SNF in Korea

Current Status of NPPs in Korea

Generation in 2011
Total : 496 TWh
Nuclear : 154.7 TWh (31.2%)



- **In operation(27.053GWe)**
  - ✓ **23 units**
    - **19 PWRs**
    - **4 PHWRs (CANDU)**
- **Under construction(3.8GWe)**
  - ✓ **3 PWRs**
    - **Shin-Kori-3 : ’08.10~**
    - **Shin-Kori-4 : ’09.08~**
    - **Shin Wolsung-2: ’08.09~**
- **Under license review(5.6GWe)**
  - ✓ **4 PWRs**
    - **Shin-Ulchin-1**
    - **Shin-Ulchin-2**
    - **Shin-Kori-5**
    - **Shin-Kori-6**

한국원자력연구원 KAERI Korea Atomic Energy Research Institute

Storage Capacity and accumulated SNF as of 2014

<국내 원전본부별 사용후핵연료 저장 현황(2014년말 기준)>

http://blog.khnp.co.kr/blog/archives/20166

Lessons we learned from failures since 1983

- The government made nine attempts to look for a repository site since 1983, but failed mostly until 2005.

- Two examples of Decide-Announce-Defend
  - Anmyeon-Do (1990-1991) - failure
  - Guleop-Do (1994-1995) - failure

- (Partial) Engagement of Public and Local Government
  - Buan (2003) – still a failure

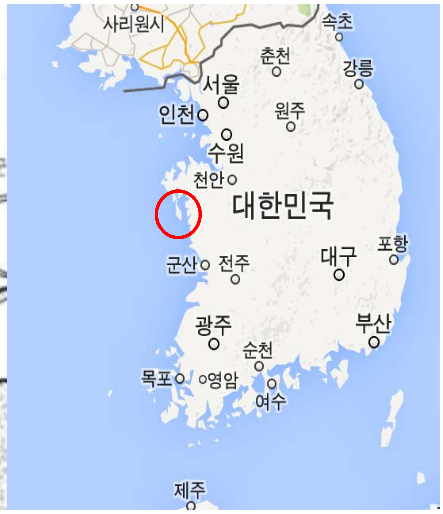
- Success with LILW through Public Engagement
  - Gyeongju city (2005~)

- PECOS for SNF

Example 1 : Decide-Announce-Defend

Anmyeon-Do (1990-1991)

- Plan : To build a spent fuel interim storage (HLW)
  To invest ~ $900M till 2000
  To establish the 2nd KAERI in the local area
- Initiated by the government without engagement of local public
- The plan was cancelled in June 1991

Example 2 : Decide-Announce-Defend

Guleop-Do (1994-1995)

- The government decided and announced.
- Proposed site for nuclear waste:
  - Island made of granite (and considered as a safe geological formation)
  - HLW (Interim storage), LILW (Permanent)
  - only 10 people lived in that island (small compensation)


Guleop-Do (1994-1995)

- The residents in the island agreed with the government plan.
- However, people in neighboring islands and Incheon City objected.

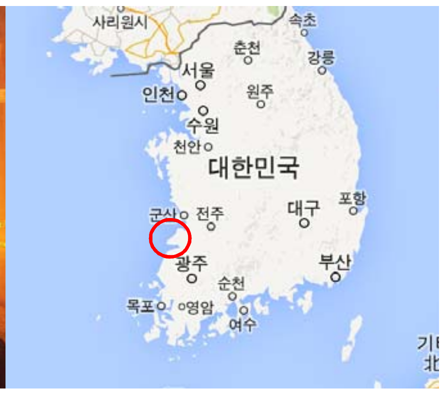
- An active fault was found under the sea near the island, and the plan was cancelled in the end of 1995.


(Partial) Engagement of Public and Local Government

Buan (2003)

- Government requested **public participation**
- Several **local governments** applied for the nuclear waste management site.
  - Package: Nuclear waste storage site & Proton Accelerator Project
  - The headquarter of Korea Hydro & Nuclear Power Co. will move to the site.
 - The local government supported and applied.
- Eruption of violence. Injuries of people. Conflict among the local people.
- The plan was cancelled in 2004.





Turning point

- On Dec. 17, 2004

 The government decided that the repository sites for LILW and SNF would be separately sought after.

- Involvement of local public was requested by the government

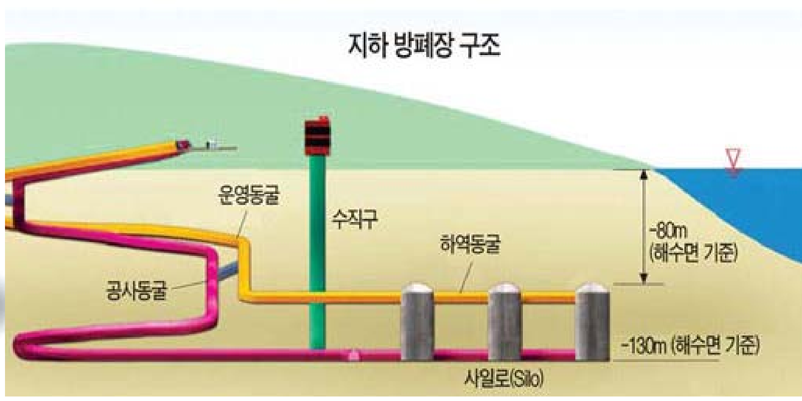
Success with LILW: Through Community Agreement

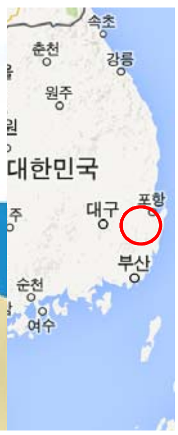
Gyeongju city (2005 ~ 2015)

- Disposal site for just LILW
- Residents applied for hosting the site

 > Local governments carried out the vote of residents (2nd Nov. 2005)

 > **Gyeongju (89.5% agreed)**, Gunsan (84.4%), Yeongdeok(79.3%), Pohang(67.5%)
- Construction started in 2008
- "Nuclear Safety and Security Commission" issued approval of use on 11 Dec. 2014
- Community Benefit





Still unsolved problems with SNF

- Nov. 2011 ~ Aug. 2012: forum for SNF was formed.
- September, 2012: a law passed for establishing **Public Engagement Commission on Spent Nuclear Fuel Management, PECOS**

PECOS for Spent Nuclear Fuels

Public Engagement Commission on Spent Nuclear Fuel Management, PECOS (2013~2015)

- The public engagement started with the launch of PECOS in 2013
- PECOS consists of 15 members, from human & social science and technical engineering, representatives recommended by NGO and residents in NPP areas.
- The commission plays a role of deciding principles and methods of the public engagement program, and **submitting recommendation (national plan on SNF) to government**.
- The commission submitted recommendation to the government on June 2015.

Public Engagement Commission on Spent Nuclear Fuel Management

Recommendation by PECOS

Recommended the government to seek a repository site for SNF:

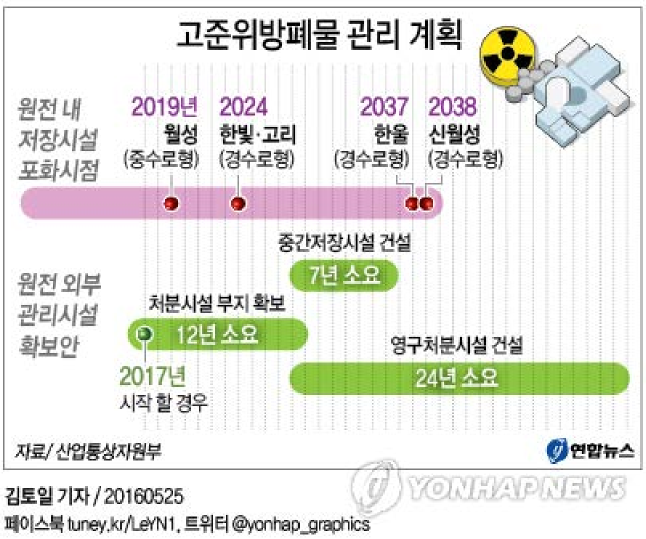
- Timeline for constructing:
  an intermediate storage (for 7 years)
  an underground Research Lab (for 14 years)
  a permanent repository (for 10 years)

- Capacity: 707,476 bundles
  LWR 42,839 bundles, HWR 664,637 bundles

- Establish a "Center for Environment Monitoring" in the region

"Government Basic Plan" for SNF

- Based on the PECOS recommendation,
  July 2015 ~ April 2016,
  a Task Force Team (in the government)
  for "Basic Plan for SNF" was worked out.



II. Status of GEN IV in Korea

Status of GEN IV (Pyro-SFR) in Korea

- On Dec. 2008, (Nuclear energy Long Range Plan)

  Pyro + SFR (Gen IV)
  ~ 2025, Pyro for 30 tons
  ~ 2028, SFR for 300 MWe

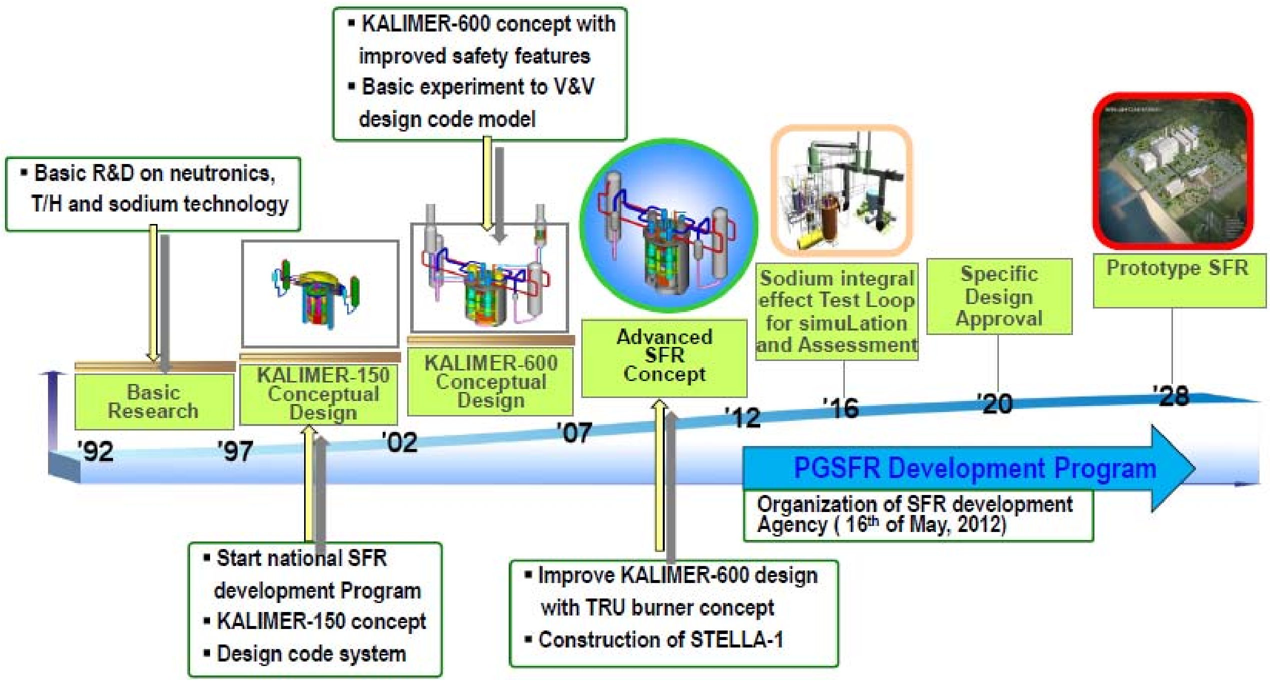
- On Nov. 2011, Revision of the original plan
  SFR (300MWe → 100MWe),

- On Jan. 2015,
  Necessity of a site for SFR (to be built by 2028)

- On June, 2015, Revision of the Korea-US Agreement
  Use of SNF for a research purpose

- By 2020, Korea-US collaboration research and agreement for feasibility of pyroprocessing (in terms of economy, non-profileration)

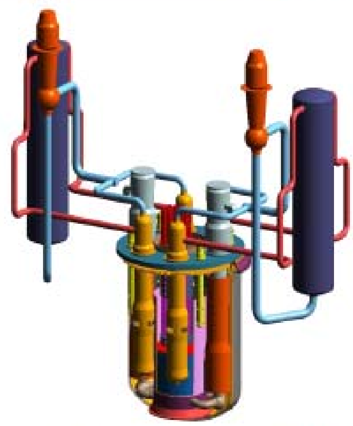
Overview of Prototype SFR Development History

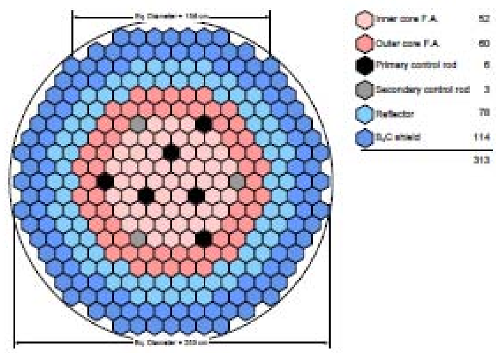


from presentation by Dr. H. K. Joo, KAERI, 2014

Overview of Prototype SFR Development

- Goal
  - Design Certification of prototype SFR by 2020 (1st Phase)
  - Construction of prototype SFR by 2028
- Work Scope
  - Reactor system design
  - Code and technology validation
  - Metal fuel development
  - BOP and component design
- Feature of Prototype SFR
  - Proliferation resistant core without blankets
  - Metallic fuel
  - Enhanced safety with passive systems
  - TRU fuel irradiation capability





from presentation by Dr. H. K. Joo, KAERI, 2014

III. ADS Research in SKKU

Topics of ADS R&D in SKKU

1. Computational modeling: ^{T}Nudy
2. Transmutation of LLFP's: ^{99}Tc, ^{129}I, ..
3. Accelerator Driven Molten Salt Reactor
4. Neutron Cross Section Measurement
5. Development of Cyclotrons for ADS

1. ^{T}Nudy
(^{ROOT} **Nu**clear **D**ata Librar**y**)

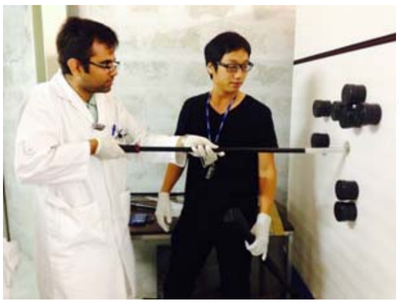
- **A C++ library, powered by ROOT, to read, process and visualize ENDF nuclear data**
- ENDF= Evaluated Nuclear Data Format
  - Nuclear reaction data for E ≤ 20 MeV, including cross sections and neutron yields
  - Written in ASCII, and can be read most conveniently by FORTRAN (i.e., fixed length records and so on)

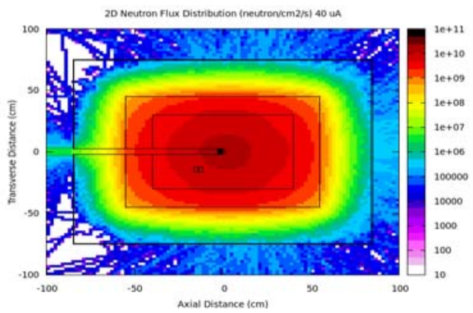
An example of ENDF file

```
… …
 4.009300+4 9.210840+1          0          0          0          04034 3 17    0
-1.537640+7-1.537640+7          0          0          1          74034 3 17    1
          7          2                                            4034 3 17    2
 1.554330+7 0.000000+0 1.575580+7 8.802450-5 1.600000+7 2.610420-34034 3 17    3
 1.700000+7 9.111520-2 1.800000+7 2.766320-1 1.900000+7 4.673160-14034 3 17    4
 2.000000+7 6.148280-1                                            4034 3 17    5
 0.000000+0 0.000000+0          0          0          0          04034 3  099999
 4.009300+4 9.210840+1          0          0          0          04034 3 22    0
… …
```

2. Transmutation of LLFPs
Experiment with a cyclotron in CAL, France

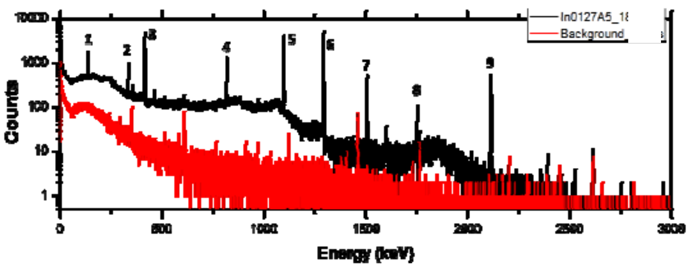
- Started a TARC experiment through an international collaboration
- Initial verification of the simulation for neutron flux with samples

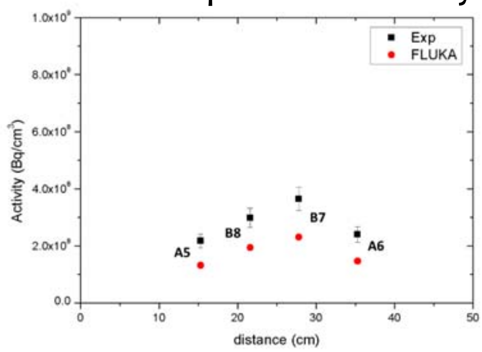




- Preliminary Results: Gamma rays from Indium sample & its activity

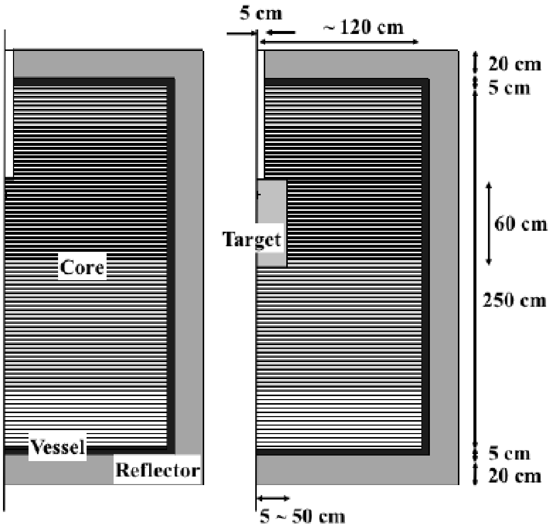
$^{115}In\,(n,\gamma)\,^{116m}In$

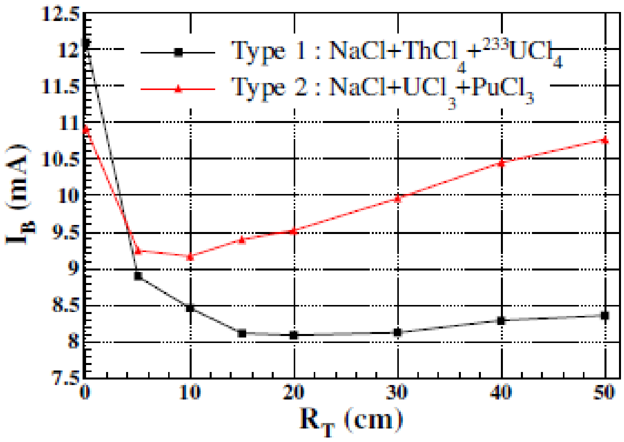




3. Acc. Driven Molten Salt Reactor

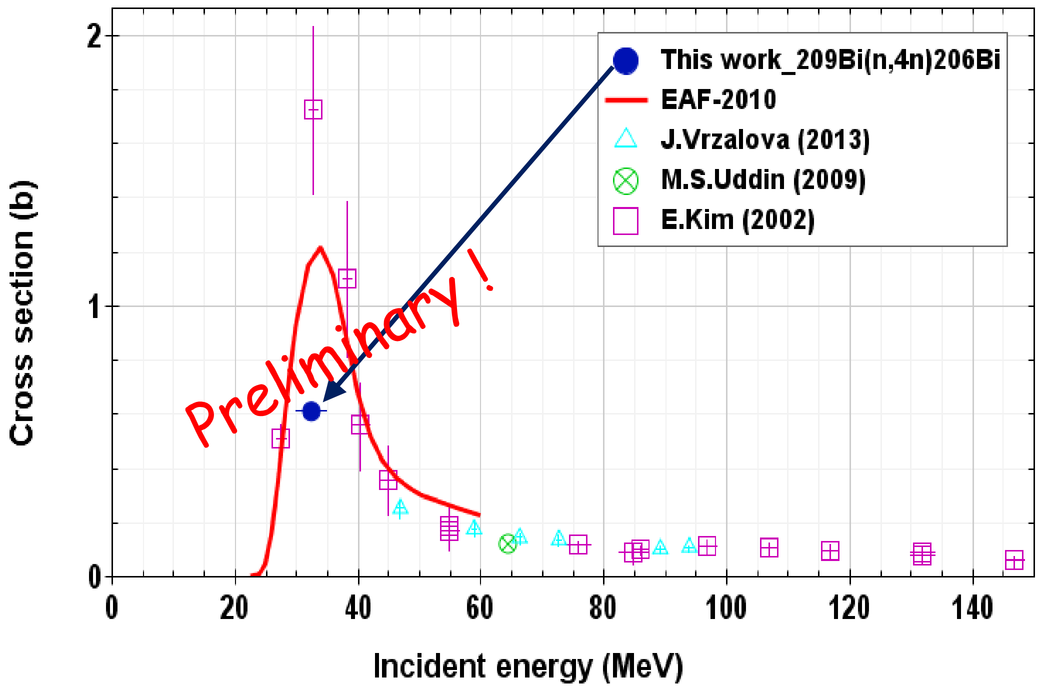
Implementation of an LBE spallation target
in an accelerator-driven molten salt subcritical reactor



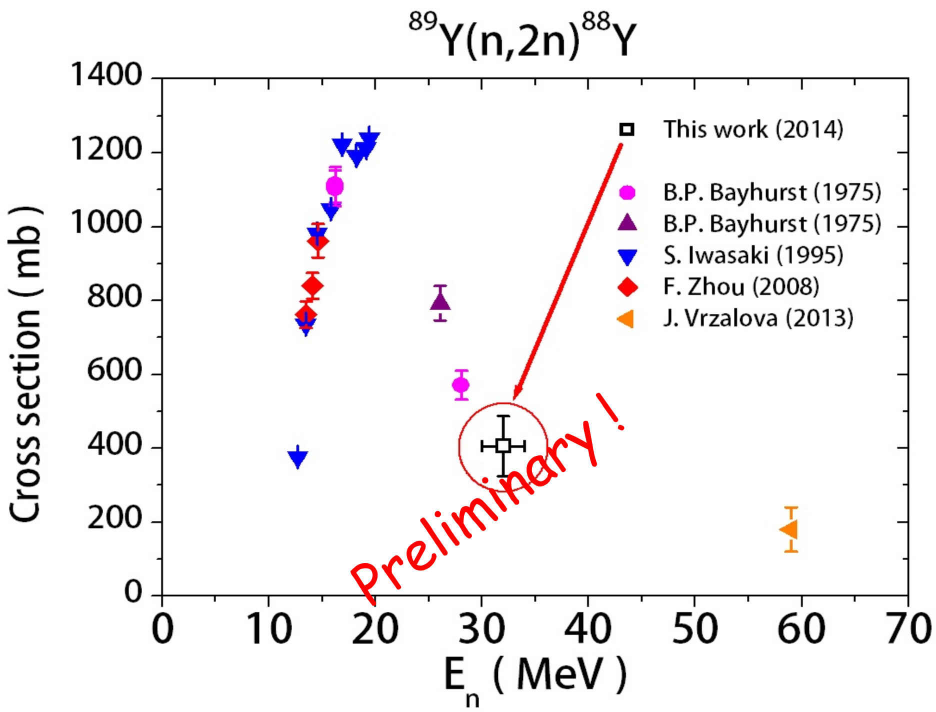


4. Neutron Cross Section Measurement at KIRAMS

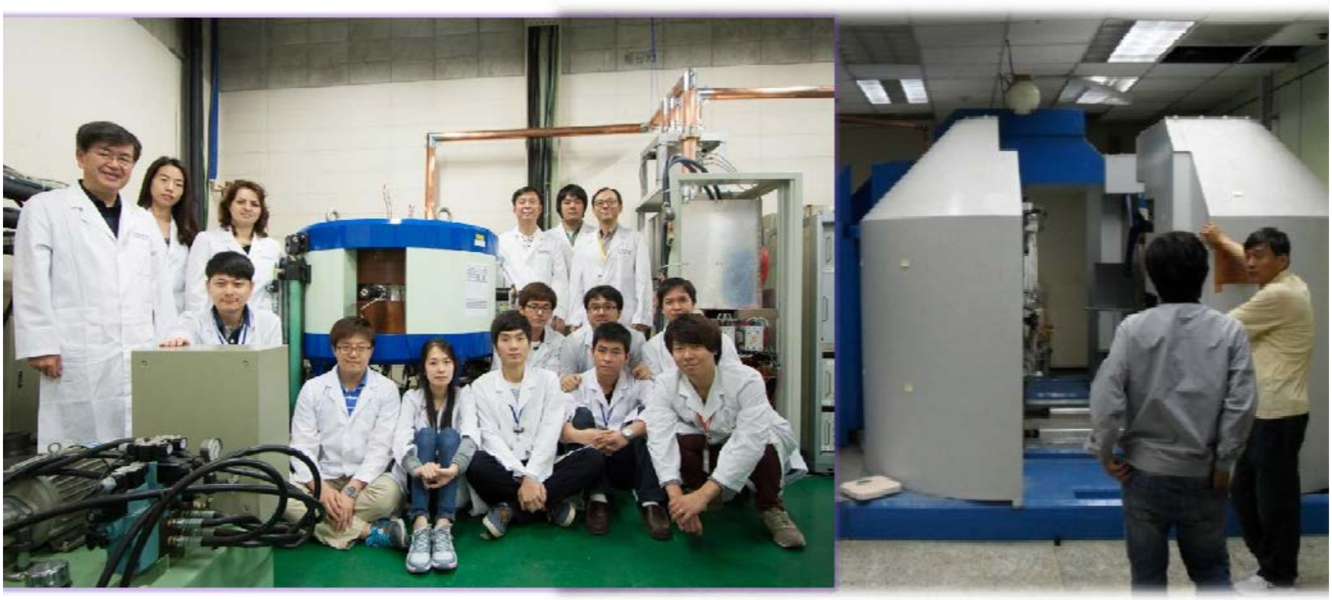
- **Estimated cross section of ^{209}Bi (n, 4n) ^{206}Bi**



- **Estimated cross section for ^{89}Y (n, 2n) ^{88}Y**



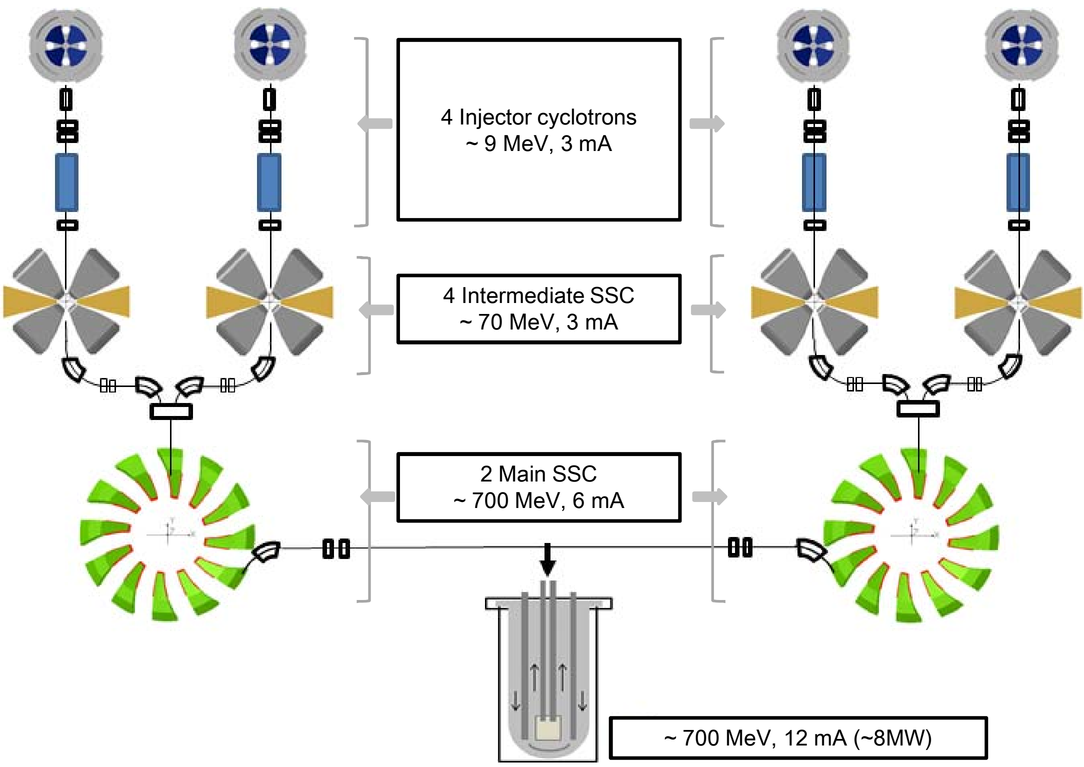
5. Accelerator Group in SKKU (Prof. Jong Seo Chai)



9 MeV, 100uA

13 MeV, 100uA

Layout of the Cyclotron System for ADS

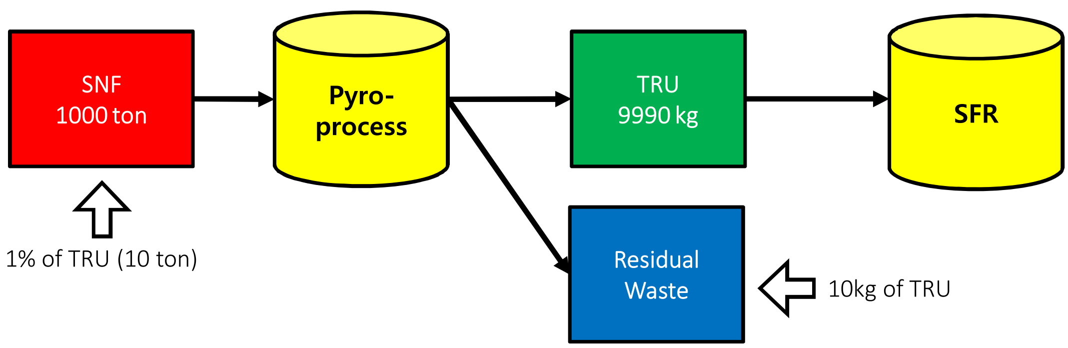


III. TORIA

(Thorium Optimized Radionuclide Incineration Arena)

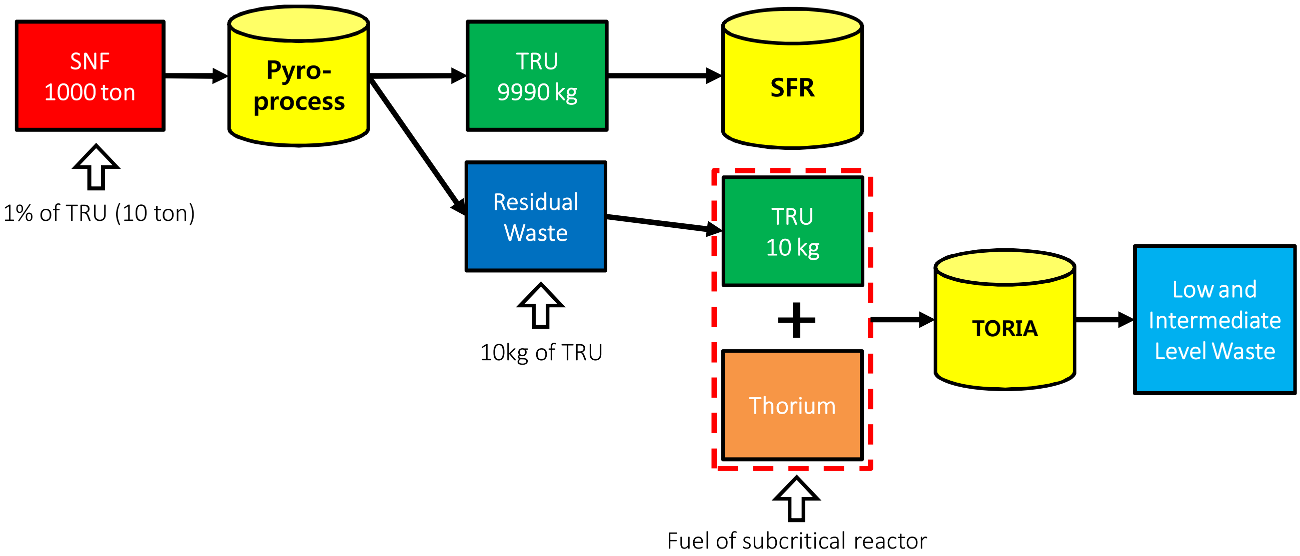
Pyroprocess-SFR System

- Anticipated amount of SNF is about 1000 ton per year at 2025 in Korea
  - It contains 1% of TRU, which is about 10 ton
- Pyroprocess separates TRU from SNF
  - Separated TRU goes to SFR
  - Residual waste contains about 10kg of TRU



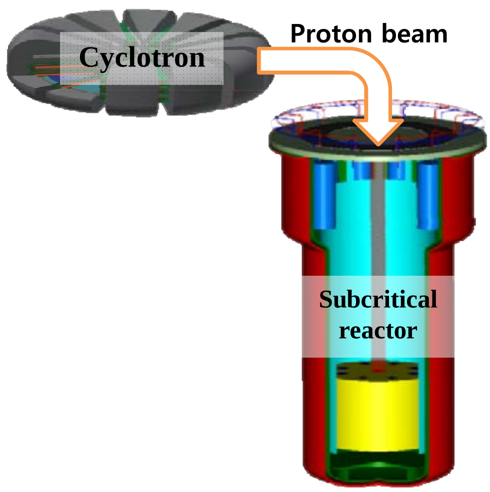
Pyroprocess-SFR-TORIA System

Residual waste containing TRU is mixed with thorium and used for fuel of TORIA. This system leaves behind only low and intermediate level waste



Concepts of TORIA

- **TORIA**: Thorium Optimized Radionuclide Incineration Arena
- Purpose
  - TORIA is designed for the purpose of managing spent nuclear fuel by burning TRU and long-lived fission product
- Characteristics
  1. Accelerator-driven subcritical system
  2. Dedicated burner
  3. Thorium based oxide fuel
  4. LBE as coolant and target material



Conceptual diagram of TORIA

Design of Critical TORIA 1

Parameter	Value
Thermal power	30MWth
Power plant efficiency	35%
Refueling interval	800 days
Primary coolant	Lead-bismuth eutectic
Fuel type	(Th-TRU)O2
Cladding, structure material	HT9
Pellet nominal density (%TD)	100.0
Active core height/equivalent diameter (H/Deq)	<1
Number of pins per one assembly	64 including 4 skeletal bar
Average effective multiplication factor	1.01104
Average core power density	28.856W/cc
Average linear power density	4.252kW/m

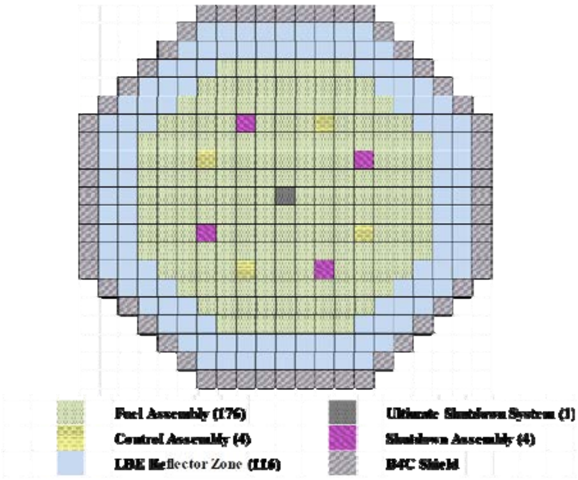
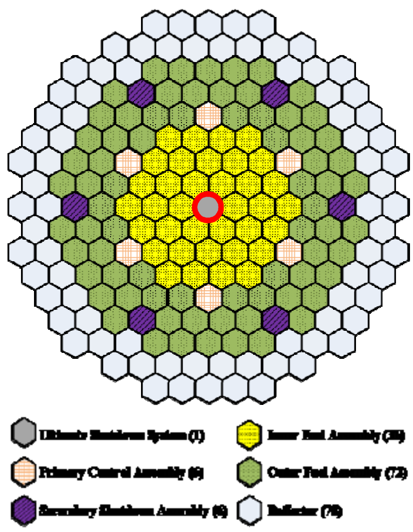


Fig 1. TORIA core model

Design of Critical TORIA 2

- Design of marine TORIA is based on the URANUS design
- Thermal power is 50MWth
- Equivalent core diameter is 1.9m and height of active core is 1.8m

Parameters		Value
Power		50 (MWth)
Number of pins per one assembly		61 including 1 skeletal bar
Pin pitch-to-diameter ratio		1.35
Fuel pin pitch		21.33 (mm)
Fuel pin diameter		14.4 (mm)
Cladding thickness		0.06cm
Active core height		1800 (mm)
Equivalent core diameter		1900 (mm)
Fission gas plenum height		1300 (mm)
Lower plenum height		300 (mm)
Volume fraction	Fuel	40.82%
	Coolant	50.03%
	Structure	9.14%



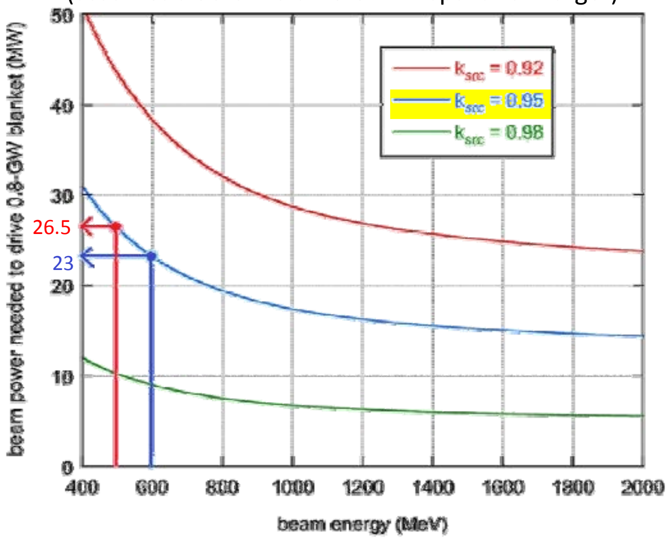
Design Criteria of Subcritical TORIA

Accelerator

The protons are injected onto a spallation target to produce source neutrons for driving the subcritical core, and proton is generated by accelerator

Beam power needed to drive a 0.8-GW ADS subcritical core

(assumes a 50-cm-diameter LBE spallation target) †



Rx Power \ Beam Energy	500 MeV	600 MeV
800 MWth	26.5 MW	23 MW
MYRRHA 100 MWth		3MW (600MeV, 5mA)
TORIA 30 MWth	1 MW (500 MeV, 2 mA)	0.86 MW (600 MeV, 1.43 mA)

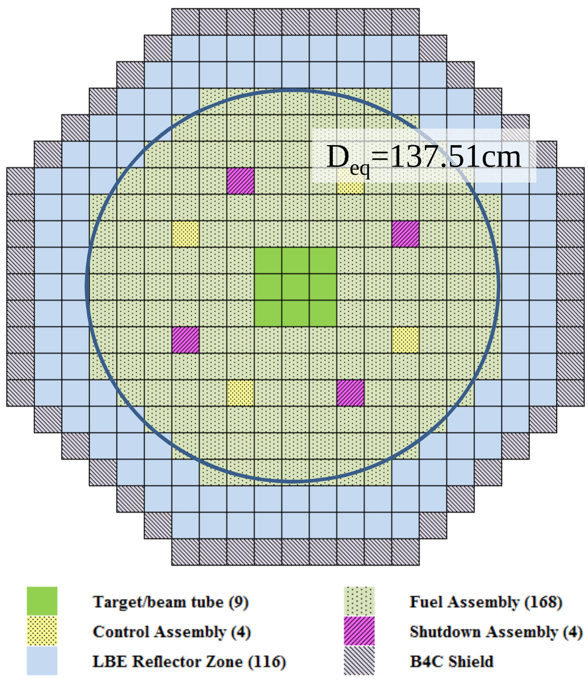
†H. Aït Abderrahim, et. al., "Accelerator and Target Technology for Accelerator Driven Transmutation and Energy Production" ADS white paper 2010

Design Criteria of TORIA

Preliminary core design

Main parameters of preliminary core

Thermal power	$30MW_{th}$
Power plant efficiency	35%
Refueling interval	1000 days
Primary coolant	Lead-bismuth eutectic
Fuel type	(Th-TRU)O2
Cladding, structure material	HT9
Pellet nominal density (%TD)	100.0
Active core height/equivalent diameter (H/D_{eq})	<1
Number of pins per one assembly	64 including 4 skeletal bar
Average effective multiplication factor	0.955
Average core power density	28.856W/cc
Average linear power density	4.252kW/m
Average discharge burnup	14.127MWd/kgHM



In 2015, Korea signed the GIF-LFR MoU to become a full member of the GIF-LFR provisional System Steering Committee

Summary

- Korea signed the GIF-LFR MoU to become a full member of the GIF-LFR provisional System Steering Committee
- SNU and SKKU are doing fundamental but original researches for transmutation and ADS.
- Close international collaboration with China, Japan and Europe is needed.

Institute of Nuclear Energy Safety Technology, CAS
Key Laboratory of Neutronics and Radiation Safety, CAS

Better Nuclear Energy Technology, Better Life!
www.fds.org.cn

Current Status of Subcritical Reactor Technology for ADS in China

Presented by: Yunqing Bai

Contributed by FDS Team
Key Laboratory of Neutronics and Radiation Safety
Institute of Nuclear Energy Safety Technology (INEST)
Chinese Academy of Sciences
www.fds.org.cn

14th International Workshop of ADS-NTT 2016, Mito, 5 Sept.

Contents

I. Strategy and plan

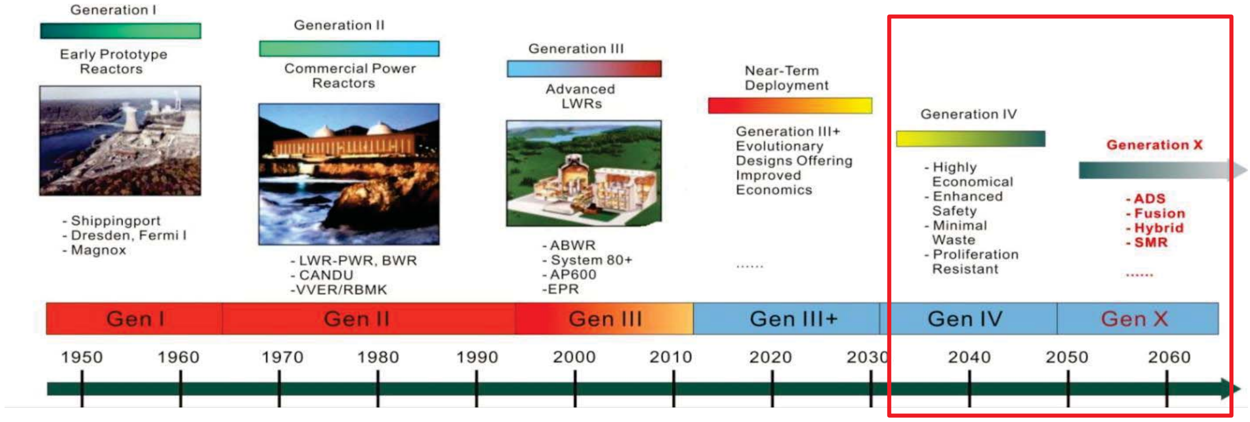
II. Design and R&D Progress

III. Summary

China's Plan on Nuclear Energy
(Plan up to 2020)

- **Nuclear power plant in China（by August, 2015）**
  - *25 reactors (~ 23.6GWe) in operation*
  - *26 reactors (~28.7GWe) under construction*
- **National plan of developing nuclear energy before 2020**
  - ***58 GWe in operation***
  - ***30 GWe under construction***
- **National plan for nuclear and radiation safety before 2020**
  - *More R&D are required to enhance nuclear safety, especially in the basic research of nuclear safety*
  - ***~79.8 billion RMB investment plan (~13.3 billion US dollars)***

Key Issues of Nuclear Energy Development

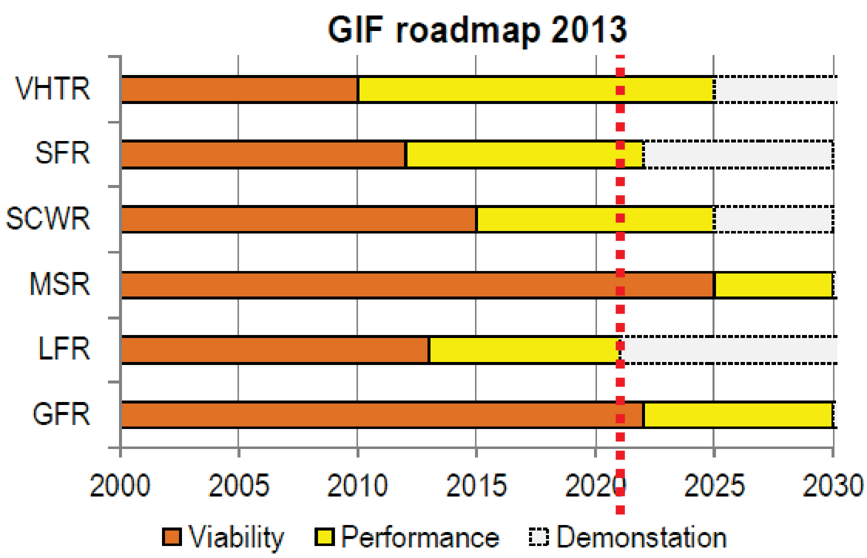


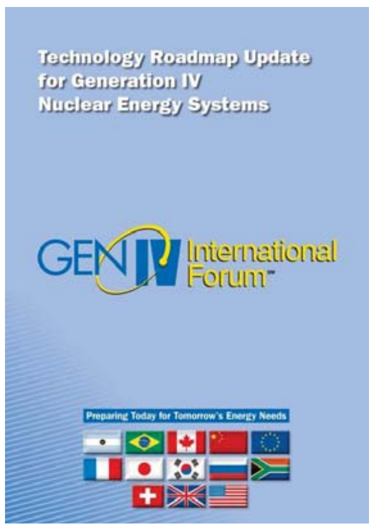
1. **Limitation of Fuel Resources:** ~60 year available resources for utilization
2. **Nuclear accident:** TMI, Chernobyl, Fukushima
3. **Disposition of Nuclear Waste:** long term radioactive toxicity

Advanced and innovative nuclear energy system should be a viable way to solve nuclear energy problems.

Latest Roadmap of Generation IV Reactors

—— GIF organization evaluated in 2014

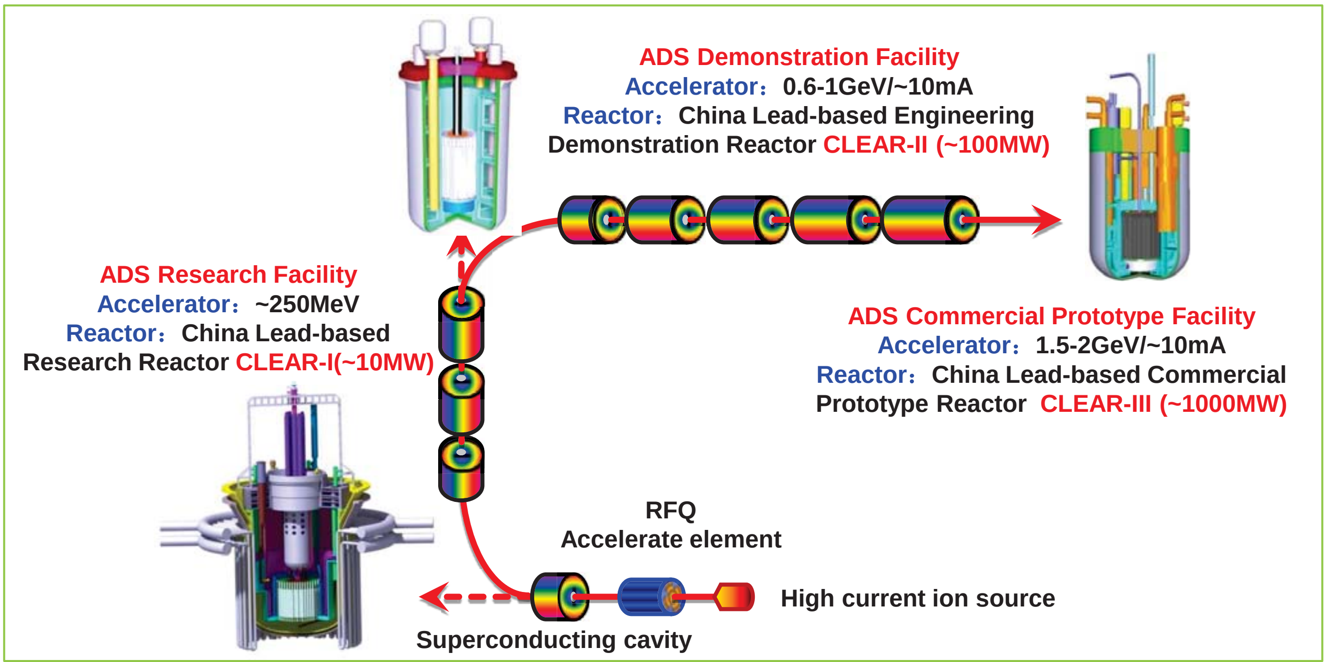




LFR is expected to be the first Generation-IV nuclear system to achieve industry demonstration and commercial application.

China Lead-based Reactor Development Plan

- Chinese Academy of Sciences (CAS) launched the ADS Project, and plan to construct demonstration ADS transmutation system ~ 2030s through three stages.
- China LEAd-based Reactor (CLEAR) is selected as the reference reactor for ADS project and for Lead cooled Fast Reactor (LFR) technology development.



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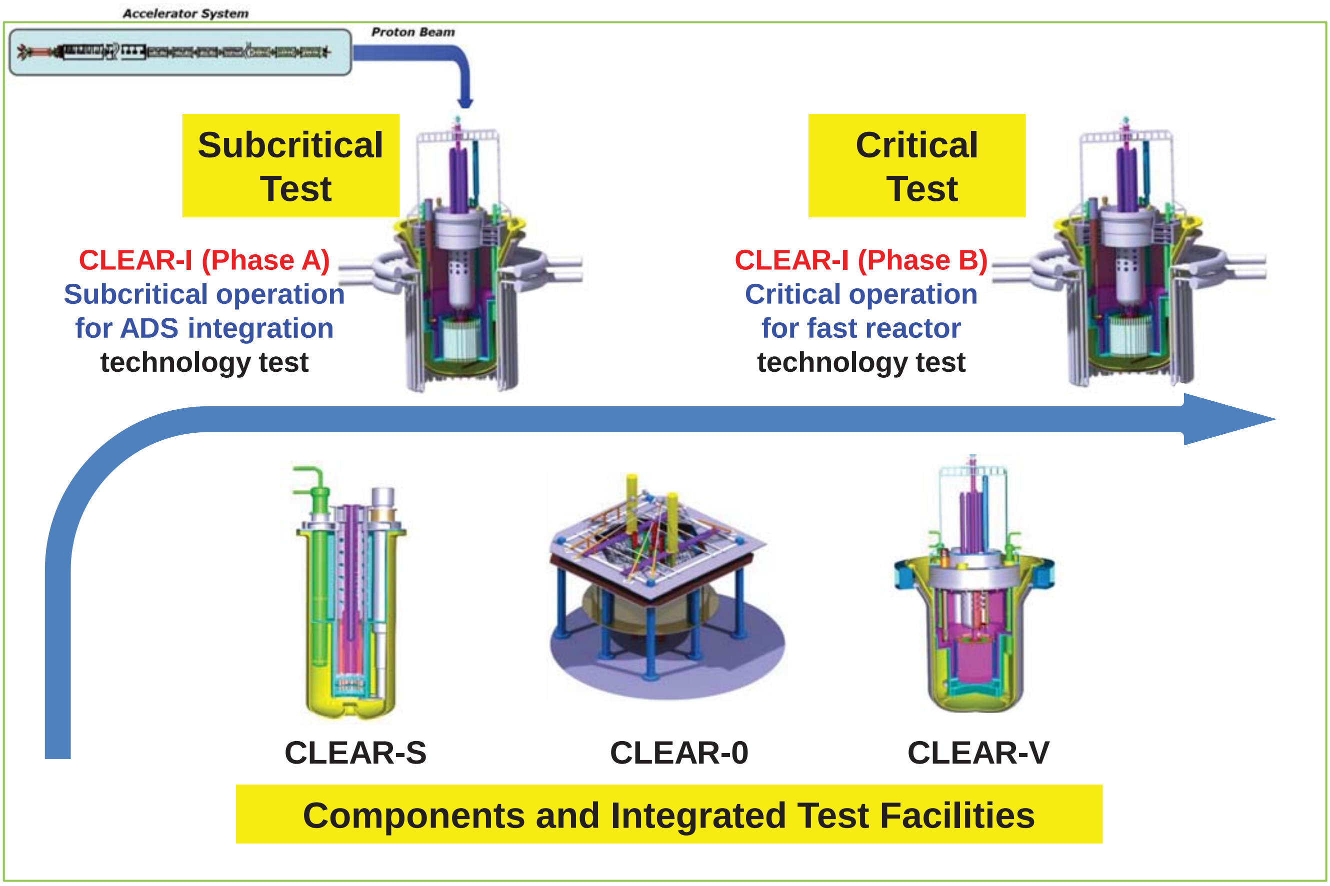
Key Laboratory of Neutronics and Radiation Safety,CAS

CLEAR-I Implementation Plan



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I. Strategy and plan

II. Design and R&D Progress

1. Reactor Design
2. Key Technology R&D
3. Safety Assessment

III. Summary

Current Status of CLEAR-I Project

❖ Reactor Design

- 2011-2014：Conceptual Design
- 2015-2016：Preliminary Engineering Design

❖ Technical R&D

- 2011-2013：PbBi Loop Construction and Components Fabrication
- 2014-2016：Thermal-hydraulic, material, safety and Integrated Test Platform Test

❖ Safety Analysis

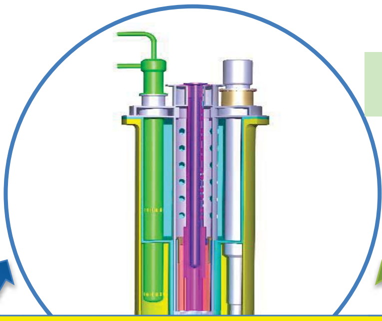
- 2011-2014：Software V&V, Accident and Environmental Impact Analysis
- 2015-2016: Integrated Simulation of System and Environmental Impact

Key Technologies and Integrated Test Facilities

3 Test Reactors in INEST/FDS

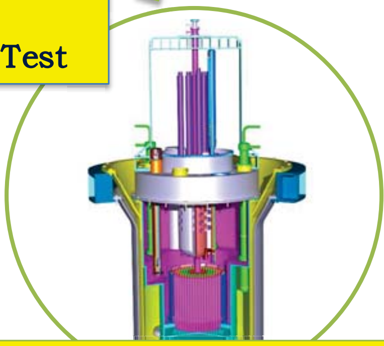
4 Kinds of Key Technologies

I. Coolant materials technology
II. Struct. Materials & Nucl. Fuel
III. Key Components Development
IV. Instrumentation and Control



Lead-alloy Cooled Non-nuclear Reactor CLEAR-S
Out-pile Integral Test

Lead-based Zero Power Reactor CLEAR-0
In-pile Integral Test



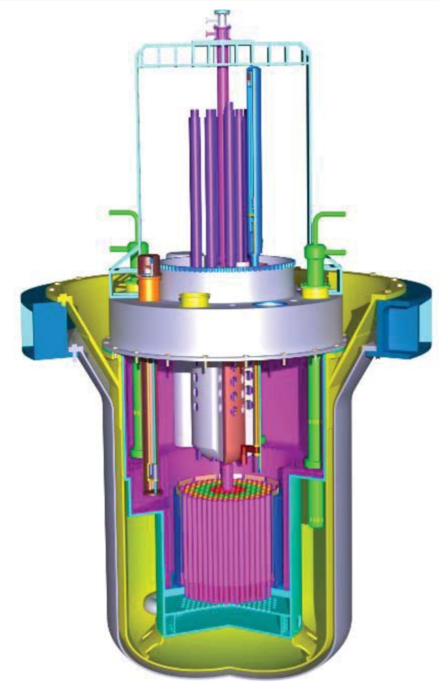
Lead-based Virtual Reactor CLEAR-V
Software V&V and Integral Test

Institute of Nuclear Energy Safety Technology,CAS
Key Laboratory of Neutronics and Radiation Safety,CAS

CLEAR-I System Design Status

- The detailed conceptual design has been done (more than 20 Systems)
- Preliminary engineering design is underway

1. Nuclear Design
2. Thermo-hydraulic Design
3. Coolant System
4. Reactor Structure
5. Reactivity Control System
6. Refueling System
7. LBE Process System
8. Fuel Assembly
9. Safety System
10. I&C System
11. Application System
12. Radiation Protection System
13. Auxiliary System
14. …



Design Objective and Principle

Design Objectives

- ADS and Lead cooled Fast Reactor technology validation platform
  - Neutronics; Thermal hydraulics; Safety characteristics
  - Key components R&D and measurement control technology
- Fundamental science and neutron irradiation research platform
  - Fuel and material irradiation
  - Isotope production and nuclear technology training

Design Principles

- Feasible technology
  - Mature material and fuel; Low power; Pool type vessel
- Reliable safety
  - Natural circulation; Passive decay heat removal system
- Capability of flexible experiment
  - Dual mode operation; Remote handling refueling system
- Technical continuity
  - MOX fuel, Minor actinides transmutation fuel…

Main Design Parameters

Parameter		Values
Core	Thermal power (MW)	10
	Activity height (m) Activity diameter (m) Fuel (enrichment)	0.8 1.05 UO_2(19.75%) at first
Cooling System	Primary coolant Inlet/Outlet temperature (℃) Coolant drive type Heat exchanger Second coolant Heat sink	LBE ~300/385 Forced Circulation 4 Water Air cooler
Material	Cladding Structure	15-15Ti/316Ti 316L

Key Technologies R&D

PbBi Coolant Loop KYLIN-II

◆ Experimental functions

- Materials & Components test
  - Corrosion of structural materials
  - Qualification of prototypical components
- Thermal-hydraulic behavior test
  - Natural/Forced/Mixed circulation
  - Fuel Bundle test
  - CFD and System Code validation
- Reactor Typical/Severe Accident Test
  - Heat exchanger tube rupture accident

◆ Main parameters

- Temperature: 200ºC~1100ºC
- Design Pressure: 25 MPa
- Mass flow rate: 50m^3/h
- Total power: ~2000kW
- Inventory of PbBi: ~20tons

Series PbBi loops were built to develop the LBE technology and support the design and construction of CLEAR.

Materials, Components and I&C Technologies

◆ Coolant Materials

Lead bismuth eutectic

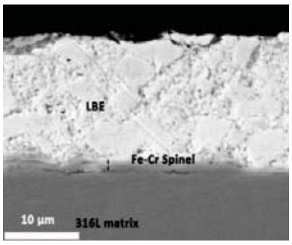
Oxygen measurement and control

◆ Key Components

Mechanical pump

Double wall heat exchanger

◆ Structural Materials and Fuel



316l corrosion

Fuel assembly simulator

◆ Instrumentation and Control

Fuel handling system

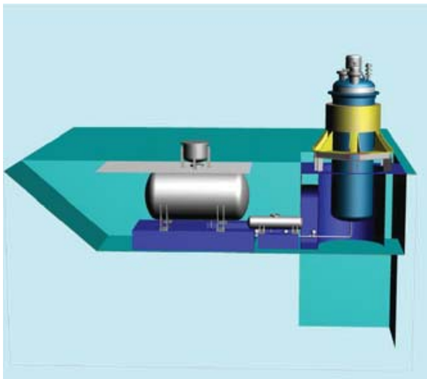
Full scope reactor simulator

Institute of Nuclear Energy Safety Technology,CAS
Key Laboratory of Neutronics and Radiation Safety,CAS

Lead-based Non-nuclear Reactor CLEAR-S

❑ Objectives and Functions

- Reactor prototype components validation
  - Pump, HX, DHR…;
  - Refueling machine, Control rod system.
- Pool thermal-hydraulic integral test
  - Integral circulation test in pool type facility;
  - Code V&V (NTC, RELAP, CFD, etc.).
- Large scale SGTR (interaction of HLM with water)



❑ Main Parameters

- Dimensions: 1:1 height, 1:2.5 diameter to CLEAR-I
- Temperature: 250°C~550°C
- Thermal power: 2.5MW (7 full scale fuel bundles)
- Mass flow rate: ~100m^3/h

Components fabrication completed, the construction is underway.

Lead-based Zero Power Reactor (CLEAR-0)

- Validation of the nuclear analysis method, code and database
- Validation of the nuclear design and control technology
- Provide experimental data to support the licensing of CLEAR-I

CLEAR-0	
Type	Zero-Power Reactor
Neutron source	Accelerator-based neutron source
Running mode	Critical Subcritical
Assembly	Hexagonal (Stainless Steel)
Fuel	UO_2
Coolant	Solid LBE (room temperature)

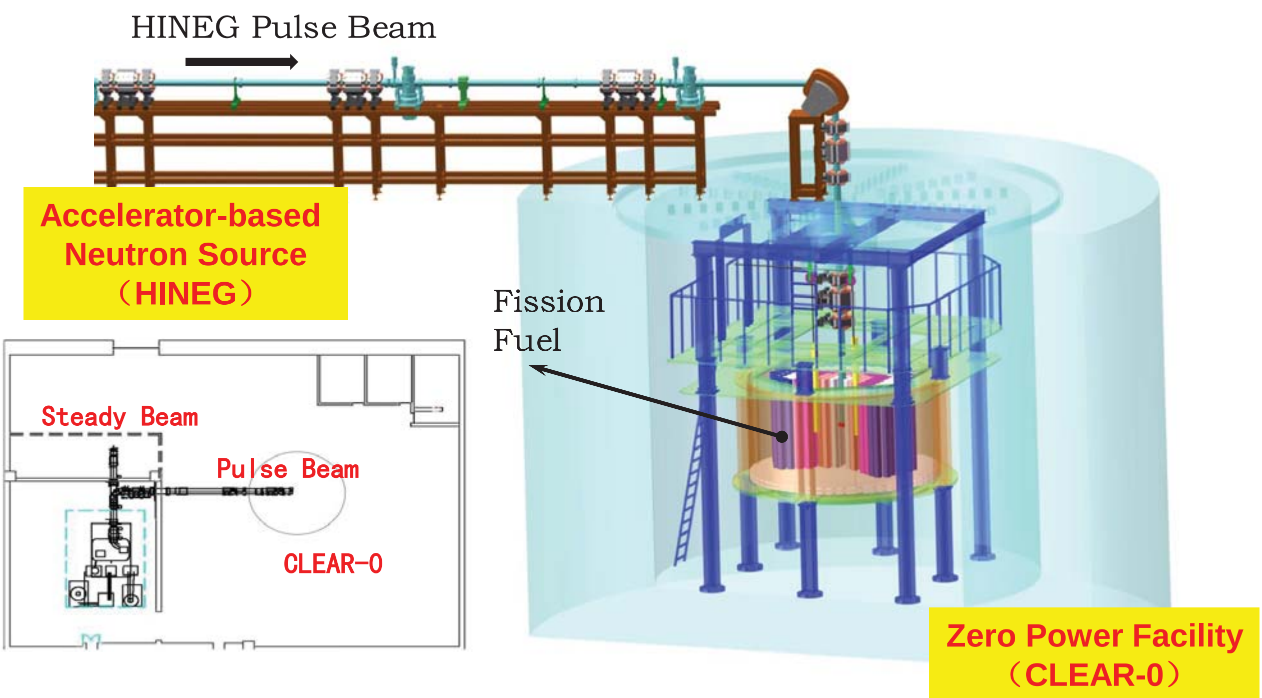
Zero Power Reactor (CLEAR-0)

Design of CLEAR-0 is completed, the construction is underway.

Institute of Nuclear Energy Safety Technology,CAS
Key Laboratory of Neutronics and Radiation Safety,CAS

Lead-based Zero-Power Facility

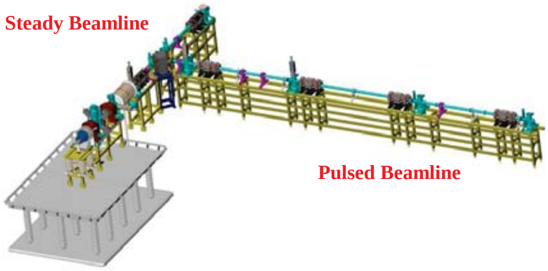
Fusion neutron generator Driven Subcritical reactor/blanket (FDS-0)



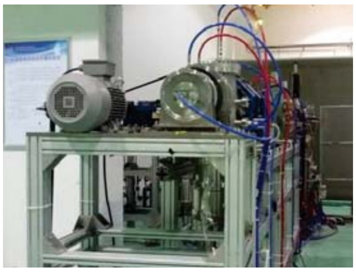
High Intensity Fusion NEutron Generator HINEG

(Phase-I, ~10^{12}-10^{13}n/s)

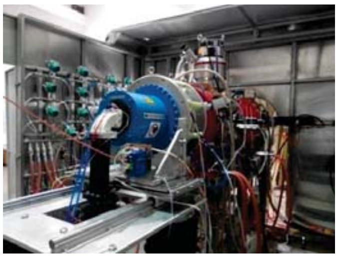
Parameter	Steady beam	Pulsed beam
Yield	~10^{12}-10^{13}n/s	>10^{10}n/s
Beam size	10-20mm	<10mm
FWHM	—	<1.5ns



HINEG-I



HINEG-I Rotating Tritium Target



Low Energy Beam Transport Section

Experimental Hall

The installation of HINEG-I has been finished and successfully produced a D-T fusion neutron yield of up to 10^{12} n/s.

Software Development and Integrated Simulation

Softwares Developed at INEST

I. Simulation of Fundamental Physical Problems

- SuperMC — Super Monte Carlo Simulation Program for Nuclear and Radiation Process
- NTC — Neutronics-Thermohydraulics Coupled Simulation Program
- MTC — Magnetic-Thermohydraulics Coupled Simulation Program
- TAS — Tritium Analysis Program for Fusion System
- RiskA — Reliability and Probabilistic Safety Assessment Program
- HENDL — Hybrid Evaluated Nuclear Data Library
- RiskBase — Database Management System for Reliability Analysis

II. Interactive Design and Optimization

- RVIS — Virtual Reality-Based Simulation System for Nuclear and Radiation Safety
- MCAM — Multi-Physics Coupling Analysis Modeling Program
- RiskAngel — Risk Monitor for Nuclear Power Plant
- ARTS — Accurate/Advanced Radiotherapy System
- SYSCODE — System Analysis Program for Parameter Optimization & Economical Assessment of Fusion Reactor
- FusionDB — Database Management System for Fusion

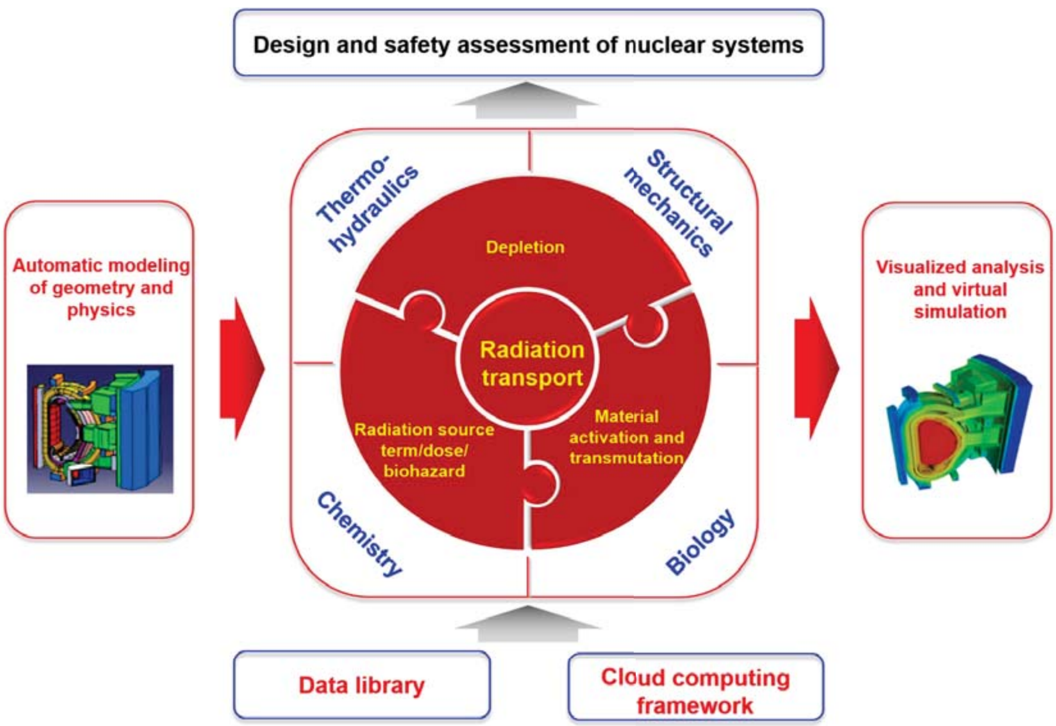
III. Multi-process Integrated Comprehensive Simulation

- Virtual4DS — Virtual Nuclear Power Plant in Digital Society
- ITER-V — Lead-based Virtual Reactor
- CLEAR-V — Virtual Integrated Simulation Platform for ITER
- VisualBUS — CAD-Based Multi-Functional 4D Neutronics Simulation System
- CROSS — Informationization Platform for Collaborative Research and Management
- NCoud — Nuclear Cloud Platform
- NBigData — Nuclear Big Data Platform

Independent intellectual property rights

➢ >800 person-years ,Certificated by international Benchmarking, Applied in 80+ nations

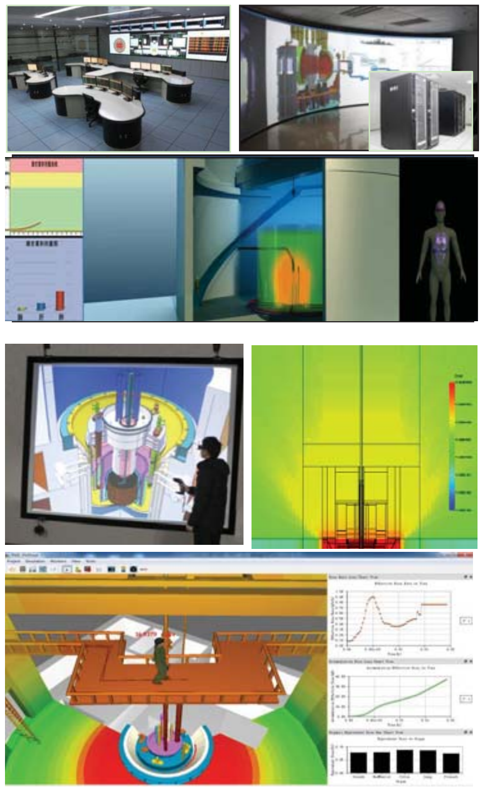
SuperMC: Super Monte Carlo Calculation Program for Nuclear and Radiation Process



Support of complex problems & Validated by thousands of benchmarking

Lead-based Virtual Reactor (CLEAR-V)

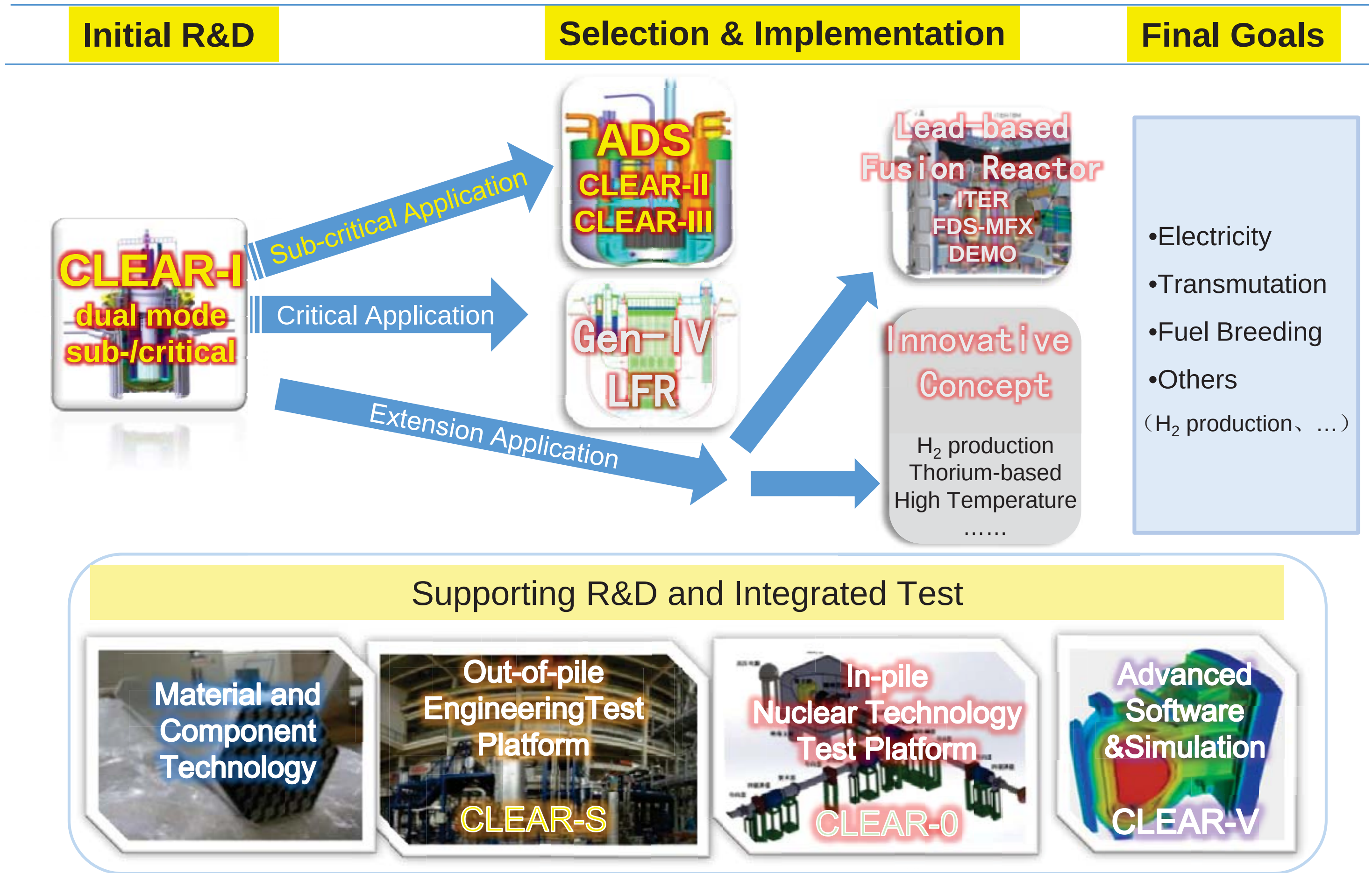
- **Reactor System Design and Optimization**
  - Nuclear, Thermal-hydraulic, structure, system design and parameter optimization
- **Multi-physics Integrated Simulation**
  - Monitor the performance of any part of the reactor at any point in full cycle
- **System Analysis and Assessment**
  - Safety and accident analysis, environmental impact assessment
- **Virtual Reality based Lifelike Simulation**
  - Virtual tour, assembly & design validation, Maintenance optimization & training



Contents

I. Strategy and plan
II. Design and R&D Progress
III. Summary

Overview of China Lead-Based Reactor Development



Summary

1. Lead-based reactor has **many attractive features** and may play **an important role** in the future energy supply, including **a bridge role** in the transition period from fission energy to fusion energy.

2. China has launched the **ADS engineering construction project** in 2011. **The engineering design and related R&D activities** for China lead-based reactors CLEAR are going on in order to finish the construction of the first engineering test system around 2020s.

3. Study on **application concepts showed good prospects** of lead-based reactor.

4. Chinese government is **encouraging wider and deeper international collaboration** on S&T research projects, including lead-based reactor program.

Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences (INEST, CAS)

- **Jointly sponsored by:**
  - Hefei Institutes of Physical Science, CAS (CASHIPS)
  - University of Science and Technology of China (USTC)
- **Key programs:**
  - Advanced Fission Reactor Design and R&D (ADS - CLEAR)
  - Fusion/Hybrid Reactor Design and R&D (ITER/FDS)
  - Nuclear Safety Innovation Project for Scientific and Technological Development
- **10 Divisions, 400~500 Staff + 200~300 Students**

~400 members

Major Research Areas:

1. **Nuclear reactor safety**
   (reactor design, nuclear detect & experiments, safety analysis methodology, …)
2. **Radiation safety and environmental impact**
   (radiation protection & shielding, chemistry safety of nuclear energy, …)
3. **Nuclear emergency and public safety**
   (nuclear safety culture, nuclear accident emergency, nuclear power economics, …)

The major professional/fundamental research basis for nuclear energy safety technology in China to promote the efficient and safe application of nuclear energy.

Institute of Nuclear Energy Safety Technology,CAS
Key Laboratory of Neutronics and Radiation Safety,CAS

Thanks for Your Attention!

Website: www.fds.org.cn

E-mail: contact@fds.org.cn

Current Status on Accelerator-Driven System (ADS) Experiments at Kyoto University Critical Assembly (KUCA)

Cheolho Pyeon

Research Reactor Institute, Kyoto University, Japan

pyeon@rri.kyoto-u.ac.jp

Contents

- Background and Purpose
- Composition of ADS in Kyoto Univ.
  - **K**yoto **U**niversity **C**ritical **A**ssembly (KUCA)
  - **F**ixed-**F**ield **A**lternating **G**radient (FFAG) accelerator
- ^{235}U-loaded ADS experiments with 100 MeV protons
- Neutron characteristics on solid targets (W, W-Be and Pb-Bi)
  - Static analyses: Reaction rate (k-source)
  - Kinetic analyses: Subcriticality ρ ($)
    Prompt neutron decay constant α (1/s)
- Summary

Background and Purpose

Background

- An original concept of ADS for producing energy and transmuting MA and LLFP
- Neutron characteristics on solid targets (W, W-Be and Pb-Bi) in ADS
- Influences of solid target on ^{235}U-loaded ADS experiments with 100 MeV protons
  - Neutron yield (Number of neutrons / one proton)
  - Reaction rate distribution (k-source)
  - Subcriticality and prompt neutron decay constant

Purpose

- Investigate neutron characteristics of solid targets through static and kinetic analyses of experiments and calculations (MCNP)

ADS with 100 MeV protons at KUCA

Fig. KUCA core

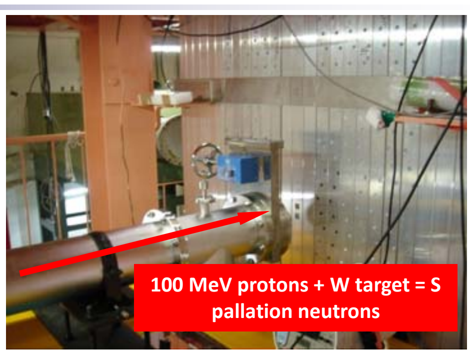


Fig. Beam line of protons

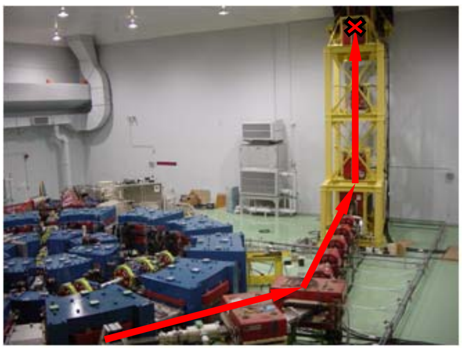
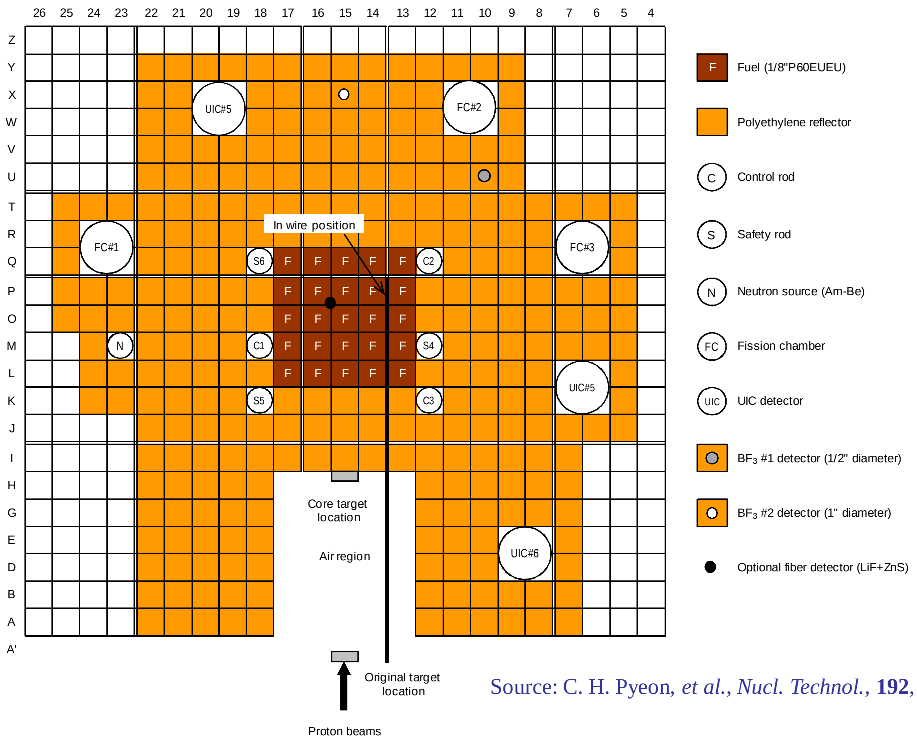


Fig. Beam line of FFAG accelerator

- **KUCA core**
  - A solid-moderated and –reflected core
    Fuel: HEU, Th, NU
    Moderator: Poly., Gr, Be
    Reflector: Al, Fe, Pb, Pb-Bi
- **FFAG accelerator**
  - 100 MeV energy
  - 1 nA intensity
  - 20 Hz repetition, 100 ns width

^{235}U-ADS core configuration



Source: C. H. Pyeon, *et al.*, *Nucl. Technol.*, **192**, 181 (2015).

Fig. Top view of core configuration of ^{235}U-ADS with 100 MeV protons

^{235}U-ADS in KUCA: Experimental analyses

Experiment

- Neutron yield
  - Protons: ^{27}Al(p, n+3p)^{24}Na
  - Spallation Neutrons: ^{115}In(n, n')^{115m}In
- Reaction rates (M and k-source)
  - Profiles: ^{115}In(n, γ)^{116m}In
- Subcriticality
  - PNS and Noise methods

Calculation

- MCNP6
- Nuclear data libraries
  - JENDL/HE-2007: Protons and spallation neutrons
  - JENDL-4.0: Transport
  - JENDL/D-99: Reaction rates

Definition of parameters

- Neutron yield = Spallation neutrons / Protons
  - Spallation neutrons: ^{115}In(n, n')^{115m}In
  - Protons: ^{27}Al(p, n+3p)^{24}Na
- (Normalized) Reaction rates = Profiles / Spallation neutrons
  - Profiles: ^{115In}(n, γ)^{116m}In (thermal) or ^{115}In(n, n')^{115m}In (fast)
  - Spallation neutrons: ^{115}In(n, n')^{115m}In

Static: Neutron yield

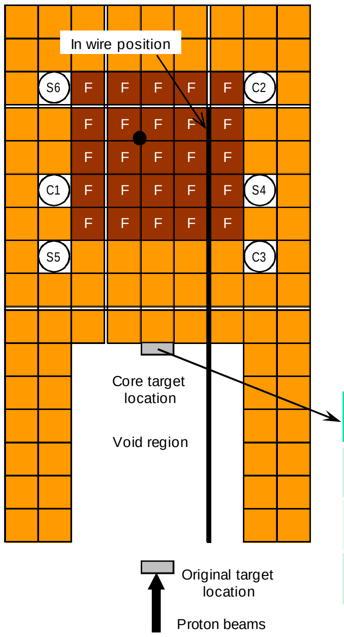


Fig. Core configuration of ^{235}U-PE core (**100 MeV protons**)

Table Dimension of target

Target	Diameter [mm]	Thickness [mm]
W	50.0	12.0
W-Be	50.0	W: 12.0 Be: 10.0
Pb-Bi	50.0	18.0

Table Comparison between measured and calculated neutron yield

Target	Calculation	Experiment	C/E value
W	0.57 ± 0.01	0.21 ± 0.01	2.66 ± 0.01
W-Be	0.32 ± 0.01	0.15 ± 0.01	2.13 ± 0.04
Pb-Bi	0.38 ± 0.01	0.17 ± 0.01	2.27 ± 0.04

Source: C. H. Pyeon, *et al.*, *Nucl. Technol.*, **192**, 181 (2015).

^{235}U-ADS: Source spectrum of target

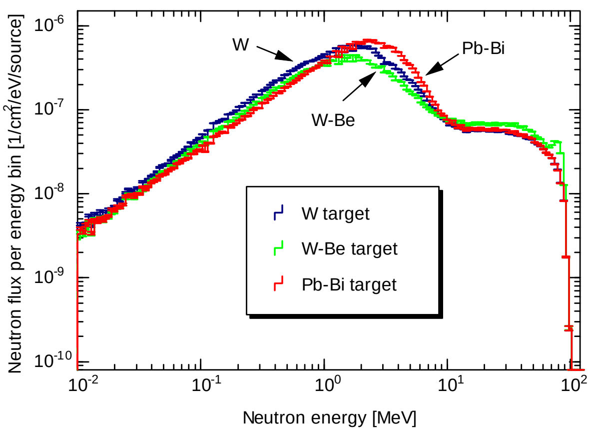


Fig. Neutron spectrum of injection of 100 MeV protons into heavy metal target

- Spectrum of spallation neutrons (100 MeV proton injection)
  - W, W-Be and Pb-Bi targets
  - Almost same

- Very unique peak ranging between 85 and 100 MeV neutrons (for 100 MeV proton injection)

-> How about influences on neutron characteristics in the core?

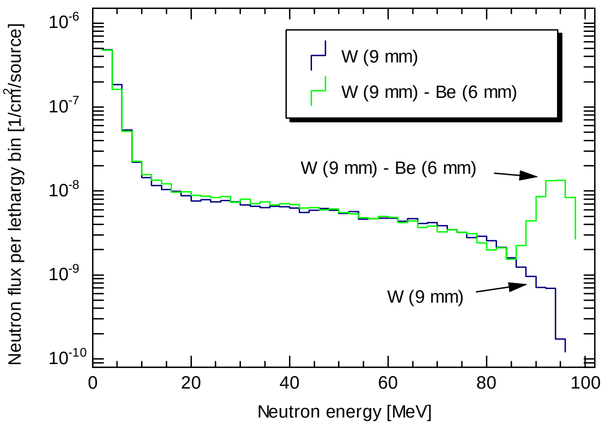


Fig. Comparison between neutron spectra of W and W-Be targets

Source: C. H. Pyeon, *et al.*, *Nucl. Technol.*, **192**, 181 (2015).

Static: Neutron multiplication

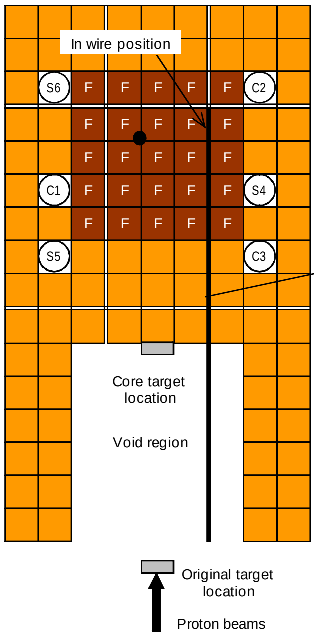


Fig. Core configuration of ^{235}U-PE core
(**100 MeV protons**)

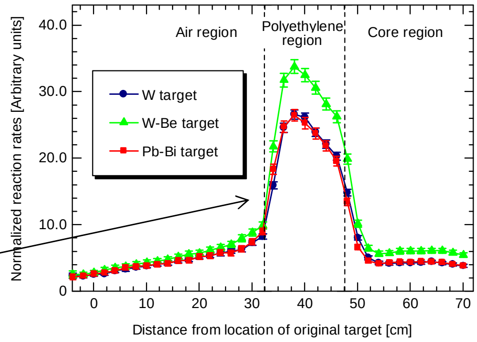


Fig. Measured reaction rate distribution (M and k-source study)

Table Comparison between measured and calculated M values
(Subcriticality: 2,657 pcm)

Target	Calculation	Experiment	C/E value
W	1.73 ± 0.01	1.85 ± 0.02	0.93 ± 0.01
W-Be	2.29 ± 0.01	2.36 ± 0.03	0.97 ± 0.01
Pb-Bi	1.95 ± 0.01	1.94 ± 0.02	1.01 ± 0.01

Source: C. H. Pyeon, *et al.*, *Nucl. Technol.*, **192**, 181 (2015).

Kinetic: Subcriticality (pcm)

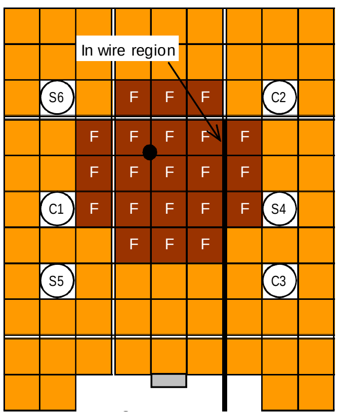


Fig. Core configuration of ^{235}U-PE core

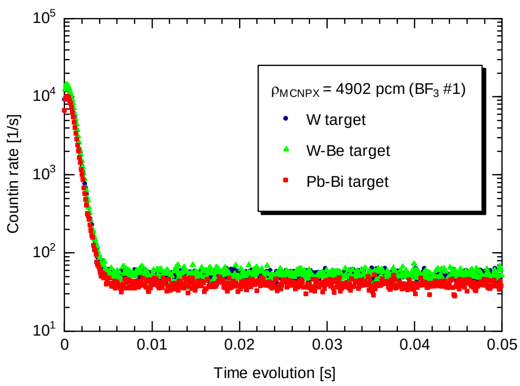


Fig. Measured neutron behavior on time evolution
(α and βeff study)

Table Measured subcriticality (dollar units) by the PNS (area ratio method) method (Ref.: 4,902 pcm)

Target	BF_3 #1 in (10, U)	BF_3 #2 in (15, X)	Optical fiber
W	4944 ± 78	6386 ± 101	6228 ± 99
W-Be	5004 ± 83	7050 ± 114	4929 ± 77
Pb-Bi	4903 ± 77	6356 ± 92	4912 ± 74

Source: C. H. Pyeon, *et al.*, *Nucl. Technol.*, **192**, 181 (2015).

Benchmarks on Solid Pb-Bi target

Table Target study on W, W-Be and Pb-Bi

keff	Reaction rate (In wire) for k-source	Subcriticality	
		PNS method	Noise method
0.987	Available	Available	Available
0.980	Available	Available	Available
0.973	Available	Available	Available
0.950	Available	Available	Available

^{235}U & Pb-Bi-zoned core with Pb-Bi target

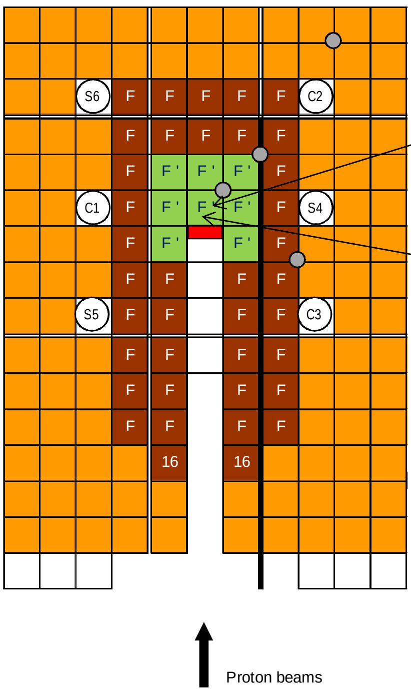


Fig. Core configuration of ^{235}U and Pb-Bi zoned core

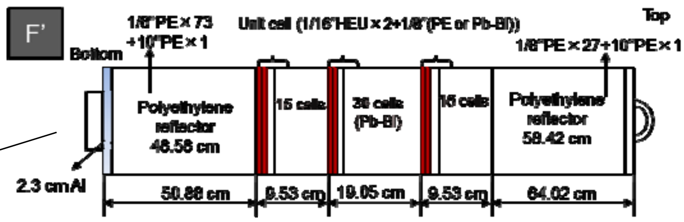


Fig. Fuel assembly of ^{235}U-PE and Pb-Bi

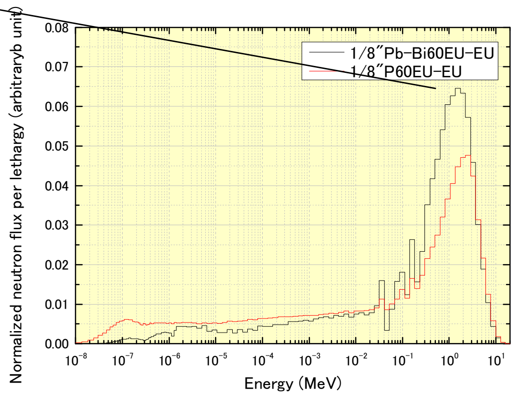


Fig. Neutron spectrum of core center in F' at 100 MeV proton injection onto Pb-Bi target

Subcriticality benchmarks

Table Subcriticality in ^{235}U & Pb-Bi-zoned core with Pb-Bi target

keff	Subcriticality	
	PNS method	Noise method
0.980	Available	Available
0.950	Available	Available
0.920	Available	Available
0.900	Available	Available

Reaction rates (Neutron spectrum) analyses

ADS experiments with 100 MeV protons

■ ^{235}U & Pb-Bi-zoned core with Pb-Bi target

- Indium reaction rate distribution: Analyses of k-source by $^{115}In(n, \gamma)^{116m}In$
- Spectrum index: $^{115}In(n, \gamma)^{116m}In$ / ^{115}In (n, n') ^{115m}In
- Neutron spectrum: Activation foils; Al, Fe, In, Au and Ni (MeV threshold)
- Subcriticality ranging between 0.98 and 0.90

Table Reaction rates in ^{235}U & Pb-Bi-zoned core with Pb-Bi target

keff	Reaction rate (In wire) for M and k-source	Activation foils for Spectrum (Al, Fe, In, Au, Ni)
0.980	Available	Available
0.950	Available	Available
0.920	Available	Available
0.900	Available	Available

IAEA ADS Exp. Benchmarks in KUCA

- **^{235}U-ADS with 14 MeV neutrons**
  (KURRI-TR-444, 2014: IAEA ADS CRP 2007)
http://www.rri.kyoto-u.ac.jp/PUB/report/03_tr/img/KURRI-TR-444.pdf

- **^{232}Th-ADS with 14 MeV neutrons or 100 MeV protons (W target)**
  (KURRI-TR(CD)-48, 2015: IAEA ADS CW 2013)
http://www.rri.kyoto-u.ac.jp/PUB/report/04_cd/img/KURRI-TR-48.pdf

- **^{235}U & Pb-Bi-zoned-ADS with 100 MeV protons & Pb-Bi target**
  (Being in IAEA ADS CRP 2016)
Contact me directly (sharing with JAEA of Japan, INEST; IMP of China and others)
  - Pb-Bi target study
  - Pb-Bi-zoned core study
  - Global results of static and kinetic studies
    (subcriticality ranging between 0.98 and 0.90)

Summary

- **Solid Pb-Bi target study of ADS with 100 MeV protons**
  - Reaction rate distribution: ^{115}In(n, γ)^{116m}In
  - Kinetic parameters by the PNS and the Noise methods
  - Subcriticality ranging between 0.99 and 0.95

- **Neutronics on ^{235}U and Pb-Bi-zoned core**
  - Kinetic parameters by the PNS and the Noise methods
  - Subcriticality ranging between 0.98 and 0.90

- **Reaction rate analyses**
  - Reaction rate distributions: ^{115}In(n, γ)^{116m}In (thermal)
    ^{115}In (n, n')^{115m}In (fast)
  - Activation foils: Al, Fe, In, Au and Ni (MeV threshold)

- **Future works (ADS with 100 MeV protons; Pb-Bi target)**
  - Neutronics (Global results) on ^{235}U and Pb zoned (Fast-like spectrum) core
  - ^{237}Np (capture and fission) and ^{241}Am (fission) irradiation

Round discussion on ADS-NTT2016

Cheolho Pyeon

Research Reactor Institute, Kyoto University, Japan

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Discussion issues

■ **Dr. Sasa of JAEA, Japan**
- Nuclear energy situation in Japan
- Future ADS design: TEF R&D and current status
- MA and Pb-Bi related technologies

■ **Prof. Hong of SSKU, Korea**
- Status on spent fuel management in Korea
- Status on GEN-IV (Pyro-SFR) in Korea
- ADS research in SSKU

■ **Dr. Bai of INEST, China**
- Strategy and plan of ADS (until 2020)
- CLEAR-0, I, II and III
- Software development for actual experimental facilities

■ **Prof. Pyeon of KU, Japan**
- Characteristics on Pb-Bi target and Pb-Bi-zoned core
- IAEA ADS benchmarks of KUCA
- Future ADS experiment plan

Open the proceedings of ADS-NTT 2016, "KURRI-KR(CD) in 2016," on KURRI web site soon!

IAEA ADS Exp. Benchmarks in KUCA

- ^{235}U-ADS with 14 MeV neutrons
  (KURRI-TR-444, 2014: IAEA ADS CRP 2007)
  http://www.rri.kyoto-u.ac.jp/PUB/report/03_tr/img/KURRI-TR-444.pdf

- ^{232}Th-ADS with 14 MeV neutrons or 100 MeV protons (W target)
  (KURRI-TR(CD)-48, 2015: IAEA ADS CW 2013)
  http://www.rri.kyoto-u.ac.jp/PUB/report/04_cd/img/KURRI-TR-48.pdf

- ^{235}U & Pb-Bi-zoned-ADS with 100 MeV protons & Pb-Bi target
  (Being in IAEA ADS CRP 2016)
  Contact me directly (sharing with JAEA of Japan, INEST; IMP of China and others)
  - Pb-Bi target study
  - Pb-Bi-zoned core study
  - Global results of static and kinetic studies
    (subcriticality ranging between 0.98 and 0.90)

10 Participant countries (13 institutions) in IAEA ADS CRP 2016:
Argentina, Belarus, China (INEST and IMP), Germany (KIT), Hungary, India (BARC), Italy (Polito Torino and ENEA), Korea (SNU), US (ANL) and Japan (JAEA and Kyoto Univ.)

M&C 2017 in Jeju, Korea on 16-20, Apr. 2017

- **Subcriticality system analysis methods (Track 4)**
  - 4-1 Subcriticality Measurement and Online Monitoring Techniques
  - 4-2 Spent Fuel Cask/Storage Analyses
  - 4-3 Deterministic and Monte Carlo Analysis of ADS
  - 4-4 Energy and Spatial Correction Factors for Subcriticality Measurements
  - 4-5 Uncertainty of the Methodologies for Subcriticality Determination
  - 4-6 Integral Parameters and their Experimental Determination
  - 4-7 Others

- **Special session** (Chair: Prof. T. Endo, Nagoya Univ., Japan)
  Title: ADS Benchmarks at KUCA
  - Energy and spatial correction factors for kinetic parameters
  - Deterministic and stochastic analysis methods
  - On-line monitoring techniques of subcriticality
  - Uncertainty of methodology for subcriticality
  - Higher-harmonics analyses for kinetic parameters
  - Development of reactor analysis codes

Please access to, http://mc2017.org/

Next meeting (Topical meeting) in 2017

- **New meeting schedule fixed since 2015:**
  - General meeting by rotation (Japan, Korea and China) in every two years (even)
  - Topical meeting (any country) in every two years (odd)

5th Rotation schedule

- 13th, 2015 (Japan): Topical meeting at JAEA (Pb-Bi techniques)
- 14th, 2016 (Japan): General meeting

- **15th, 2017 (???): Topical meeting: Topic and Venue -> Any suggestion?**

- 16th, 2018 (Korea): General meeting
- 17th, 2019 (???): Topical meeting
- 18th, 2020 (China): General meeting

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