Accelerator-Driven System (ADS) Study in Kyoto University Research Reactor Institute (KURRI)

Cheol Ho Pyeon

Research Reactor Institute, Kyoto University, Japan

Contents

- Background and Purpose
- Composition of ADS in Kyoto Univ. (KUCA + 100 MeV protons)
  - **K**yoto **U**niversity **C**ritical **A**ssembly (KUCA)
  - **F**ixed-**F**ield **A**lternating **G**radient (FFAG) accelerator
- ADS experiments with 100 MeV protons
  - Injection of high-energy protons into ^{235}U- and ^{232}Th-loaded cores

^{235}U-loaded: C. H. Pyeon *et al.*, *J. Nucl. Sci. Technol.*, **46**, 1091 (2009).
J. Y. Lim *et al.*, *Sci. Technol. Nucl. Install.*, **2012**, 395878, 9 pages, (2012).
C. H. Pyeon *et al.*, *Nucl. Eng. Technol.*, **45**, 81 (2013).
Y. Takahashi *et al.*, *Ann. Nucl. Energy*, **54**, 162 (2013).
T. Yagi *et al.*, *Appl. Radiat. Isot.*, **72**, 11 (2013).
^{232}Th-loaded: C. H. Pyeon *et al.*, *Ann. Nucl. Energy*, **38**, 2298 (2011).
C. H. Pyeon *et al.*, *Nucl. Sci. Eng.*, (2014). [in print]

- Forthcoming ADS experiments with 100 MeV protons
  - Uncertainties of x-sec data of Pb, Bi and Pb-Bi (critical state)
  - Mockup ADS experiments with the use of ^{235}U-loaded and Pb-Bi-zoned core
  - MA nuclear transmutation in ADS: ^{237}Np capture and ^{241}Am fission
  - Conversion analyses: ^{232}Th capture and ^{233}U fission
- Summary

Background

- ADS Research and Development (since the end of **1990's**) for producing energy and transmuting minor actinides (MA) and long-lived fission products (LLFP)

- World's first injection of 100 MeV protons onto tungsten (W) target at KUCA on **4th Mar. 2009**

  C. H. Pyeon *et al.*, *J. Nucl. Sci. Technol.*, **46**, 1091 (2009).
  C. H. Pyeon *et al.*, *J. Nucl. Sci. Technol.*, **47**, 1090 (2010).

- ^{232}Th-loaded ADS experiments with 100 MeV protons on **3rd Mar. 2010**

  C. H. Pyeon *et al.*, *Ann. Nucl. Energy*, **38**, 2298 (2011).

- Successive ^{235}U- and ^{232}Th-loaded ADS experiments with 100 MeV protons on **2011, 2012 and 2013**

  J. Y. Lim *et al.*, *Sci. Technol. Nucl. Install.*, **2012**, 395878, 9 pages, (2012).
  C. H. Pyeon *et al.*, *Nucl. Eng. Technol.*, **45**, 81 (2013).
  Y. Takahashi *et al.*, *Ann. Nucl. Energy*, **54**, 162 (2013).
  T. Yagi *et al.*, *Appl. Radiat. Isot.*, **72**, 11 (2013).
  C. H. Pyeon *et al.*, *Nucl. Sci. Eng.*, (2014). [in print]

Road map of ADS for nuclear transmutation

Power

Demonstration

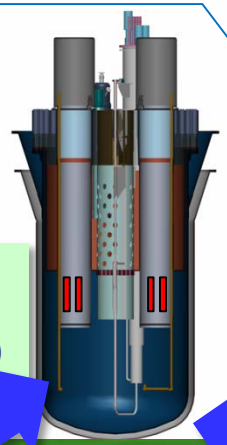
Principle

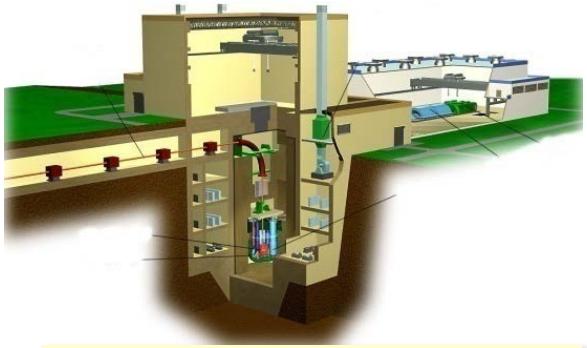
Concept

ADS tech. w/o MA fuel (Pb-Bi core, Accelerator, Operation experiences)

MYRRHA in Belgium
- ~2.4 MW-beam, 50~100 MWth
- Demonstration of ADS tech.
- Fuel irradiation

TEF of J-PARC in Japan
- Pb-Bi target exp.
- Reactor physics exp. (MA in kg order)
- R&D of basic and eng.





Actual ADS plant
- 30 MW-beam, 800 MWth
- MA nucl. trans. of 10 LWR plants

R&D of
- Reactor physics of MA fuel
- Target materials

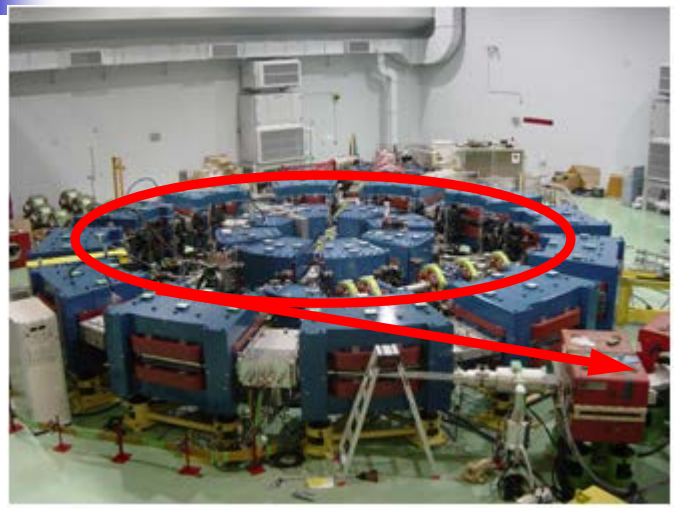
Reactor Physics Exps. at KUCA

①KUCA-FFAG: Reactor Physics Exp.

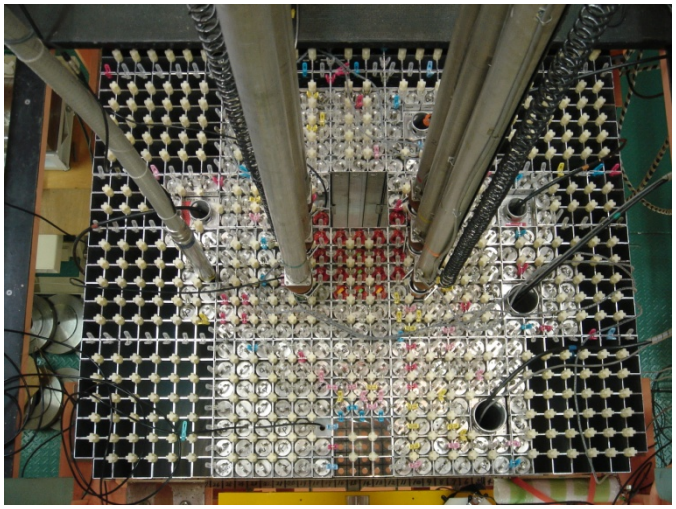
②ADS plant R&D of engineering feasibility

- **High-reliability of accelerator**
- **Control of subcriticality**
- **Removal system of heat decay**

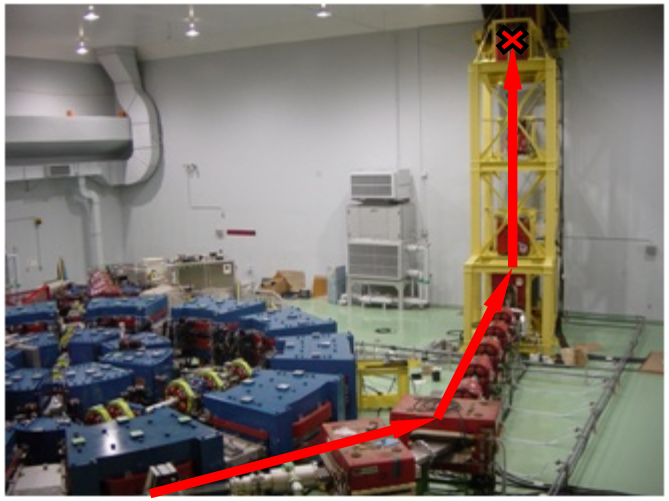
ADS composition in KUCA



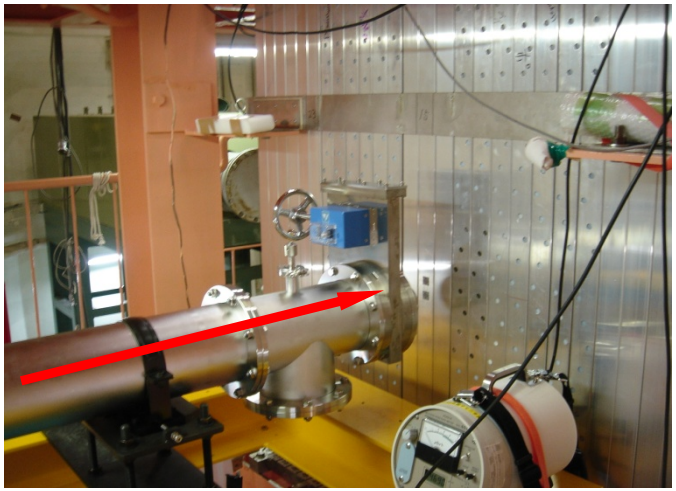
FFAG accelerator



KUCA A-core



100 MeV proton beam line



Key parameters in ADS (Reactor physics)

Reactor core

- **Neutron spectrum** - Soft or Hard: Thermal or Fast
- **Subcriticality** - Near critical or Deep subcritical

External source

- **Neutron spectrum** - High-energy neutrons
  (ex. 14 MeV neutrons vs. 100 MeV protons)
- Beam specification - Energy, Intensity, Beam spot,
  Beam repetition rate, Beam width

Research objectives

Investigate the neutronic characteristics and feasibility of ADS, from the viewpoint of energy amplifier system and nuclear transmutation

First injection of spallation neutrons

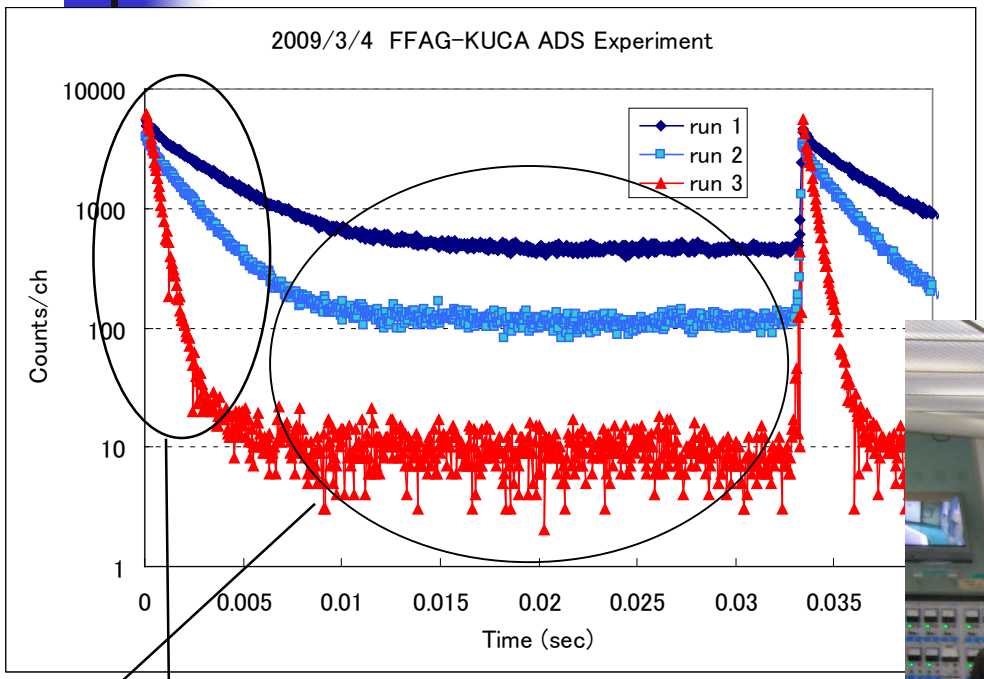
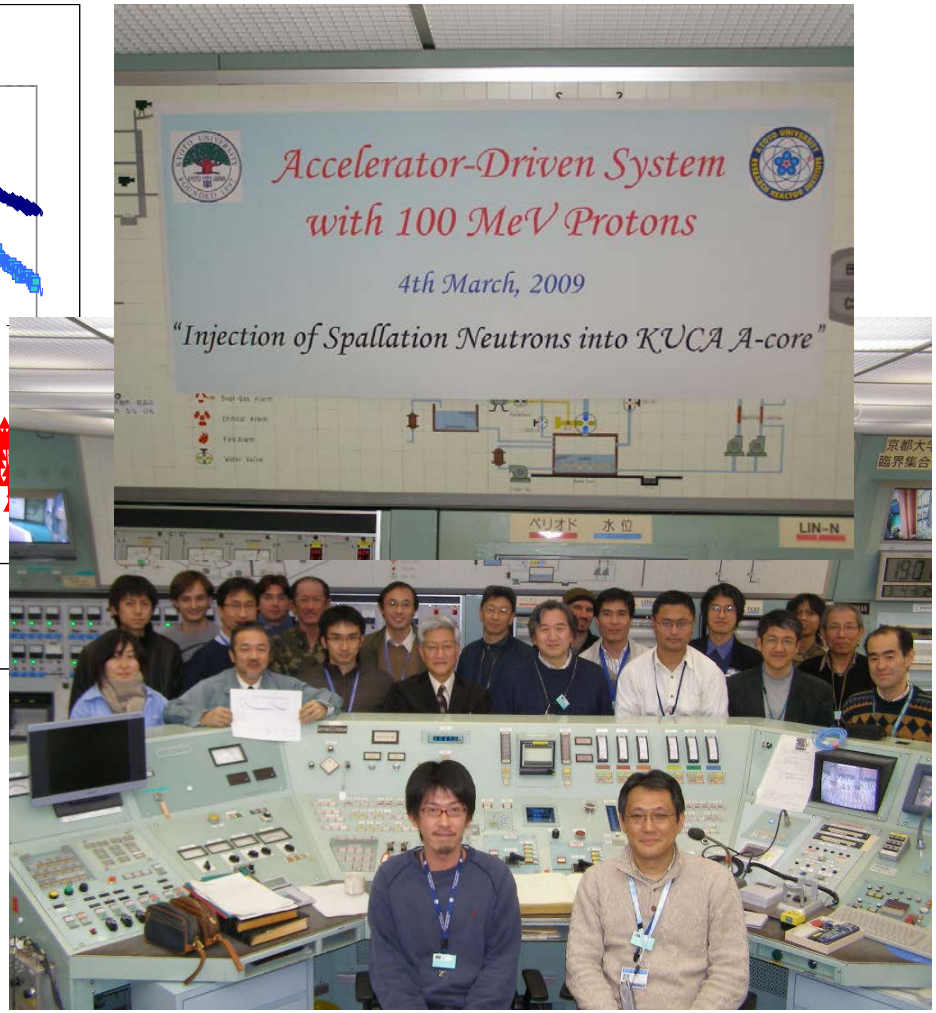


Fig. Time series of neutrons

Spallation neutrons from target

Delayed neutrons in core



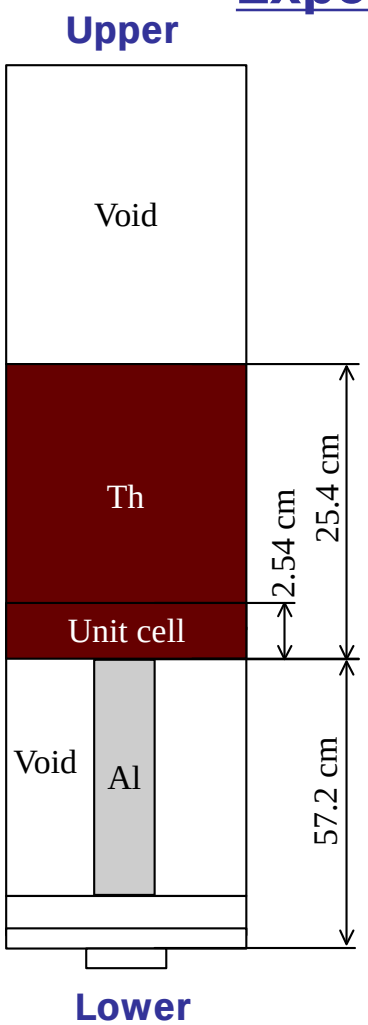
C. H. Pyeon *et al.*, *J. Nucl. Sci. Technol.*, **46**, 1091 (2009).

Neutron multiplication by spallation neutrons generated by protons

^{232}Th-loaded ADS Exp. (Energy amplifier system)

Experimental settings

- Fuel size: 5 × 5
- Volume: 27.65 × 27.65 × 25.40 cm^3
- k_{eff} = 0.03250 (MCNPX with ENDF/B-VII.0)
- ^{232}Th(n, f) threshold: 2.0 MeV
- ^{115}In(n, n')^{115m}In threshold: 0.35 MeV
- Protons: 100 MeV, 0.03 nA, 200 ns, 30 Hz
- Tungsten target (80 mm diam. and 10 mm thick)



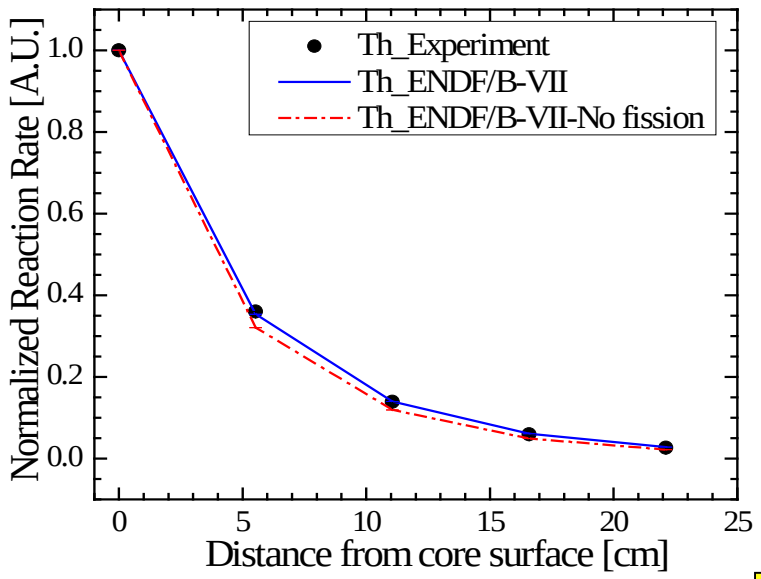
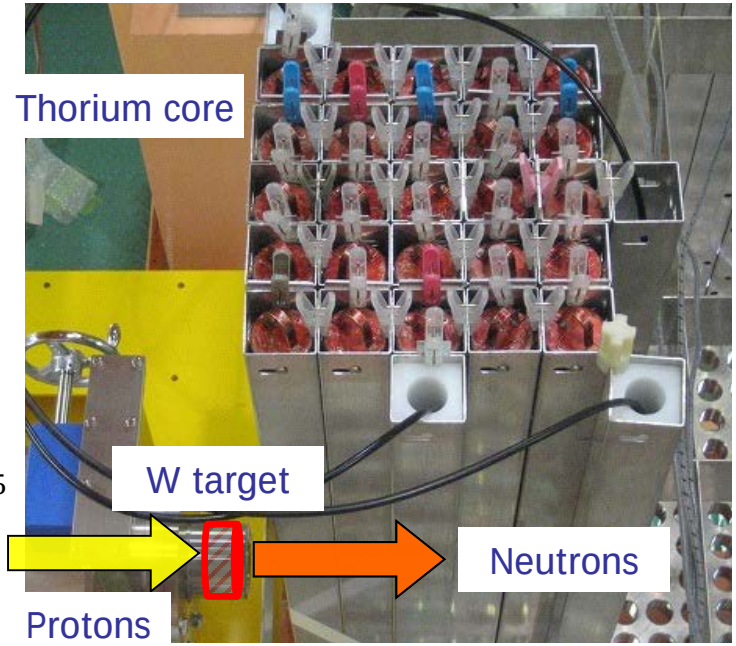


Fig. Comparison of measured and calculated reaction rates in ^{232}Th-loaded core

C. H. Pyeon *et al.*, *Ann. Nucl. Energy*, **38**, 2298 (2011).



Static benchmarks on ^{232}Th-ADS (for IAEA CW*)

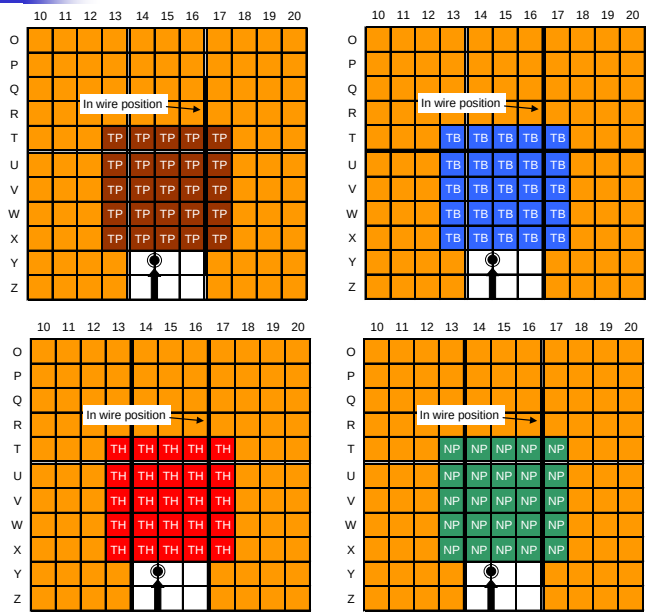


Fig. Core configuration of ^{232}Th-loaded cores

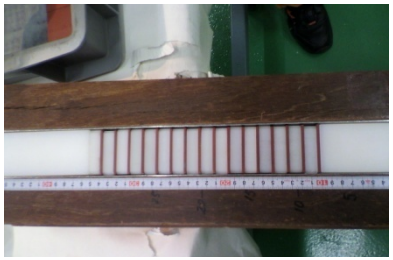


Fig. Th-PE cells

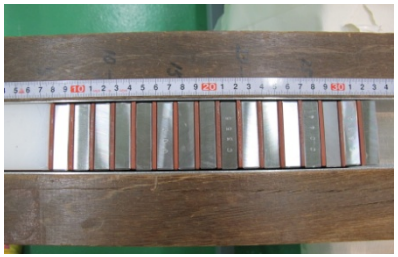


Fig. Th-Be cells

C. H. Pyeon *et al.*, *Nucl. Sci. Eng.*, (2014). [in print]

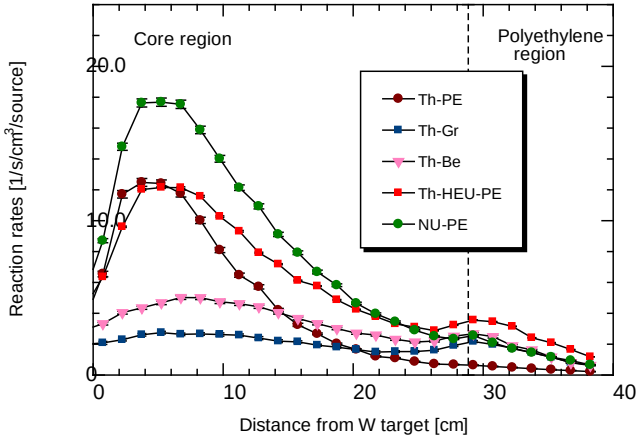


Fig. Measured ^{115}In (n, γ)^{116m}In reaction rates (**100 MeV protons**)

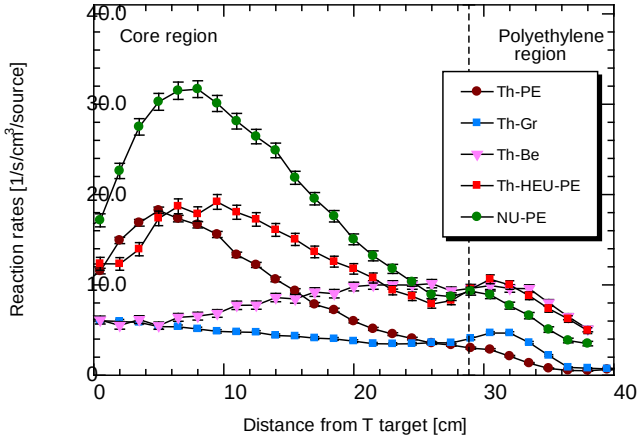


Fig. Measured ^{115}In (n, γ)^{116m}In reaction rates (**14 MeV neutrons**)

*: IAEA CW: "Thorium-ADS Benchmarks at KUCA," *IAEA Collaboration Work on ADS* (2013).

Kinetic benchmarks on ^{232}Th-ADS (for IAEA CW)

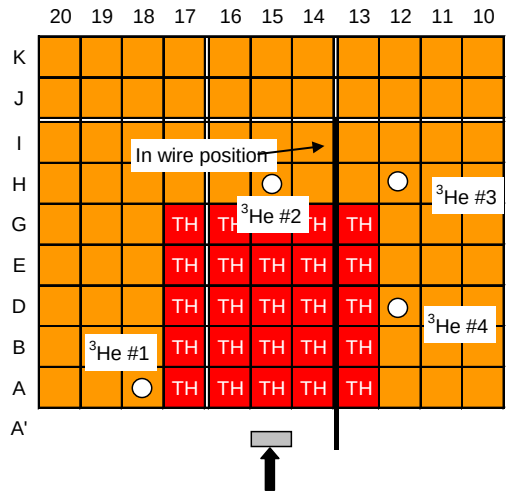


Fig. Core configuration of ^{232}Th-Poly. Cores (100 MeV protons)

Table Results in k_{eff} (^{3}He #3; Area ratio method)

	Cal.	Exp.	
Core	**MCNPX**	**100 MeV Protons**	**14 MeV Neutrons**
Th-HEU-PE	**0.5876**	**0.7346**	**0.6577**

β_{eff} = 8.491E-03; SRAC-CITATION 107-G, 3-D

α = 5065 ± 28 (100 MeV Protons)

5288 ± 13 (14 MeV Neutrons)

C. H. Pyeon *et al.*, *Nucl. Sci. Eng.*, (2014). [in print]

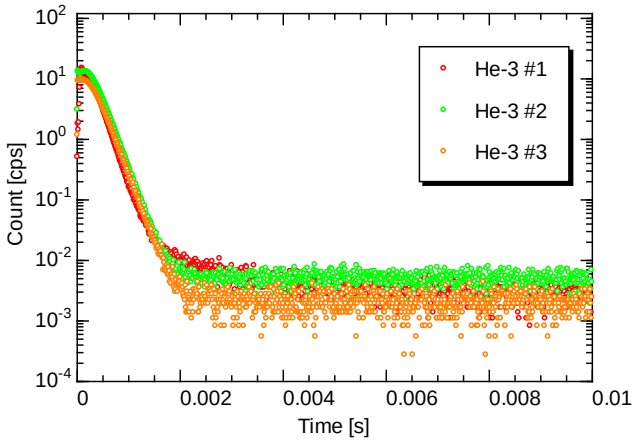


Fig. Results in Th-HEU-PE with 100 MeV protons

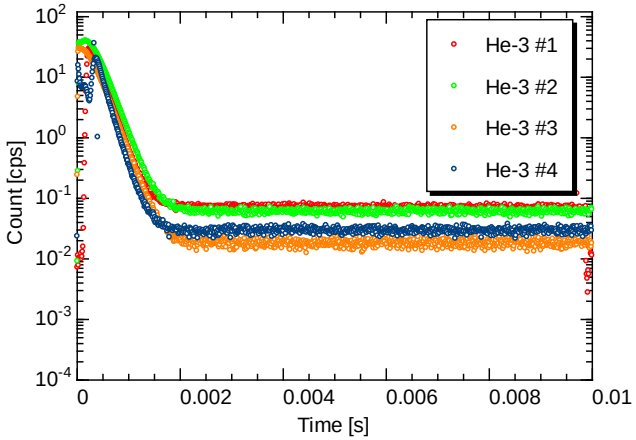


Fig. Results in Th-HEU-PE with 14 MeV neutrons

Collaboration with JAEA (Pb-Bi x-sec.)

- **Motivation**
  - Discrepancy between JENDL-3.3 and JENDL-4.0 of Pb-Bi x-sec. through numerical simulations of JAEA ADS model (Pb-Bi coolant model)
- **Experiments at KUCA (critical state)**
  - Sample worth (reactivity) of Pb and Pb-Bi plates in the critical state

Forthcoming experiments (Successive investigation)

- Sample worth of Pb, Bi and Pb-Bi plates in the critical state (finished in Pb and Pb-Bi)

Table Sample reactivity (C/E value) of Pb plates (unit: pcm)

Reactivity (pcm)	JENDL-3.3	JENDL-4.0	ENDF/B-VII.0
89	1.62±0.14	1.17±0.11	1.05±0.11
105	1.57±0.11	1.09±0.09	0.97±0.09
140	1.52±0.08	1.04±0.07	1.02±0.06
151	1.66±0.08	1.17±0.07	1.13±0.07

MA conversion analyses (^{237}Np and ^{241}Am)

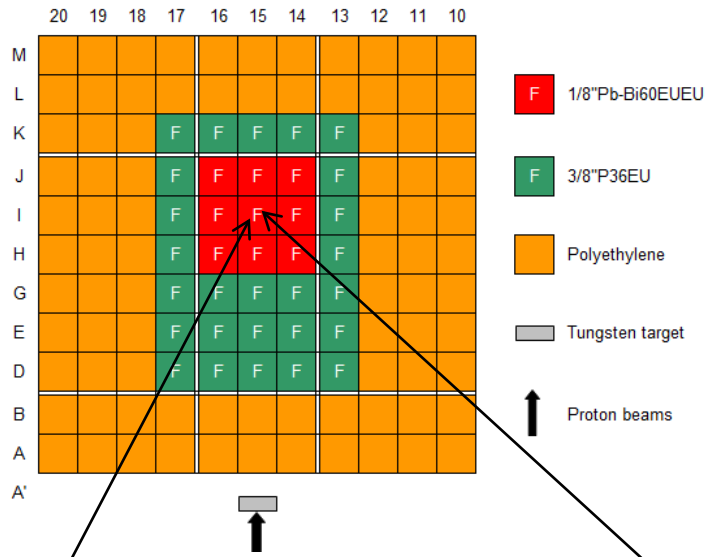


Fig. U-loaded and Pb-Bi-zoned core

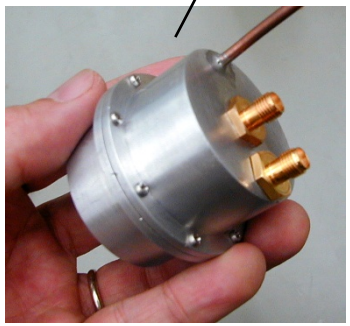


Fig. BTB fission chamber

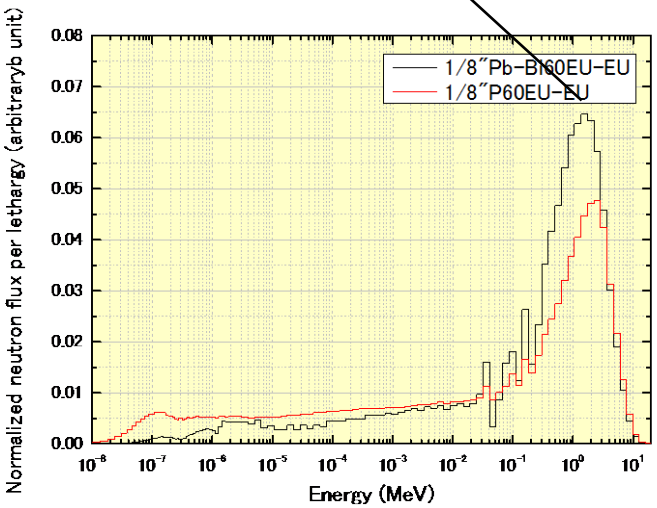


Fig. Neutron spectrum in Pb-Bi zone

- ^{235}U-loaded and Pb-Bi-zoned core
- Back-To-Back Type Fission Chamber (**BTB fission chamber**)
- Electrodeposited samples
  - Test sample: ^{237}Np or ^{241}Am, Reference sample: ^{235}U or ^{238}U
  - Loaded in a void element at core center
  - Simultaneous irradiation of test & reference samples
- ADS experiments with the variation of subcriticality and neutron spectrum in the core, and external neutron source

Another forthcoming ADS experiment

- ^{232}Th-loaded ADS experiments
- Conversion analyses of ^{232}Th capture and ^{233}U fission reactions

Summary

- **ADS project (Kart & Lab. project) in Kyoto Univ.**
  - Basic study on nuclear transmutation by ADS with high-energy protons
- **Injection of 100 MeV protons into the reactor core**
  - ^{235}U-loaded ADS exp. with 100 MeV protons (World's first injection)
  - ^{232}Th-loaded ADS exp. with 100 MeV protons
    - ✓ Static experiments: ^{232}Th fission reactions by MCNPX with ENDF/B-VII.0
    - ✓ Kinetic experiments: subcriticality and prompt decay constants
    - ✓ Comparative study on neutron spectrum and external neutron source
- **^{235}U-loaded ADS exp. with 100 MeV protons (No slide)**
  - Study on two-layer and Pb-Bi target at the target and in the core

<u>Forthcoming ADS experiments with 100 MeV protons</u>

- Uncertainties of Bi x-sec. (critical state)
- Conversion analyses of ^{237}Np/^{241}Am in ^{235}U-loaded and Pb-Bi zoned core
- Another conversion analyses using ^{232}Th/^{233}U