Forthcoming Experiments on Accelerator-Driven System with 100 MeV Protons at Kyoto University Critical Assembly

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  - **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).

    ^{232}Th-loaded: C. H. Pyeon *et al.*, *Ann. Nucl. Energy*, **38**, 2298 (2011).
    C. H. Pyeon *et al.*, *Nucl. Sci. Eng.*, (2013). [to be submitted]; see also PHYSOR2012
- Forthcoming ADS experiments with 100 MeV protons
  - Uncertainties of x-sec data of Pb 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 for producing energy and for 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).

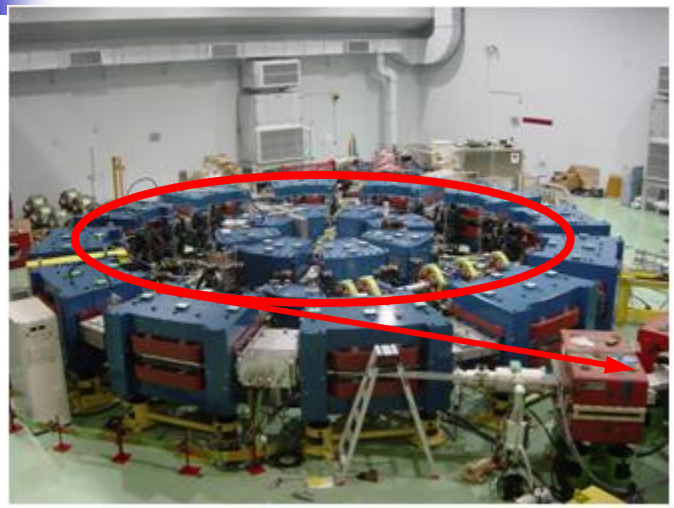
- ^{232}Th-loaded ADS experiments with 100 MeV protons on **3rd Mar. 2010**

  C. H. Pyeon *et al.*, *Ann. Nucl. Energy*, **38**, 2298 (2011).
  C. H. Pyeon *et al.*, *Nucl. Sci. Eng.*, (2013). [to be submitted]; see also PHYSOR2012.

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

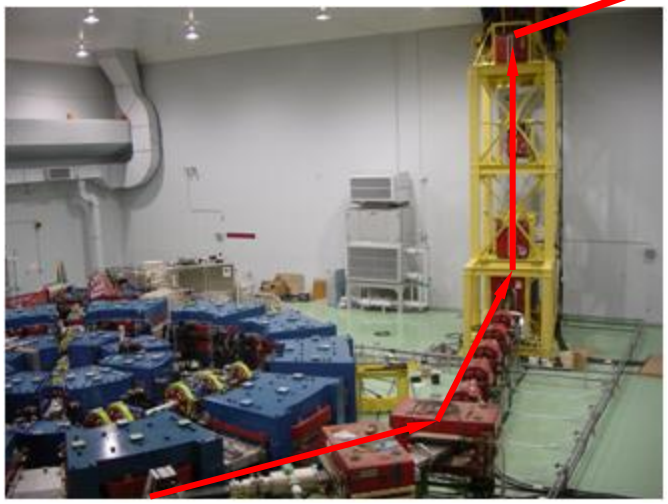
  J. Y. Lim *et al.*, *Sci. Technol. Nucl. Install.*, **2012**, 395878, 9 pages, (2012).
  C. H. Pyeon *et al.*, *Nucl. Eng. Technol.*, **45**, 81 (2013).
  Y. Takahashi *et al.*, *Ann. Nucl. Energy*, **54**, 162 (2013).
  C. H. Pyeon *et al.*, *Nucl. Sci. Eng.*, (2013). [to be submitted]; see also PHYSOR2012

ADS composition in KUCA

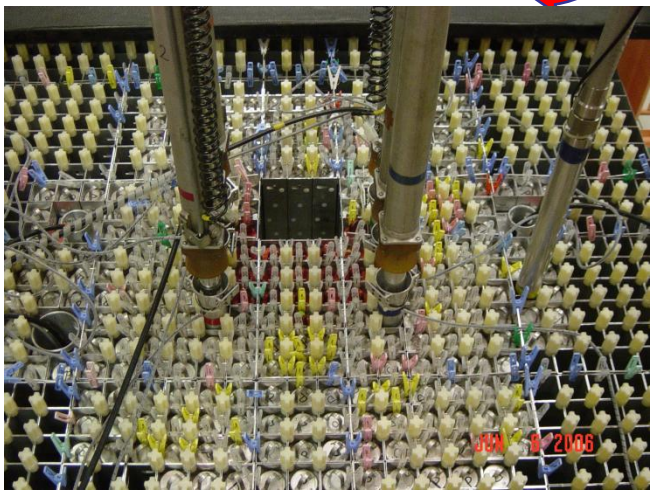


FFAG accelerator

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

Objectives

Investigate the neutronic characteristics of ADS, from the viewpoint of nuclear transmutation

First injection of spallation neutrons - 2009

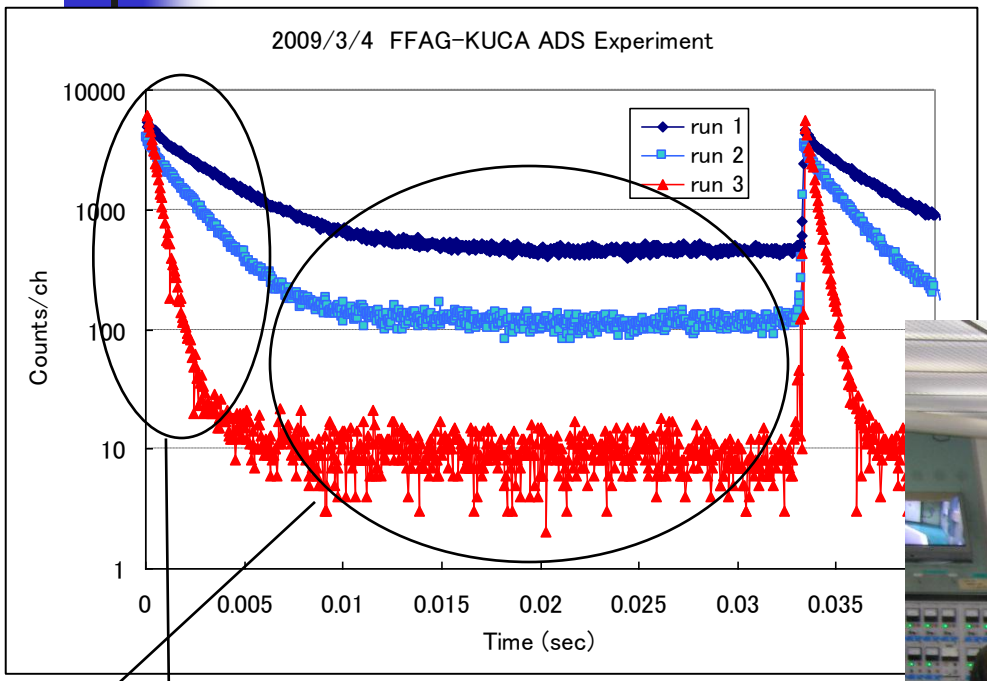
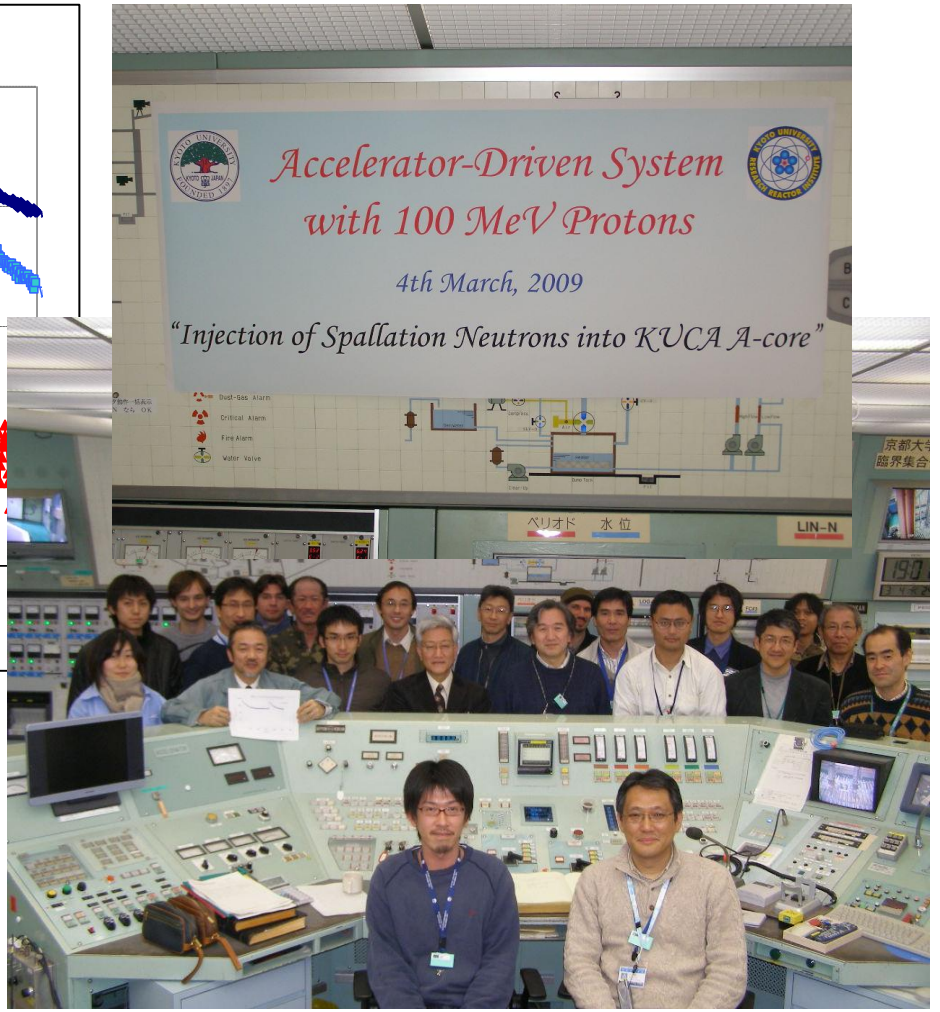


Fig. Time series of neutrons

Spallation neutrons from target

Delayed neutrons in core

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

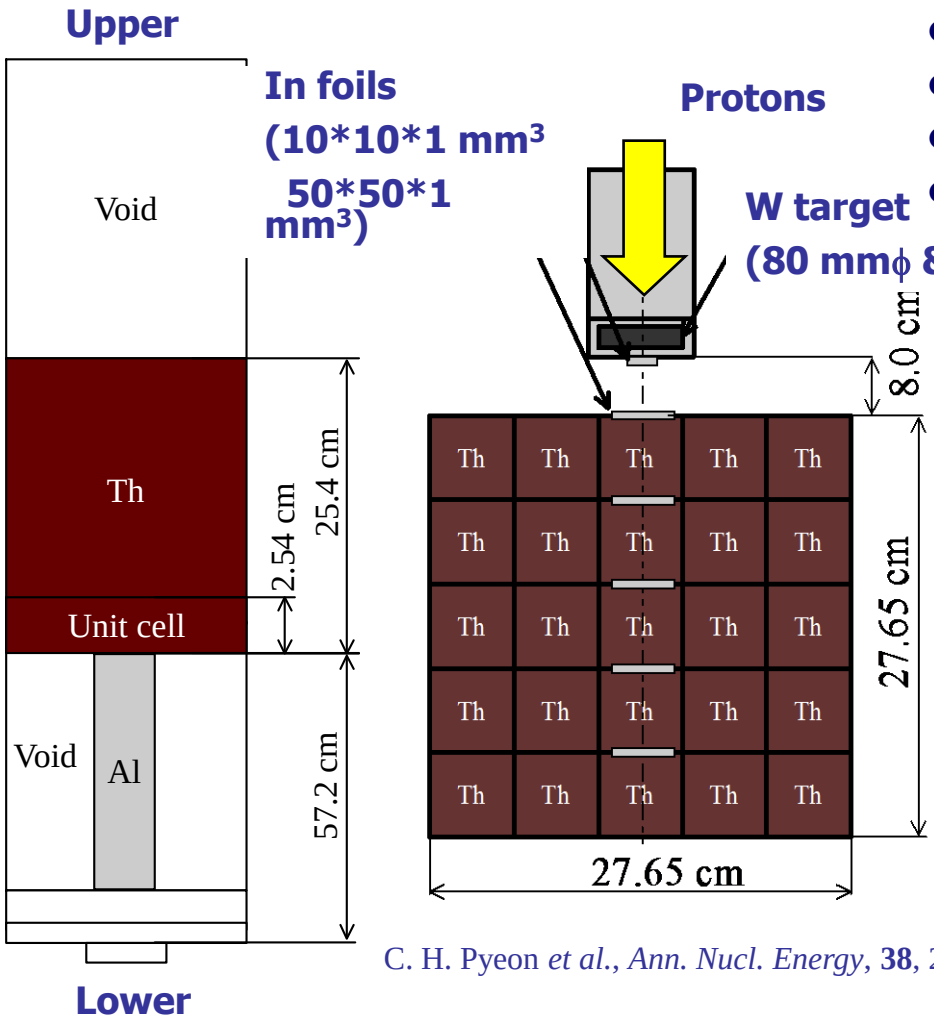


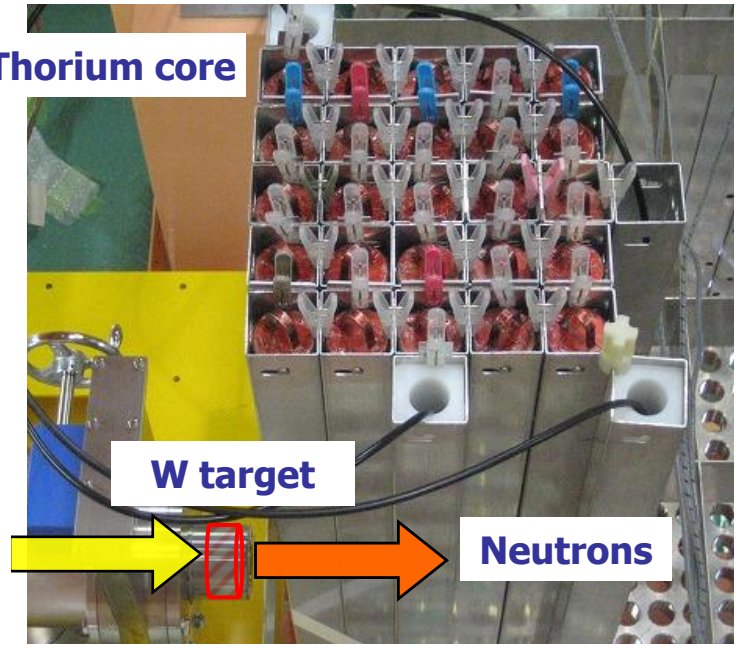
Neutron multiplication by spallation neutrons generated by protons

Exp. settings of ^{232}Th-loaded ADS Exp. - 2010

Experimental settings

- Fuel size: 5×5
- Volume: 27.65×27.65×25.40 cm^3
- k_{eff} = 0.03250 (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





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

Comparative study on ^{232}Th-ADS - 2011

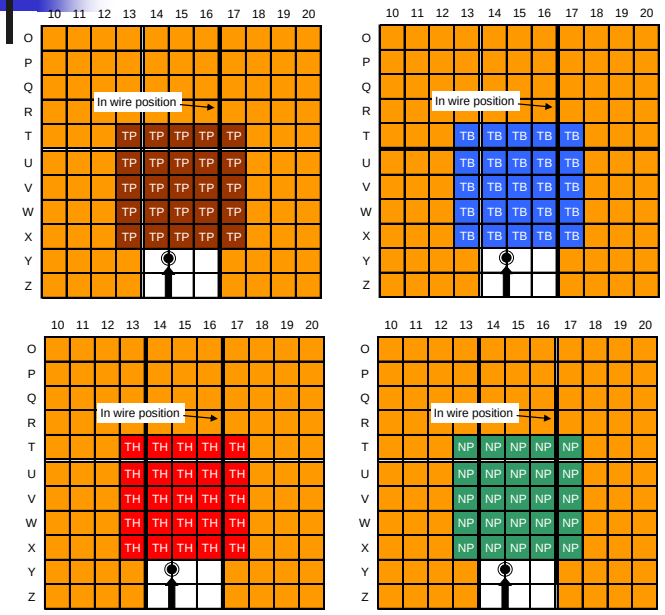


Fig. Core configuration of ^{232}Th-loaded cores

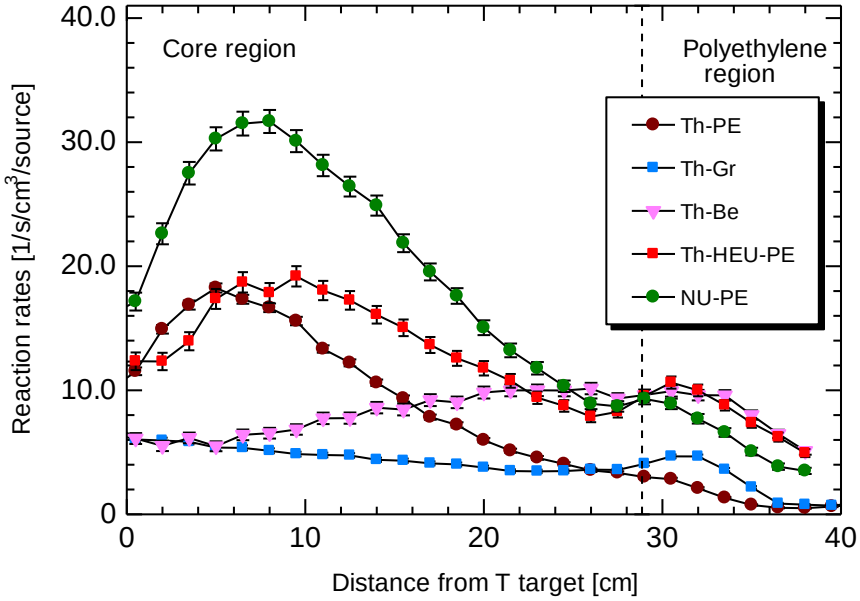


Fig. Comparison of measured ^{115}In (n, γ)^{116m}In reaction rates in ^{232}Th-loaded cores with 14 MeV neutrons

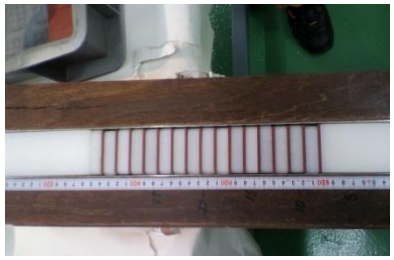


Fig. Th-PE cells

Fig. Th-Be cells

Confirmed (Protons: 0.1 nA increased)

- Effect of
  - Neutron spectrum in the core
  - External neutron source at the target

  on the neutron multiplication
- Sensitivity of ^{232}Th capture reactions

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Pulsed neutron method (^{232}Th-ADS) - 2012

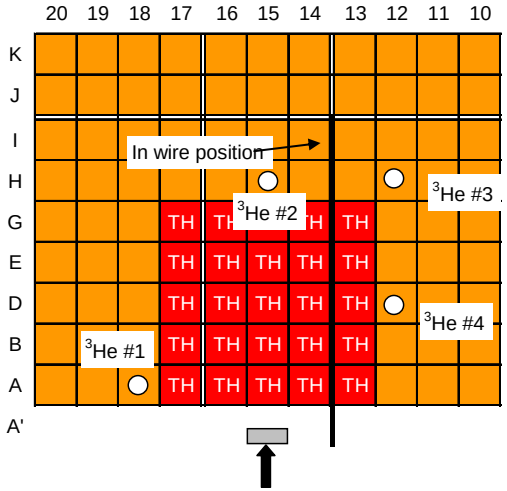

Fig. Core configuration of ^{232}Th-Poly. Cores (100 MeV protons)

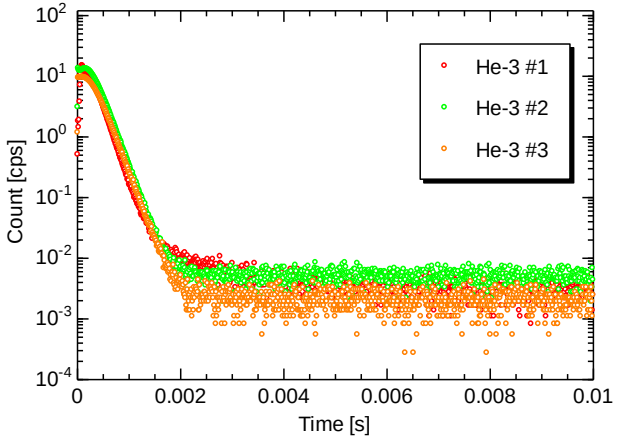

Fig. Results in Th-HEU-PE with 100 MeV protons

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)

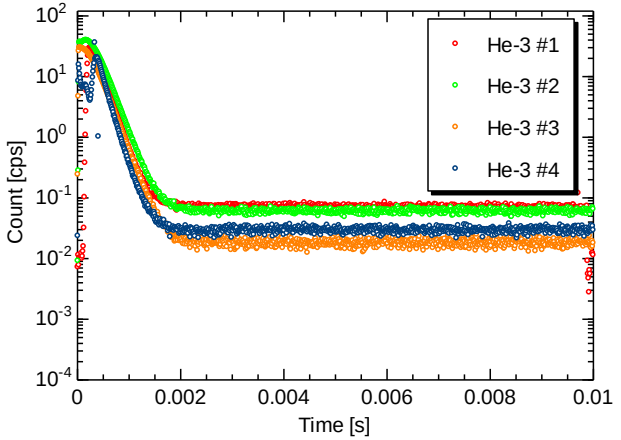

Fig. Results in Th-HEU-PE with 14 MeV neutrons

C. H. Pyeon *et al.*, *Nucl. Sci. Eng.*, (2013). [to be submitted]; see also PHYSOR2012.

Two-layer target study (^{235}U-core) - 2013

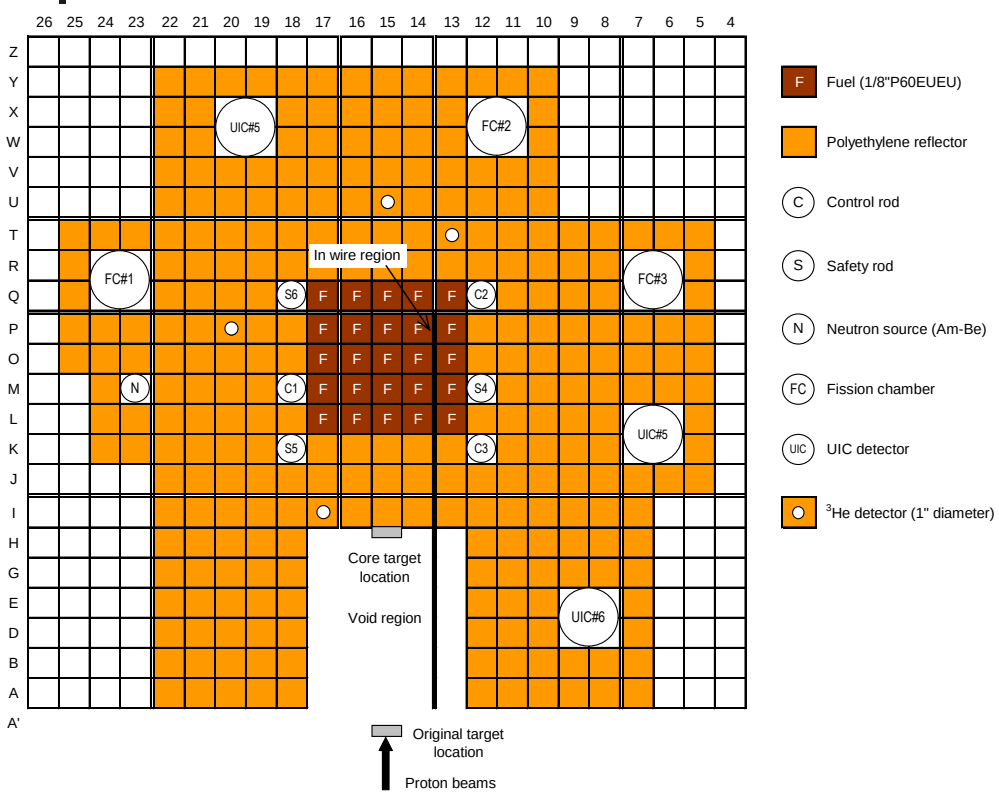

Fig. Core configuration of ^{235}U-loaded cores (100 MeV protons)

(Protons: 100 MeV, 0.5 nA, 100 ns, 20 Hz)

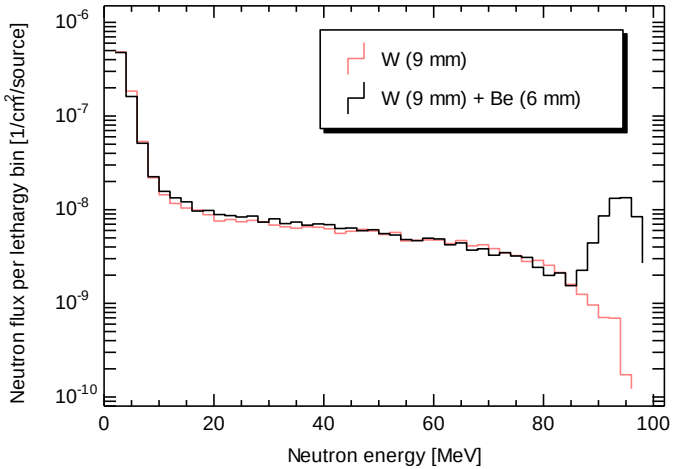

Fig. Neutron spectra (W vs. W+Be)

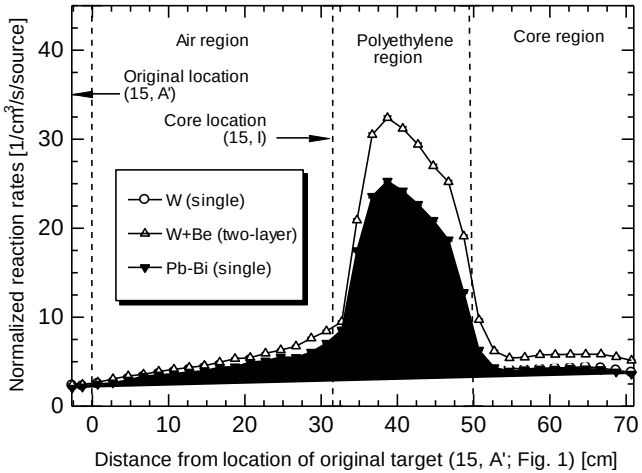

Fig. In reaction rates (W, W+Be and Pb-Bi)

Uncertainties of Pb and Pb-Bi x-secs.

➢ Motivation

- Discrepancy between JENDL-3.3 and JENDL-4.0 of Pb-Bi x-secs. through numerical simulations of JAEA ADS model (Pb-Bi coolant model)

➢ Experiments at KUCA (critical state)

- Sample worth (reactivity) of Pb plates in the critical state

Forthcoming experiments (Successive investigation)

- ◆ Sample worth of Pb-Bi plates in the critical state

Table Sample reactivity of Pb plates (unit: pcm)

# of Pb	Exp.	J-3.3	J-4.0	E-VII.0
Pb 20	1.99±3.49	10.92±5.81	0.99±4.23	0.99±4.98
Pb 40	20.93±3.36	46.62±5.81	22.82±4.23	24.80±4.23
Pb 20+20	44.75±3.82	68.43±5.81	45.63±4.23	37.70±5.81
Pb 60	48.73±2.95	94.19±4.23	58.52±4.22	47.61±4.23

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

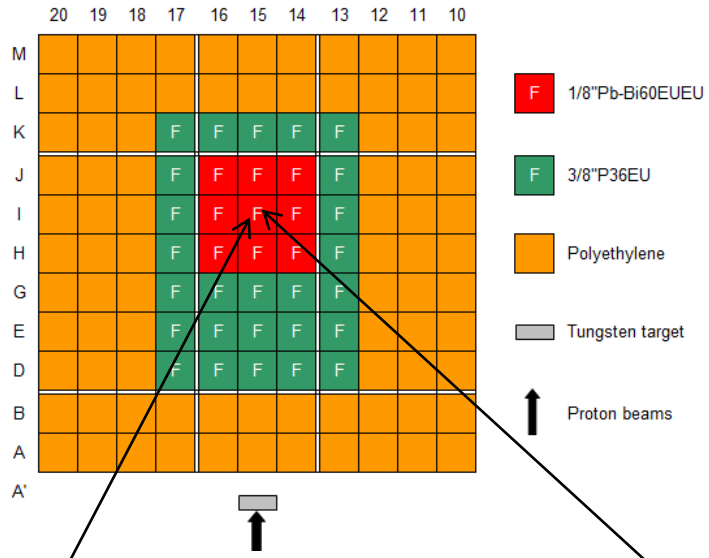

Fig. U-loaded and Pb-Bi-zoned core

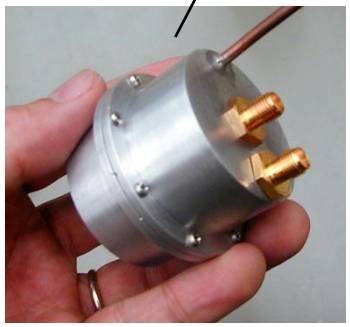

Fig. BTB fission chamber

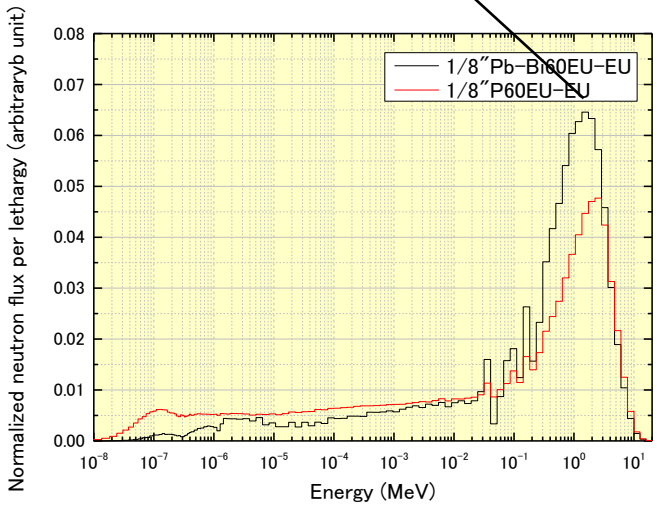

Fig. Neutron spectrum in Pb-Bi zone

- Uranium-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

- Thorium-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 sources
- **^{235}U-loaded ADS exp. with 100 MeV protons**
  - Study on two-layer and Pb-Bi target at the target and in the core

Forthcoming ADS experiments with 100 MeV protons

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