Progress Review of Accelerator-Driven System in Kyoto University Critical Assembly

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- Summary

Background and Purpose

Background

- ADS Research and Development
  for producing energy and for transmuting MA and LLFP
  (in Kyoto Univ. as **Energy amplifier system**)

- Successful extraction of proton beams of 100 MeV & a few pA
  at a main ring of FFAG accelerator on **Oct. 2008**

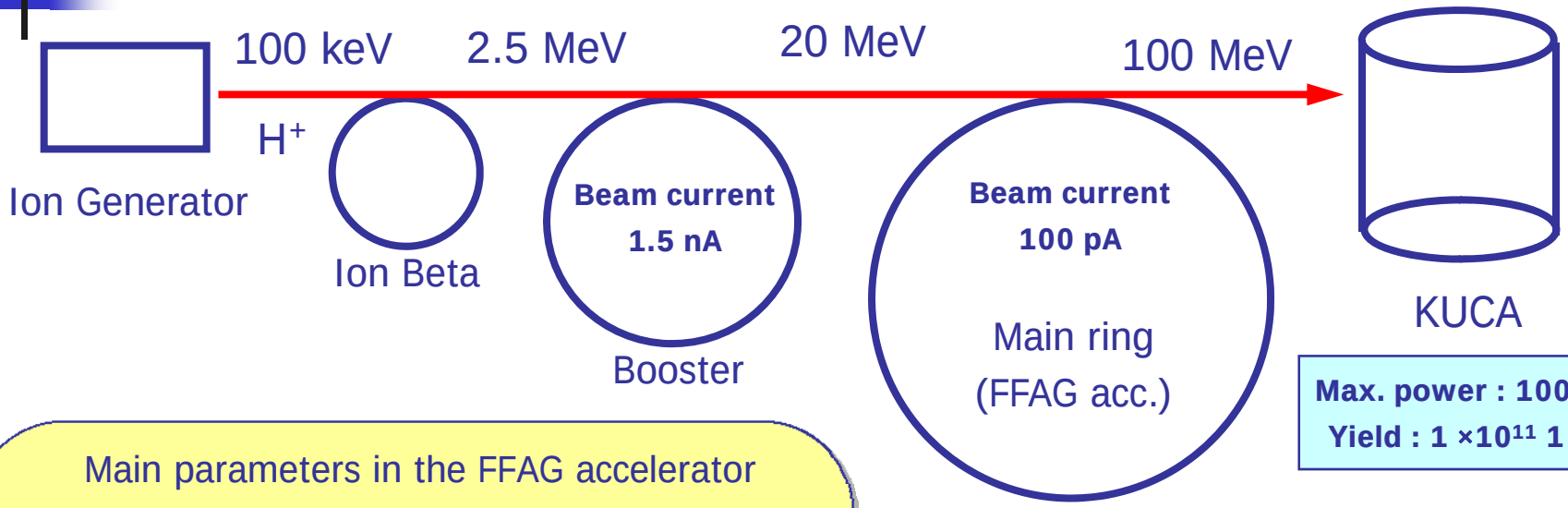
- ADS experiments with 100 MeV protons & a few pA
  on **4th Mar. 2009** (^{235}U-loaded core in well-thermalized spectrum)

- Thorium-loaded ADS experiments with 100 MeV protons & 30 pA
  on **3rd Mar. 2010** (^{232}Th-loaded core in hard spectrum)

Purpose

- Examine neutronic characteristics of ADS coupling with
  the KUCA A-core with high-energy protons (from the FFAG accelerator)

ADS composition

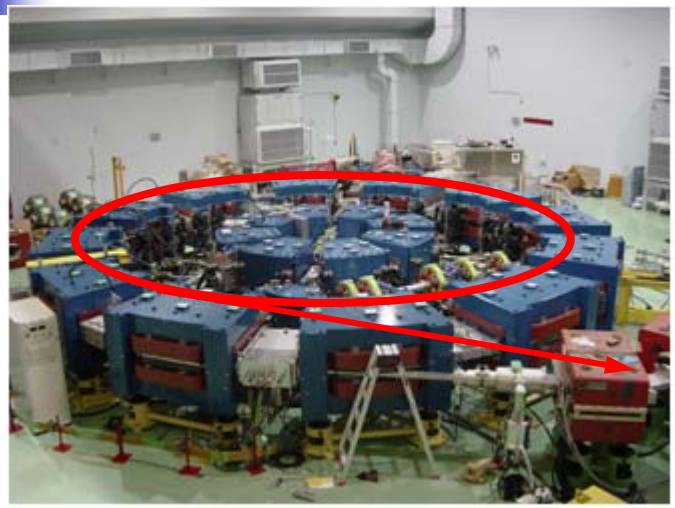


Max. power : 100 W
Yield : 1 ×10^{11} 1/s

Main parameters in the FFAG accelerator

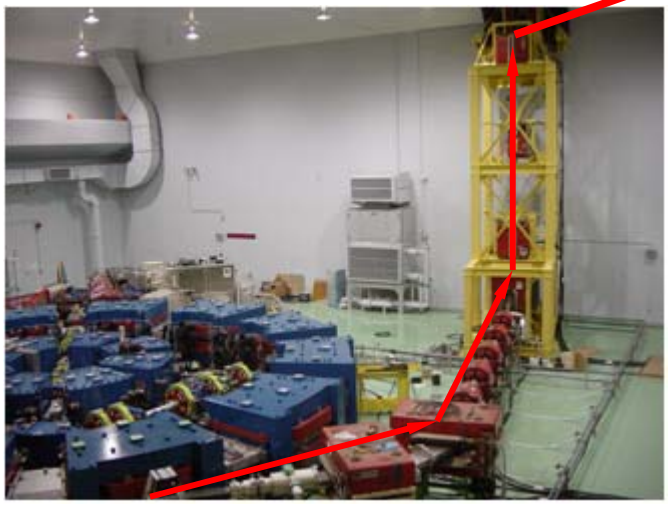
# of sectors	12
Energy	2.5 – 150 MeV
Repetition rate	120 Hz
Average beam current	1 nA
Rf frequency	1.5 - 4.6 MHz
Field index	7.5
Closed orbit radius	4.4 - 5.3 m

ADS composition in KUCA

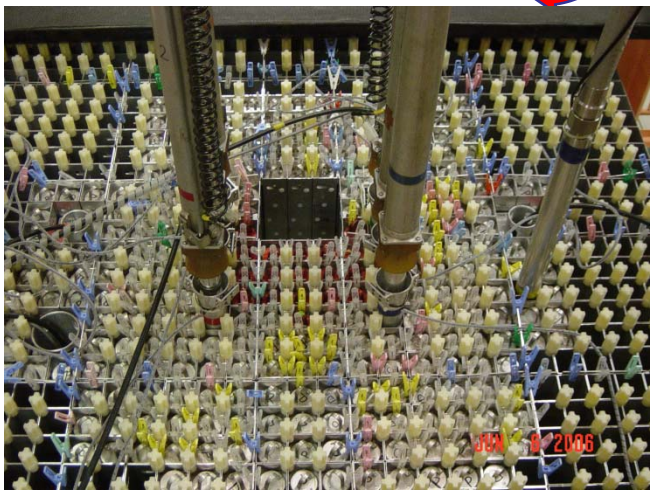


FFAG accelerator

KUCA A-core



100 MeV proton beam line



Basic exp. on ADS with 14 MeV neutrons

✧ **Critical Assembly**

- Highly-enriched uranium
- Polyethylene reflector and moderator
- Thermal neutron field
- Zero power reactor (Ave. mW order)

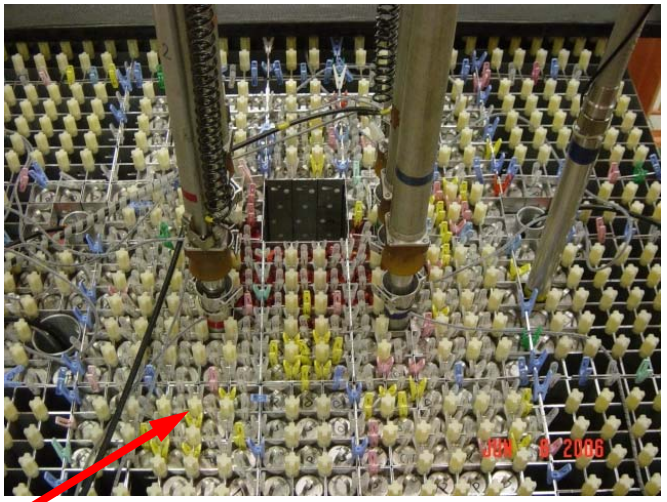


Fig. KUCA A-core

Tritium target

14 MeV neutrons

Fig. Cockcroft-Walton type Accelerator

✧ **Accelerator (D-T reactions)**

- 14 MeV pulsed neutrons
- Pulse repetition: 0.1 to 30,000 Hz
- Pulse width: 0.3 to 100 μs
- Spot size: 2.5 cm
- Yield: 1×10^{8} 1/s, Intensity: 0.5 mA
- HV: 180 keV, Duty ratio: Max. 1%

KUCA A-core (Solid-moderated core)

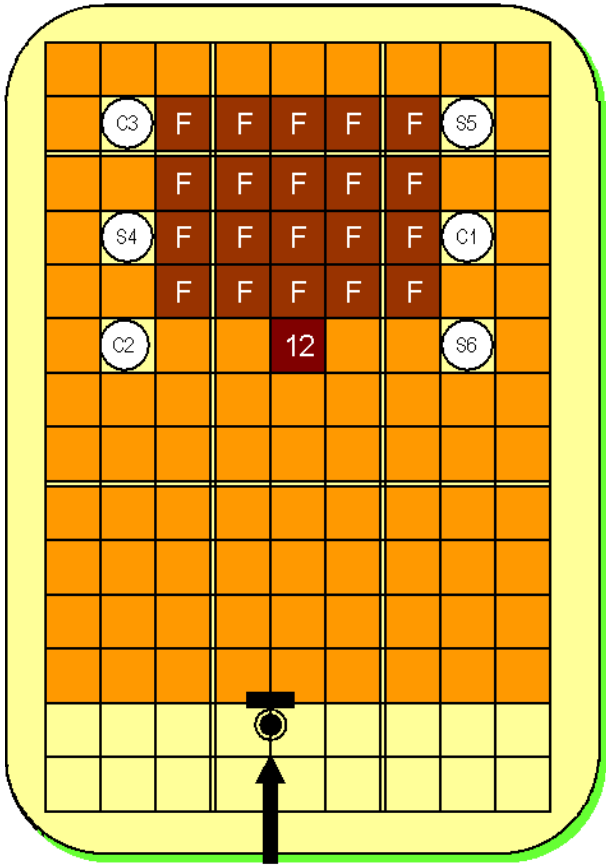


Fig. KUCA A-core (Reference core)

- KUCA A-core -

A solid-moderated and -reflected core

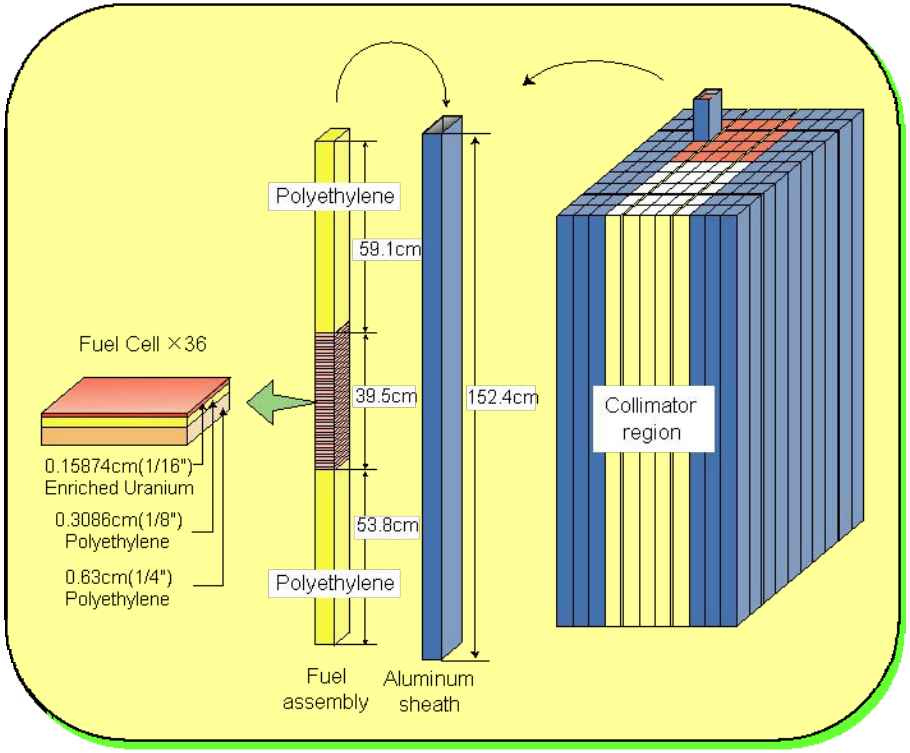


Fig. Image of KUCA A-core and fuel assembly loaded

Neutron guide and Beam duct

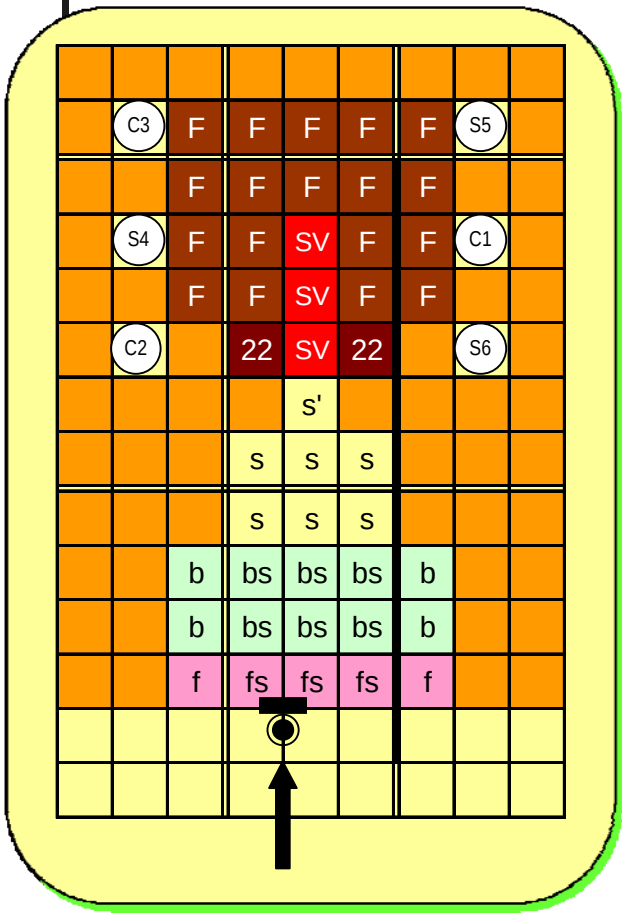


Fig. Top view of neutron guide core

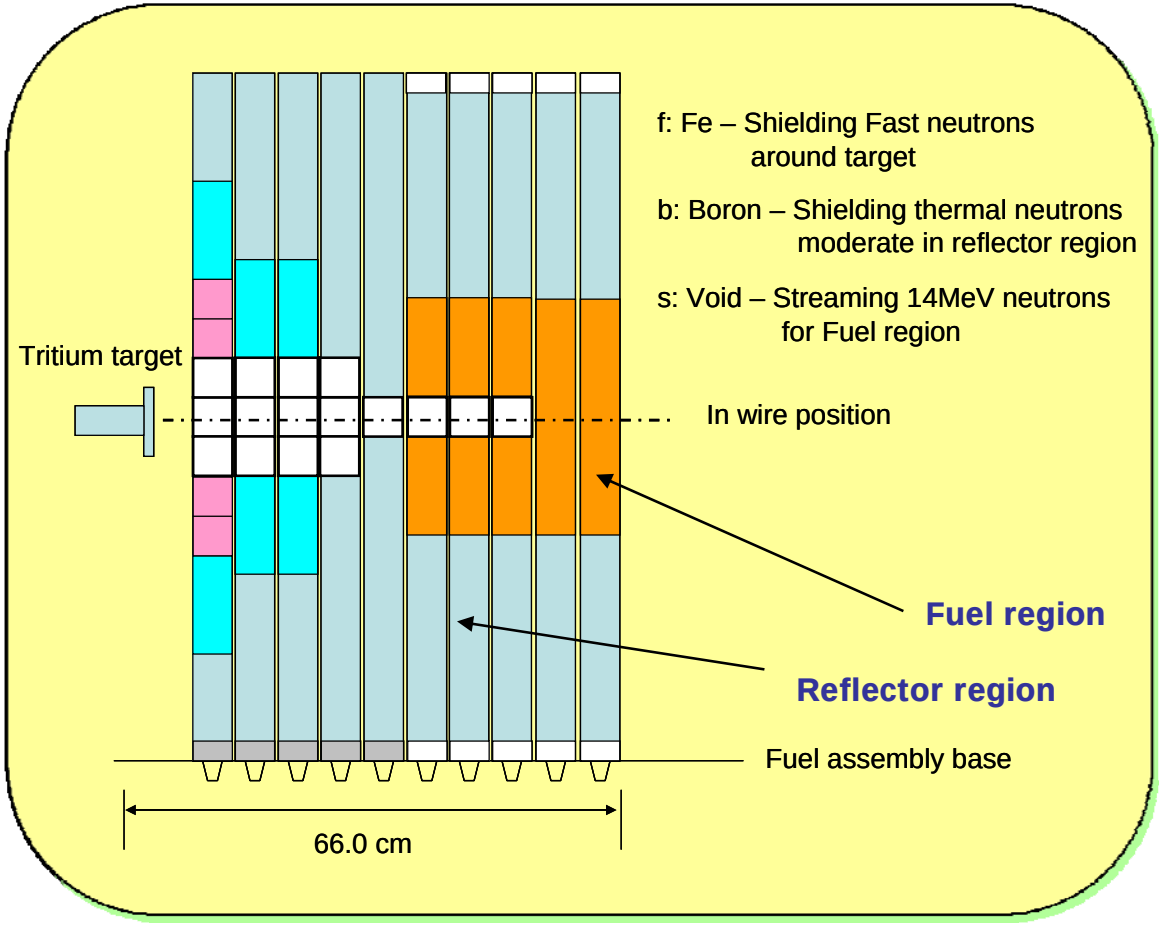


Fig. Side view of neutron guide and beam duct

Static experiments (14 MeV neutrons)

Table Comparison between measured and calculated subcriticalities

Experiment (%Δk/k)	MCNP (JENDL-3.3) (%Δk/k)	MCNP (ENDF/B-VI.2) (%Δk/k)
-0.68±0.04	-0.68±0.01	-0.67±0.03
-0.89±0.05	-0.98±0.06	-0.91±0.03
-1.34±0.07	-1.35±0.02	-1.40±0.05
-1.76±0.09	-1.71±0.05	-1.72±0.04

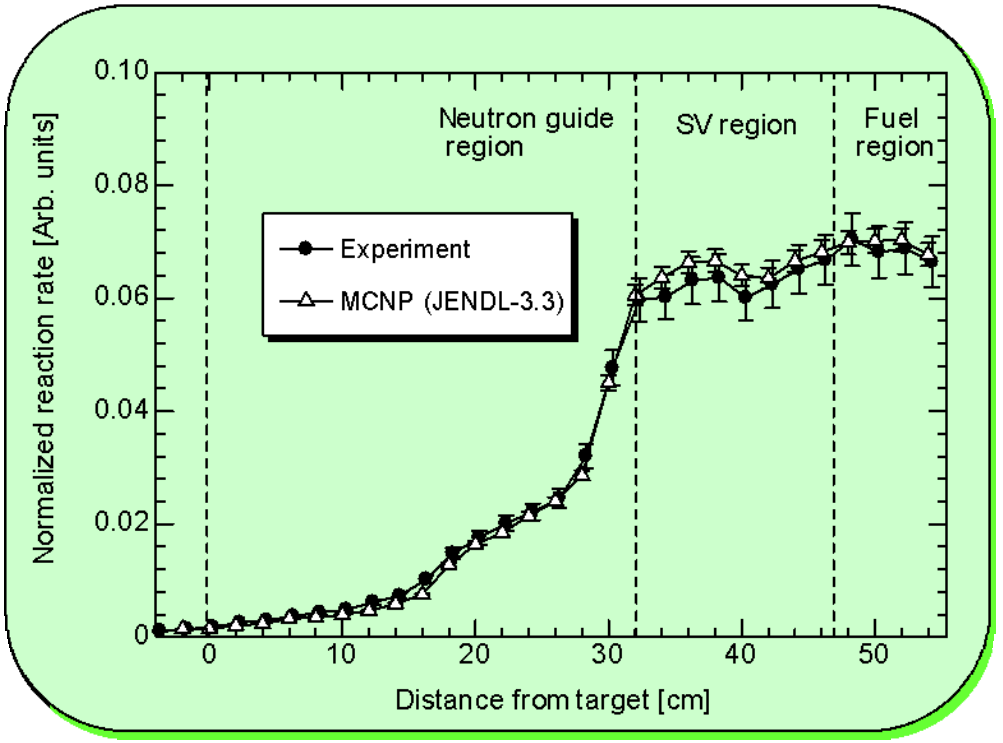
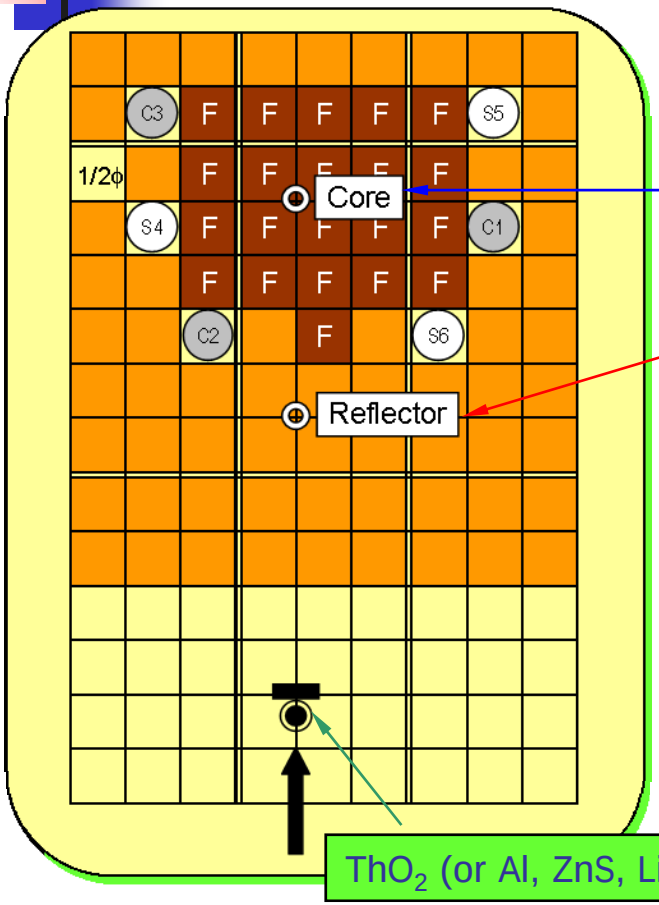


Fig. Comparison of measured In reaction rates distribution with calculated one

- **Confirmation of calculation precision by Monte Carlo approach**
  (Reaction rates, Neutron spectrum)

Kinetic experiments (14 MeV neutrons)



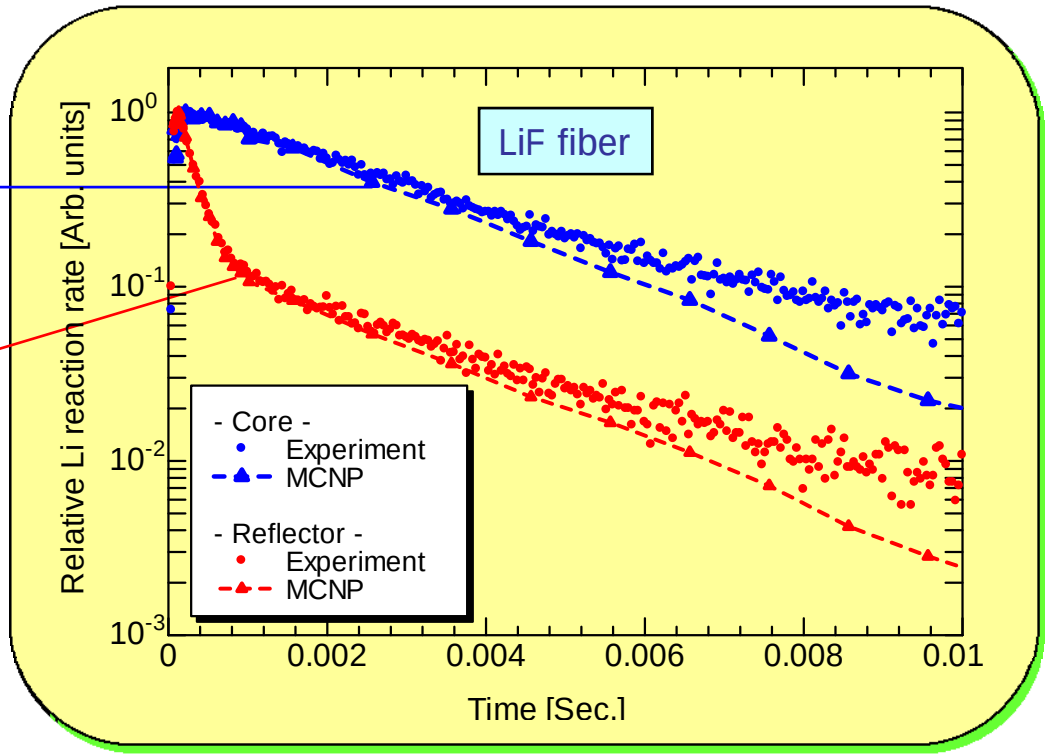


Fig. Comparison of measured neutron decay behavior by optical fiber detector system with calculated one

- **Investigation of measurement technique using the optical fiber detection system**
- **Feasibility of subcriticality measurement and position dependence of subcriticality**

First injection of spallation neutrons

World's first injection of spallation neutrons into the core (March, 2009)

- **FFAG accelerator**
  - Energy: 100 MeV
  - Intensity: About 3 pA
  - Repetition rate: 30 Hz
  - Tungsten (W) target:
    80 mmϕ and 10 mmt
- **KUCA A-core: ^{235}U-loaded core**
  - Highly-enriched uranium
  - Polyethylene moderator/reflector
  - Subcriticality: around k_{eff} = 0.992

Static exp. with 100 MeV protons

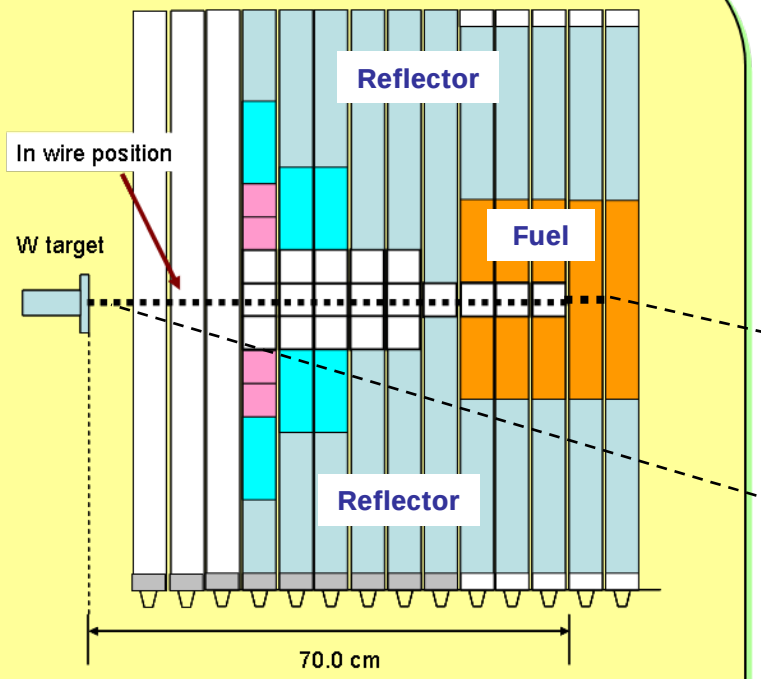


Fig. Side view of the KUCA A-core

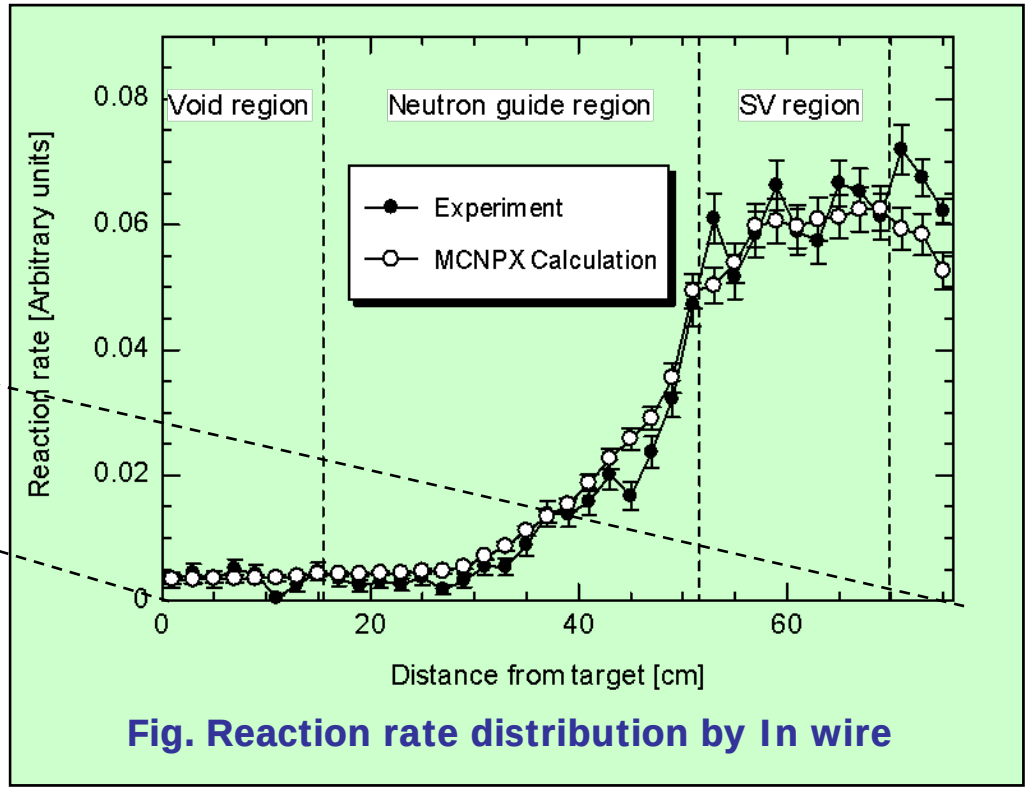


Fig. Reaction rate distribution by In wire

Reaction rate distribution

- ✓ Measure ^{115}In (n, γ) ^{116m}In (Exp. error: Too large)
- ✓ Effects on subcriticality and core configuration

Kinetic exp. with 100 MeV protons

Neutron multiplication by spallation neutrons generated by protons

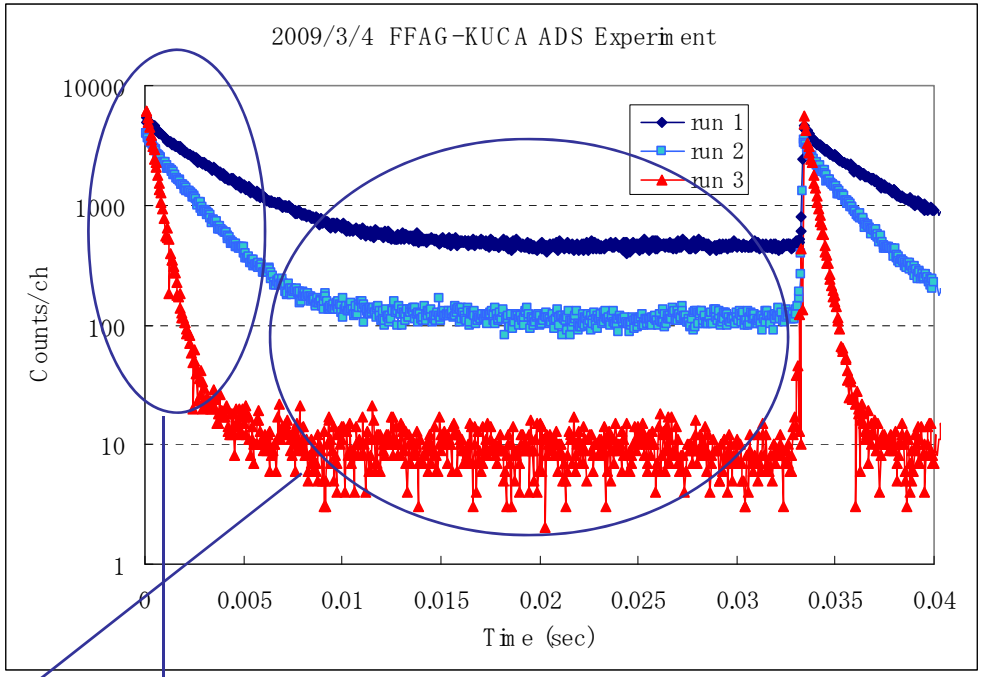


Fig. Time series of position dependence on measurement

Spallation neutrons from target

Delayed neutrons in core

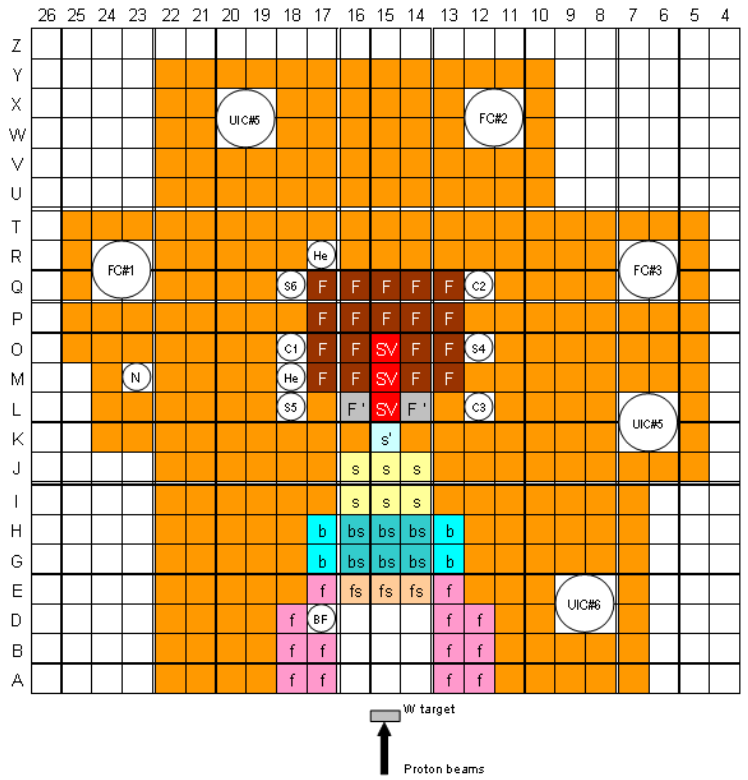


Fig. Top view of the KUCA A-core

^{232}Th-loaded exp. with protons

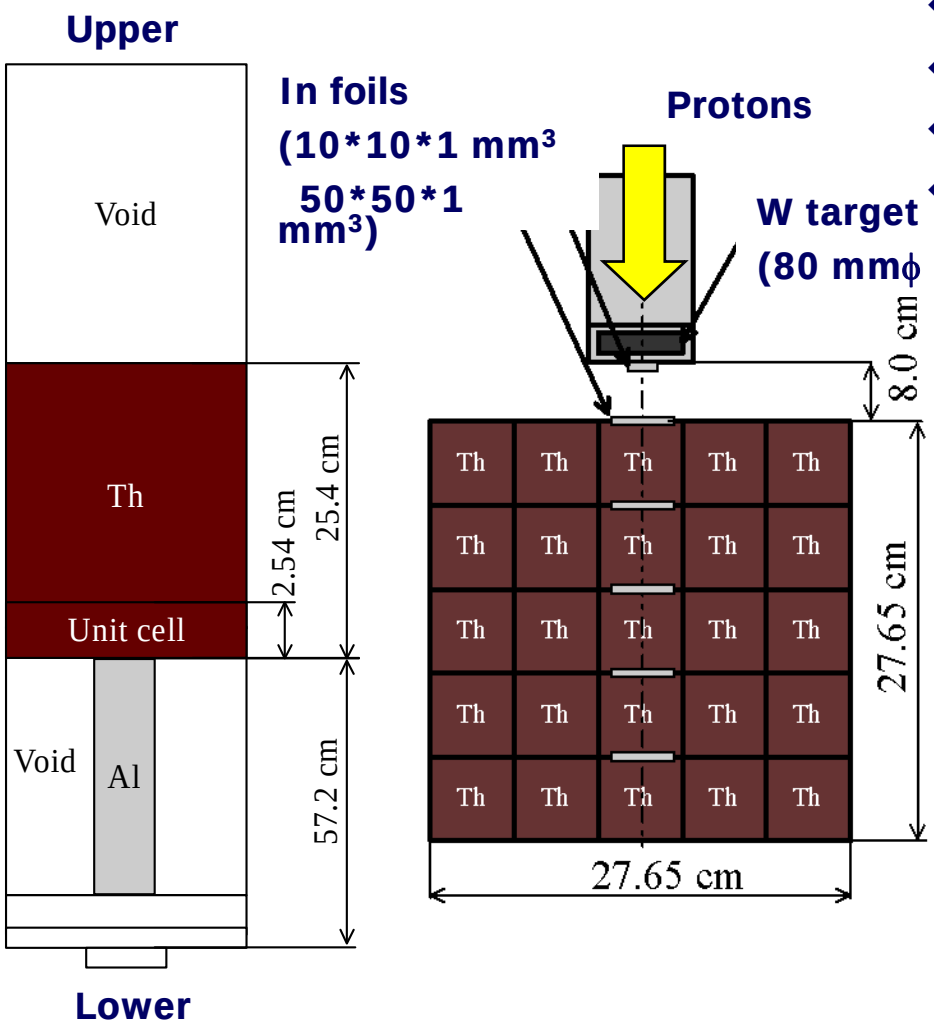
- **FFAG accelerator**
  - Energy: 100 MeV
  - Intensity: 30 pA
  - Repetition rate: 30 Hz
  - W (tungsten) target:
    80 mmϕ and 10 mmt
- **KUCA core using Thorium**
  - Nat. Thorium metal
  - No moderator, Graphite

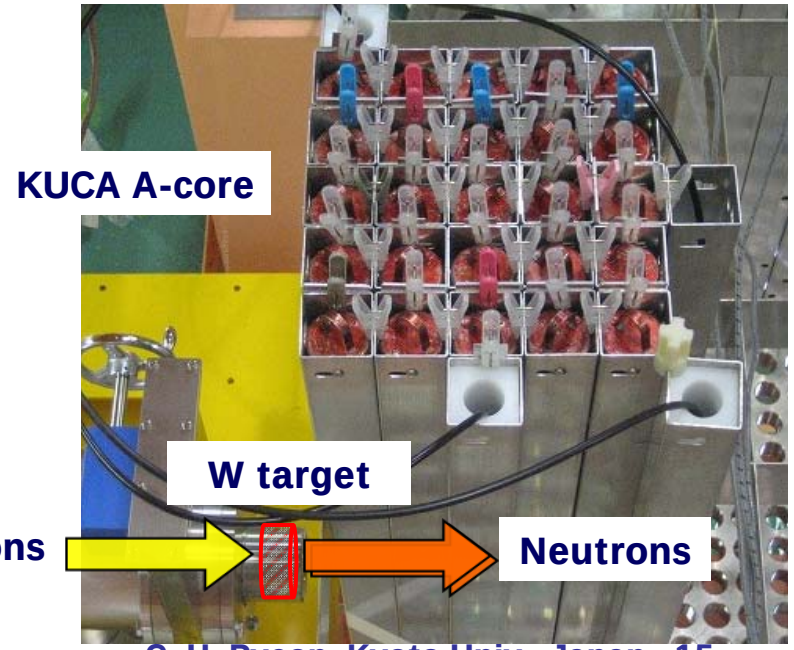
Objective: Confirm thorium fission reactions by spallation neutrons

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

Experimental settings

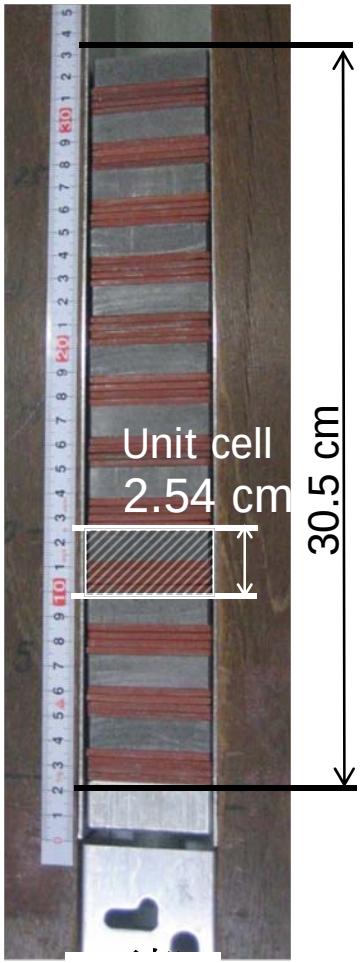
- Fuel size: 5×5
- Volume: 27.65×27.65×25.40 cm^3
- k_{eff} = 0.03250 (ENDF/B-VII.0)
- ^{232}Th(n, f) threshold: 1.5 MeV
- ^{115}In(n, n')^{115m}In threshold: 0.35 MeV

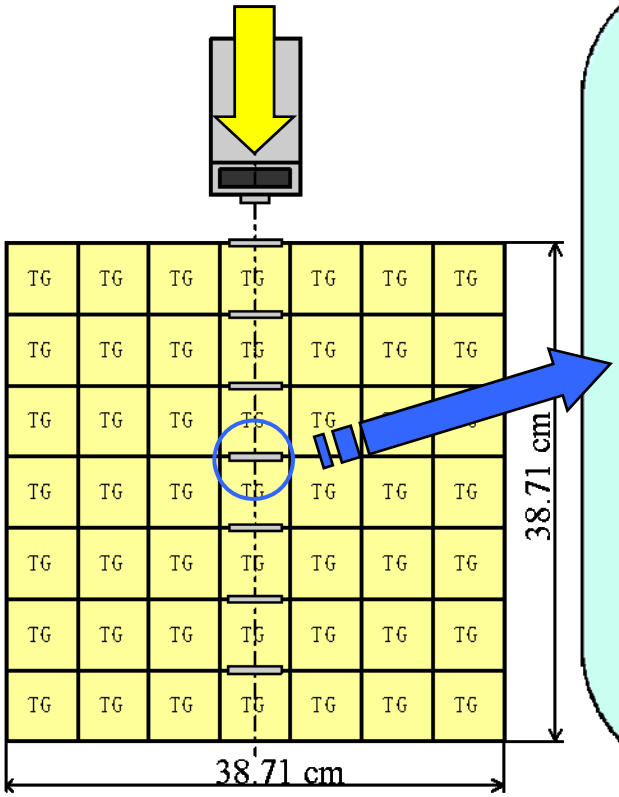




^{232}Th-loaded ADS with Graphite

- Fuel size: 7×7
- Core volume: 38.71×38.71×30.48 cm^3
  (2.4 times than Th-core)
- k_{eff} = 0.02399 (ENDF/B-VII.0)





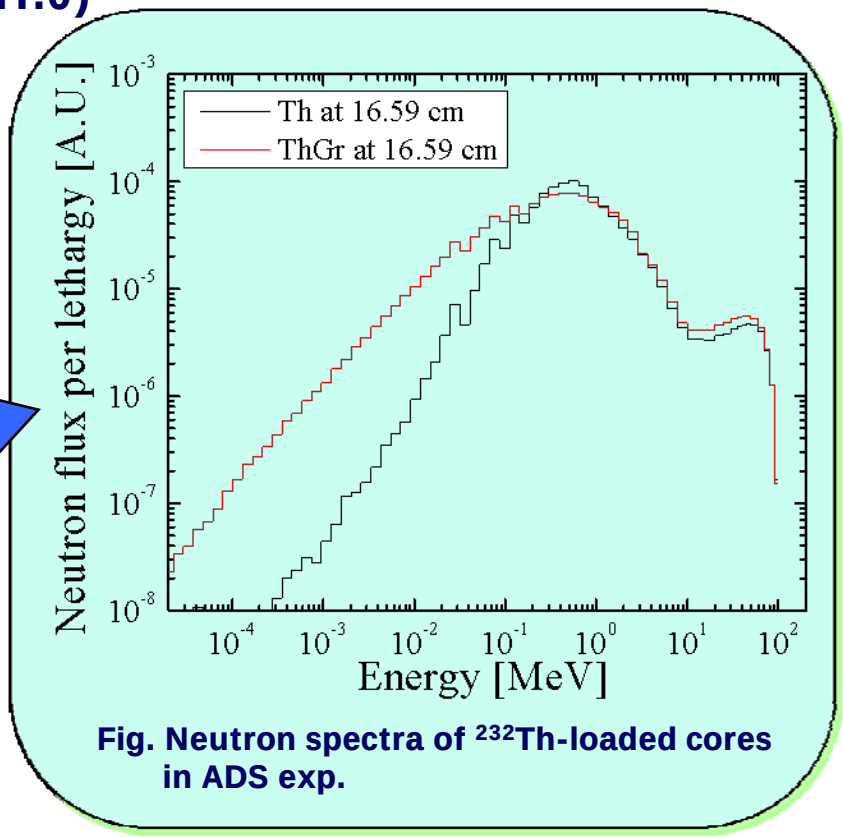


Fig. Neutron spectra of ^{232}Th-loaded cores in ADS exp.

Experimental results in ^{232}Th-loaded ADS

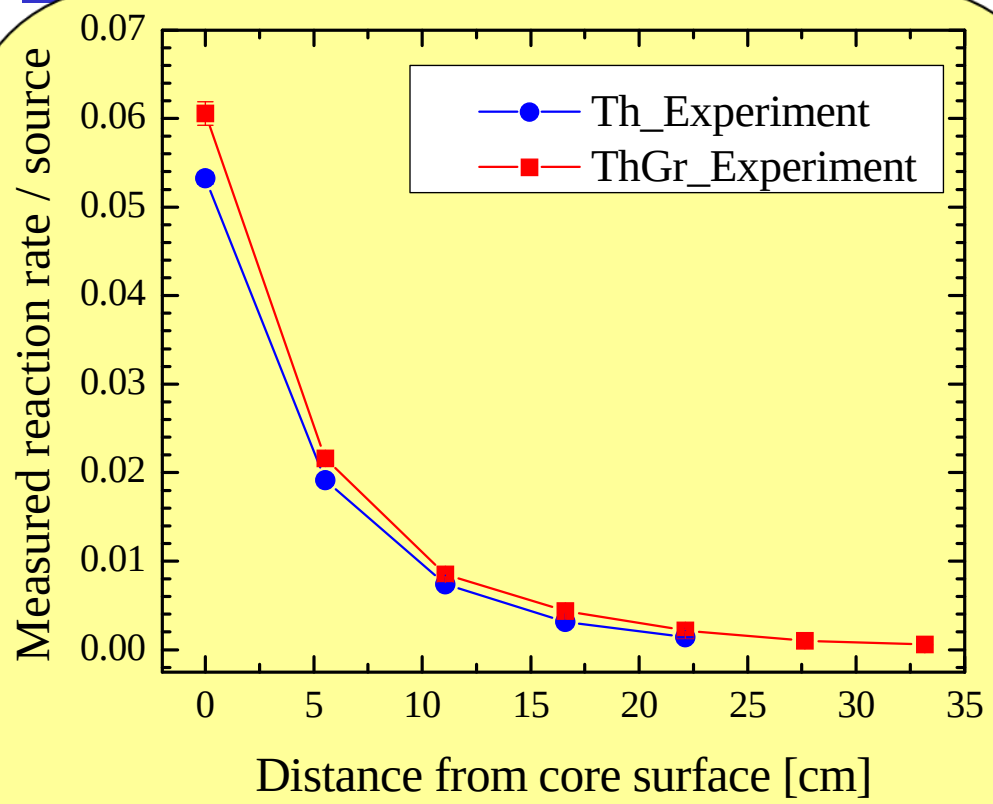


Fig. Comparison of measured reaction rates in ^{232}Th-loaded ADS experiments

Table Ratio of measured reaction rates normalized by target information (In foil)

Distance (cm)	Ratio (ThGr/Th)
0	1.14±0.03
5.53	1.13±0.03
11.06	1.15±0.05
16.59	1.39±0.08
22.12	1.56±0.11

Confirmation of increasing reaction rates of 50 % at max. in the core

=> Decreasing the leakage effect by the large core size

MCNPX (ENDF/B-VII) analyses

- ^{232}Th fission reactions by Monte Carlo approach

$$RR_{total} = RR_{source} + RR_{fission}$$

Solution

- Convert Th fission reactions to capture reactions ("fission turnoff" option)

$$RR'_{total} = RR_{source} + RR_{capture}$$

- **Finally**,

$$RR_{fission} = RR_{total} - RR'_{total} + RR_{capture}$$

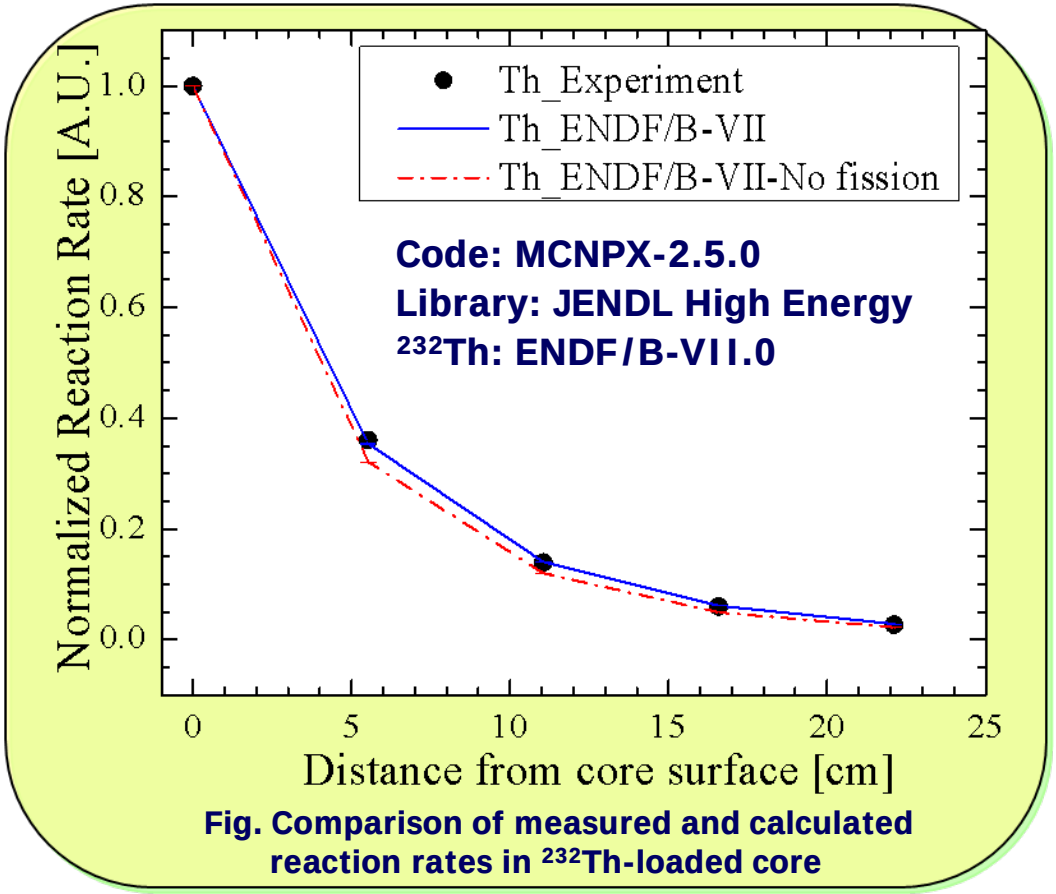
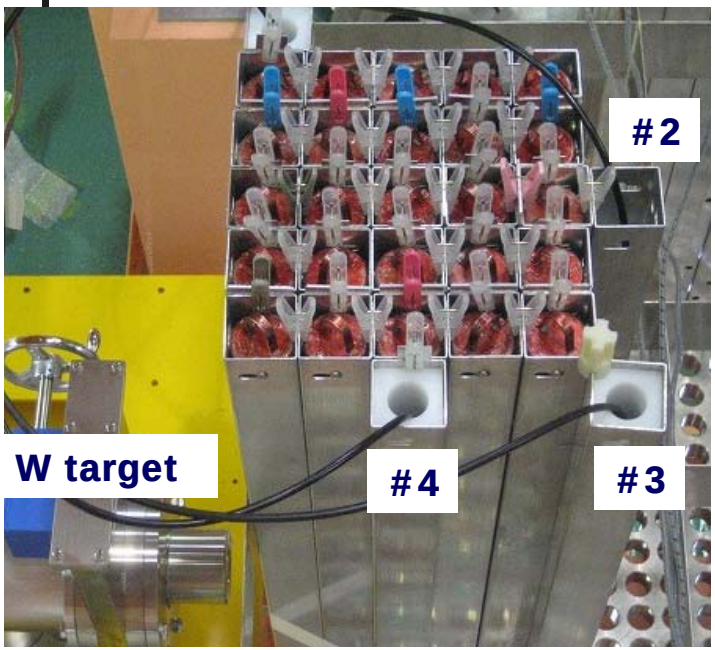


Fig. Comparison of measured and calculated reaction rates in ^{232}Th-loaded core

Confirmation of ^{232}Th fission reactions generated by spallation neutrons (using "fission turnoff" option in MCNPX)

^{232}Th-loaded ADS with 100 MeV protons



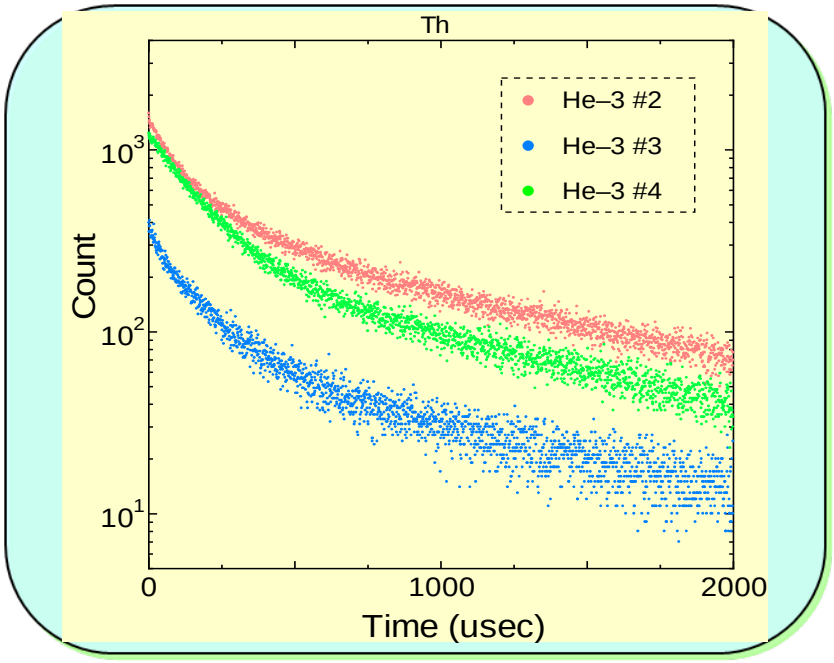


Fig. Neutron density of time evolution by Pulsed neutron method in Th-loaded core

Important knowledge

- No deduction of Subcriticality (--> Very large neutron decay constant)
- Further efforts for a variety of ADS options using fuels (Th, HEU, NU) and moderators (Poly., Al, Graphite and Be)

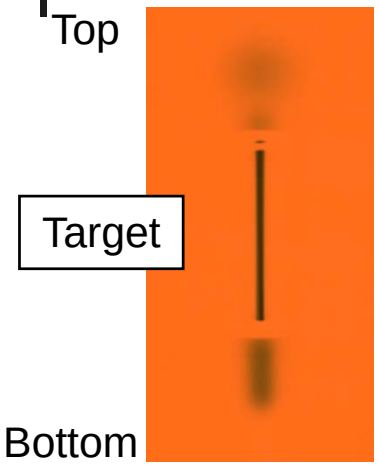
Summary

- **ADS project (Kart & Lab. project) in KURRI**
  - Energy amplifier system using ADS with high-energy protons
- **ADS experiments with 14 MeV neutrons**
  - Static and Kinetic experiments
- **ADS experiments with 100 MeV protons**
  - **^{235}U-loaded ADS**: World`s first injection of spallation neutrons into the KUCA A-core
  - **^{232}Th-loaded ADS**: Experimental analyses of Th fission reactions

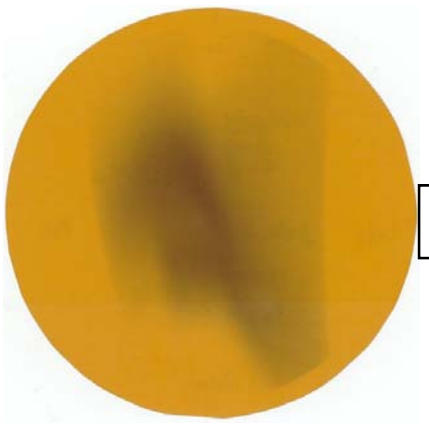
In the future

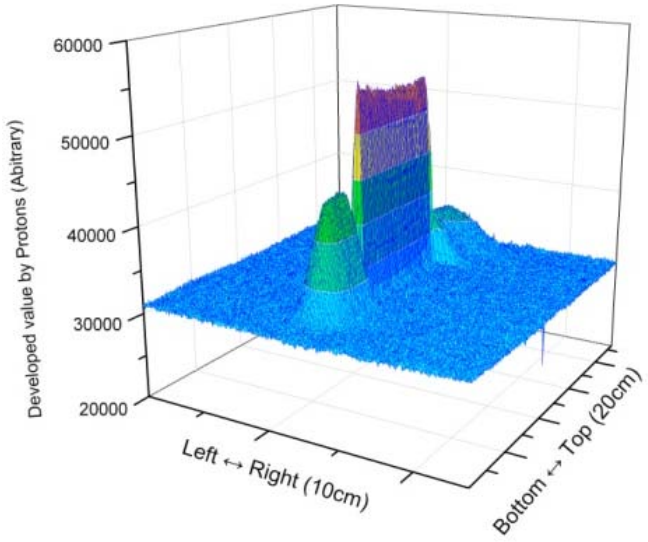
- Further efforts for a variety of ADS options using fuels (^{232}Th, HEU and NU) and moderators (Poly., Graphite, Al and Be) for nuclear transmutation using ^{237}Np and ^{241}Am (foil or detector)
- Experimental analyses of conversion ratio of ^{232}Th fission and capture reactions

Improvement of proton beams



Mar. 2009	Spec.	Mar. 2010
3 pA	Intensity	30 pA
90 MeV	Energy	100 MeV
Slit	Shape	Oscillated circle





Confirmation of improved proton injection