Subcriticality Measurements of Accelerator-Driven System in Kyoto University Critical Assembly

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First Injection of Spallation Neutrons

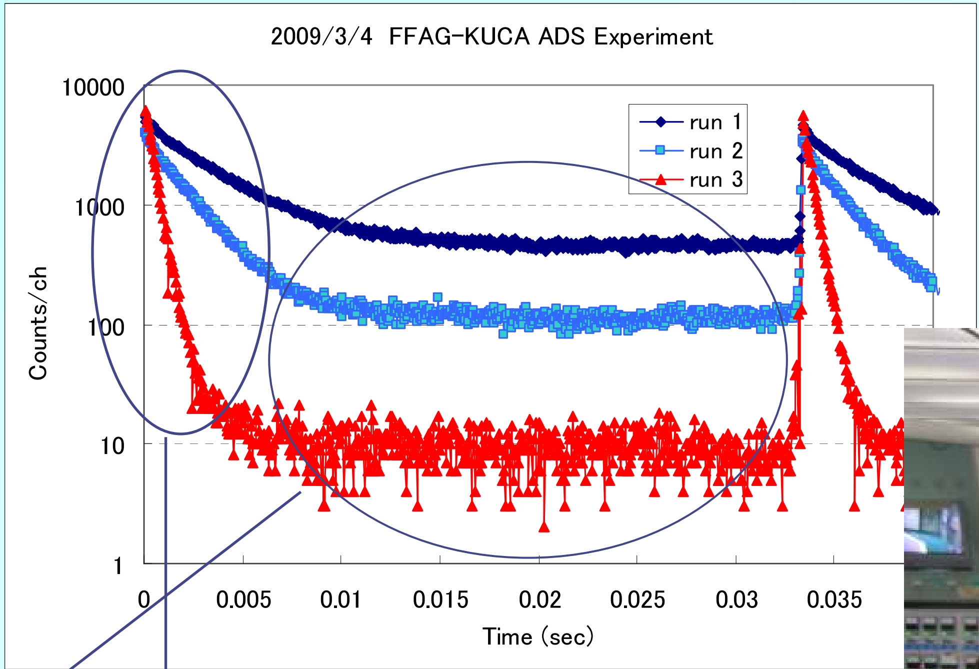
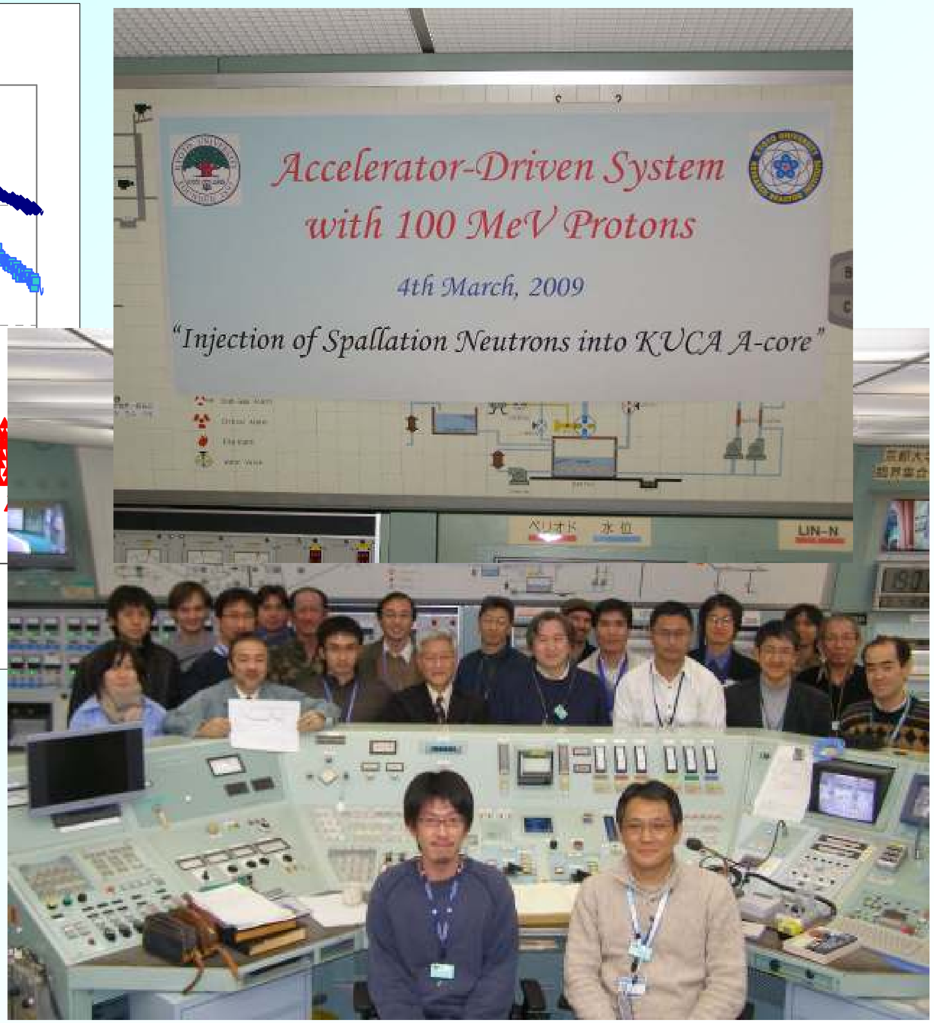


Fig. Time series of neutrons

Spallation neutrons from target

Delayed neutrons in core



Neutron multiplication by spallation neutrons generated by protons

Proton Beam Characteristics

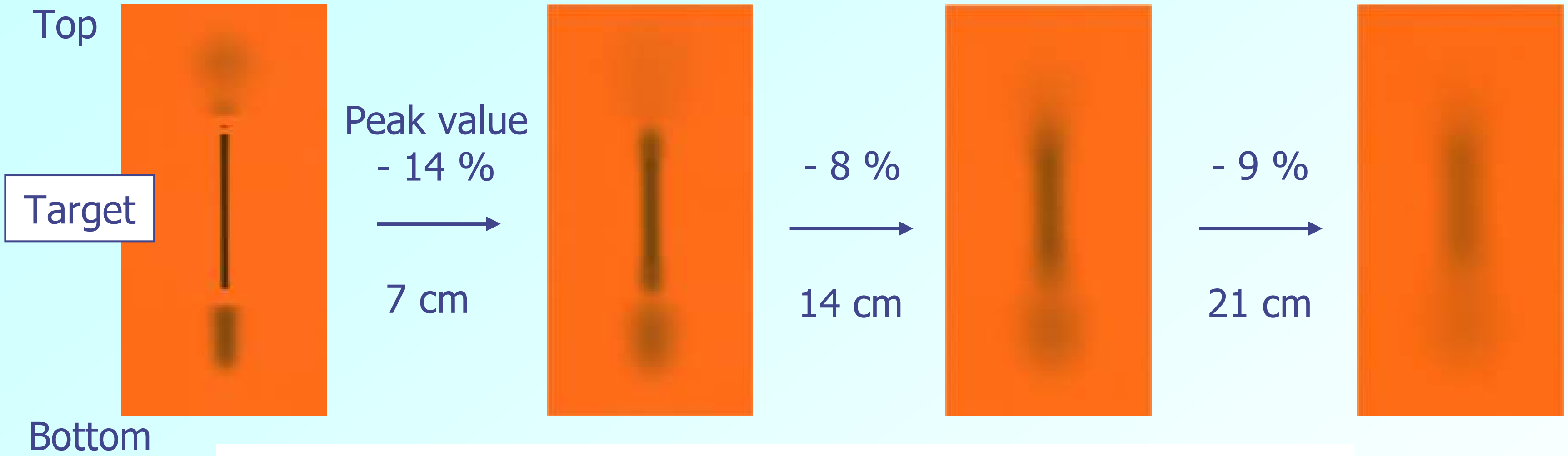


Fig. Results of Gafchromic films varying the distance from target

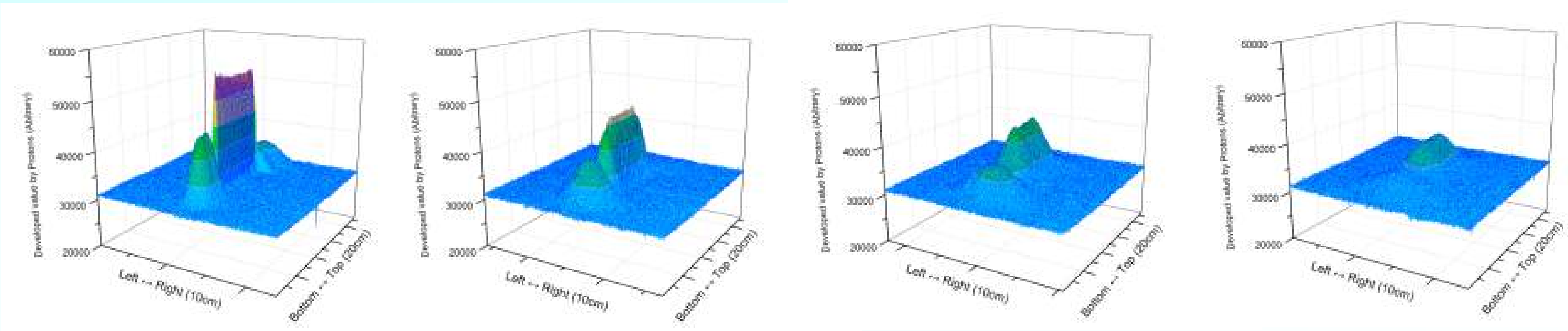


Fig. Results of scanning data of Gafchromic films varying the distance from target

Reaction rate (In wire in Axial)

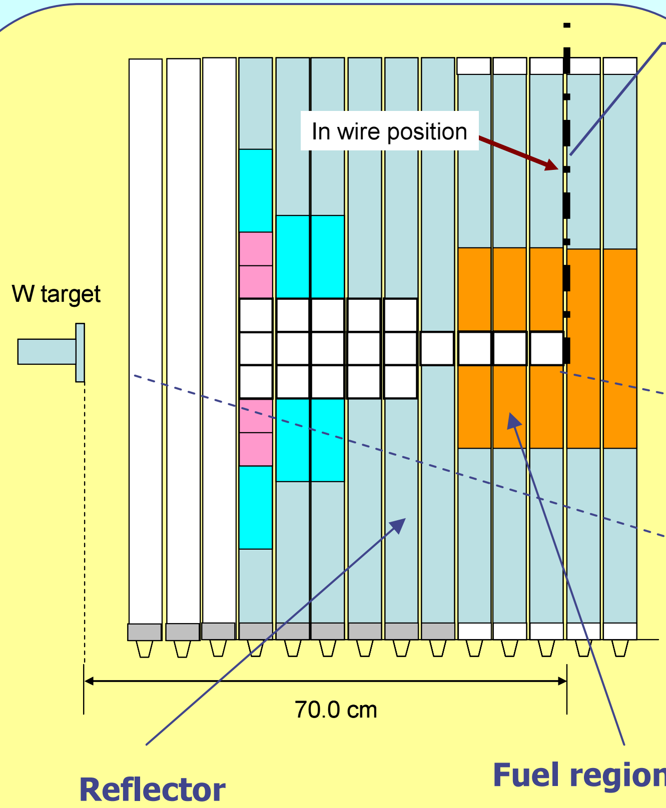


Fig. Side view of ADS core in KUCA A-core

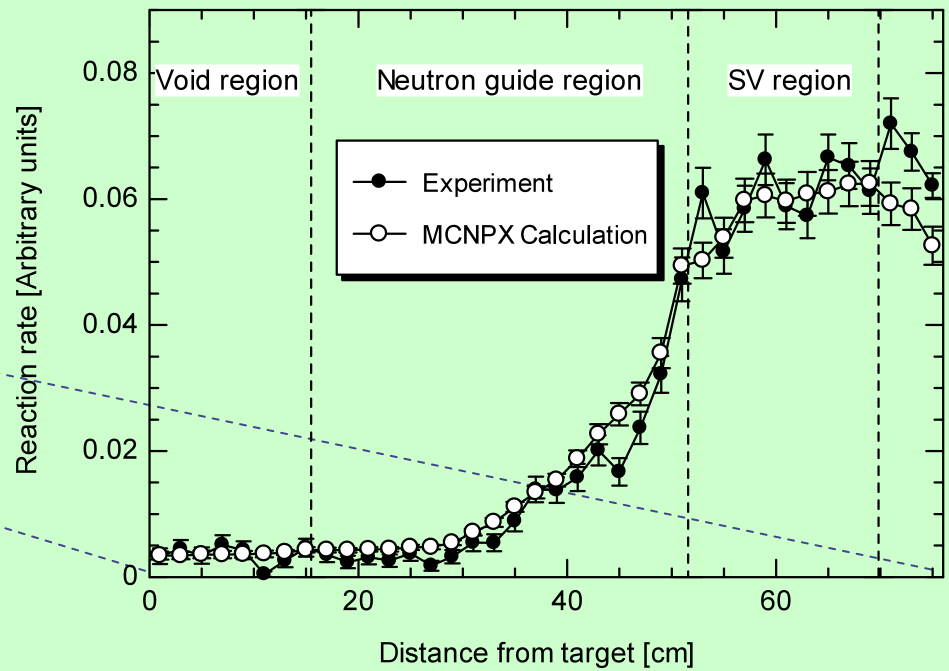


Fig. Reaction rate distribution by In wire

Reaction rate distribution

✓ Measure $^{115}In\ (n, \gamma)\ ^{116m}In$ (Exp. error: Too large)

✓ Confirm calculation precision by MCNPX

Contents

- ADS IAEA Benchmark problems (KART in KUCA)
- A unique optical fiber detection system
- Kinetic parameter measurement using optical fiber
  - ✓ Neutron multiplication
  - ✓ Neutron decay constant and Subcriticality
- IAEA benchmark problems Phase 2:

  Subcriticality measurements
  - ✓ Pulsed neutron (PN) method
  - ✓ Neutron noise (NN) method

    (Feynman-α and Rossi-α methods)
  - ✓ Neutron source multiplication (NSM) method

IAEA Benchmarks at KART (Phase 1 & 2)

- **Phase 1: Static experiments (14 MeV D-T neutrons)**
  - Indium (In) wire (Reaction rates) distribution
  - Reactivity (Excess reactivity and Subcriticality)
  - Neutron spectrum (Reaction rates and Unfolding analyses)

- **Phase 2: Kinetic experiments (14 MeV D-T neutrons)**
  - Neutron multiplication analyses (M=(F+S)/S)
  - Subcriticality measurement methods (Rossi-α, Feynman-α, Pulsed neutrons and Neutron source multiplication (NSM) methods)
  - Neutron decay constant (Relationship between α and ρ)

KUCA A-core

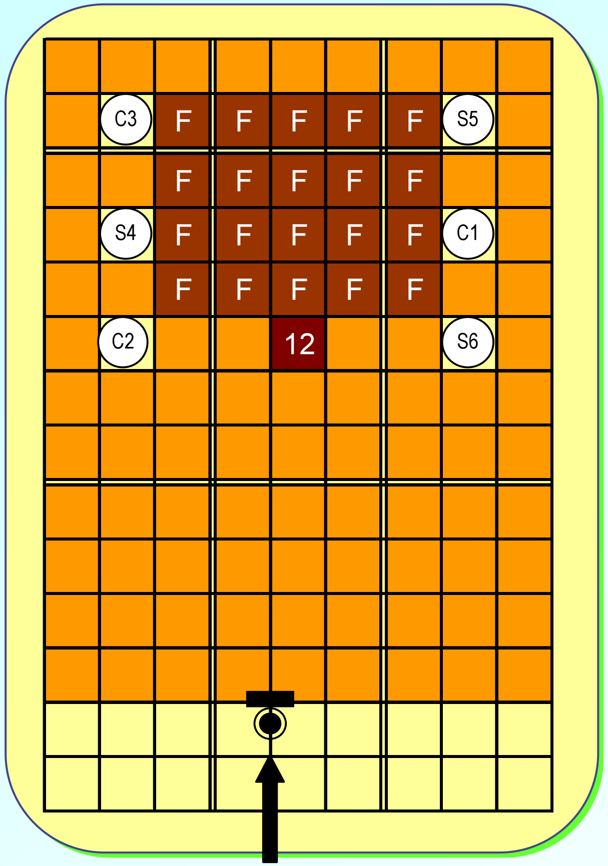


Fig. KUCA A-core (Reference core)

- KUCA A-core -

A solid-moderated and -reflected core

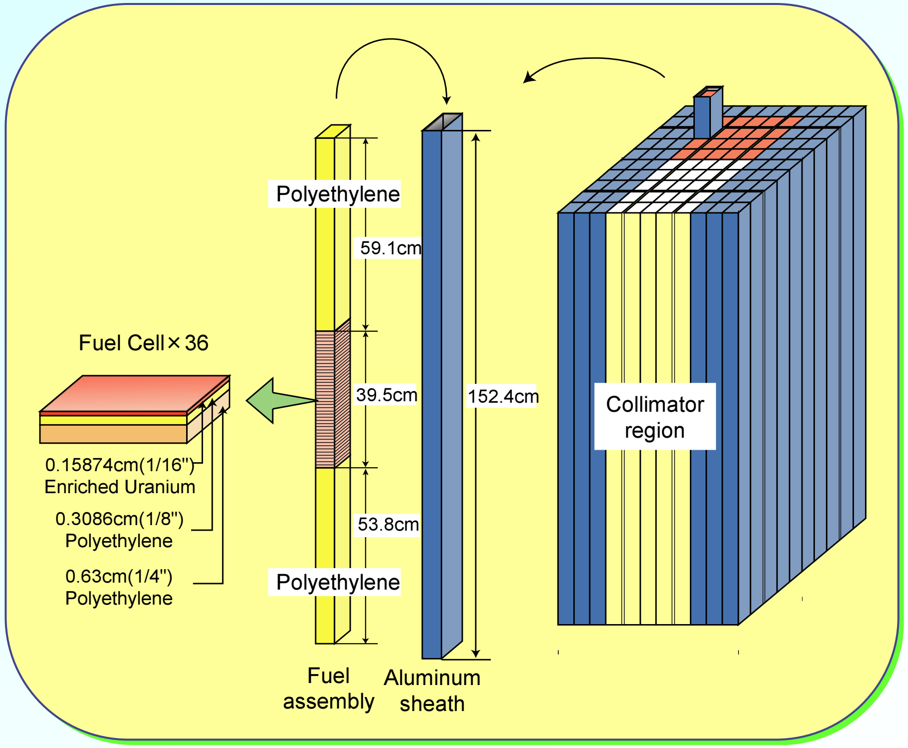


Fig. Image of KUCA A-core and fuel assembly loaded

Neutron guide and Beam duct

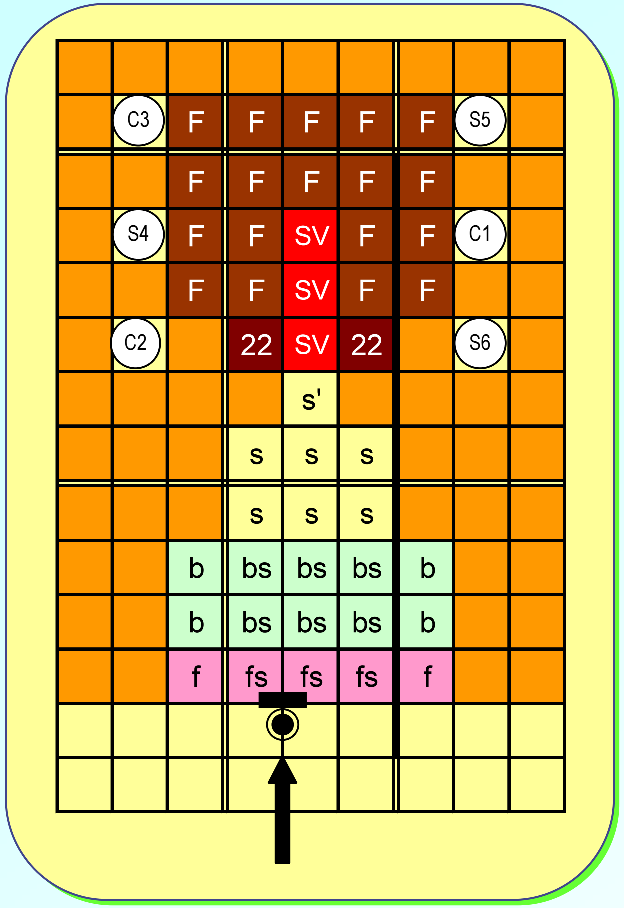


Fig. Top view of neutron guide core

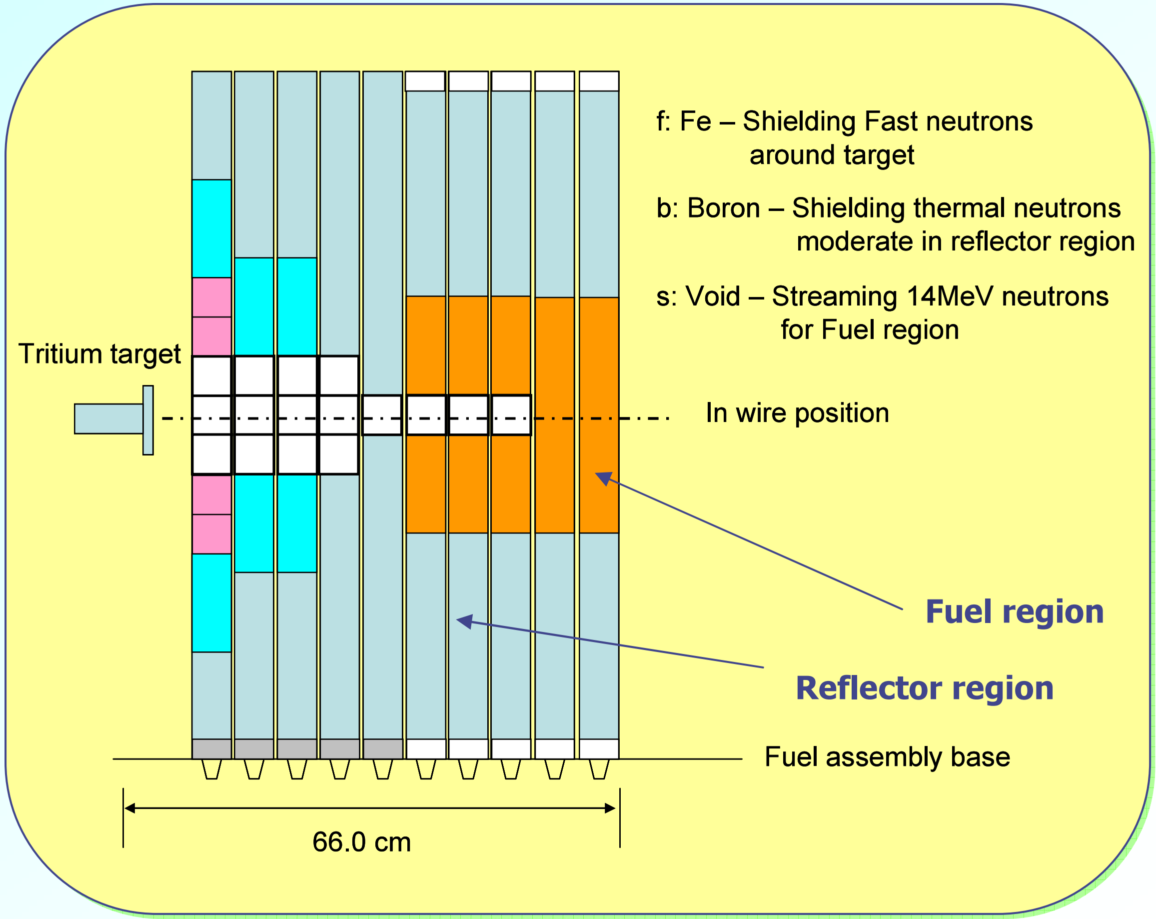


Fig. Side view of neutron guide and beam duct

Optical Fiber Detection System

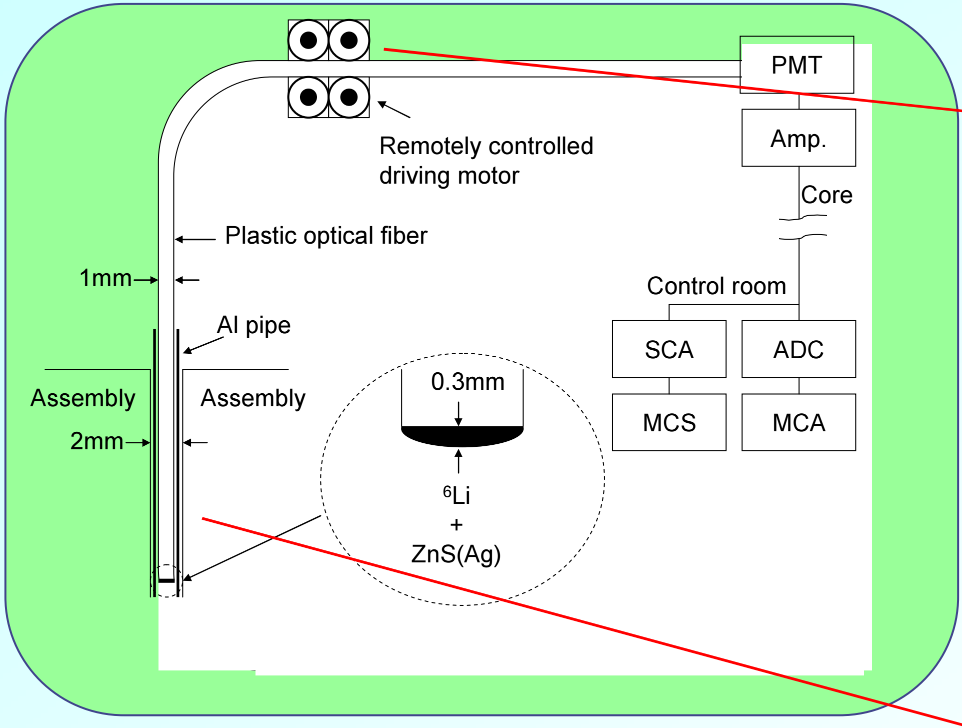


Fig. Remote driving system

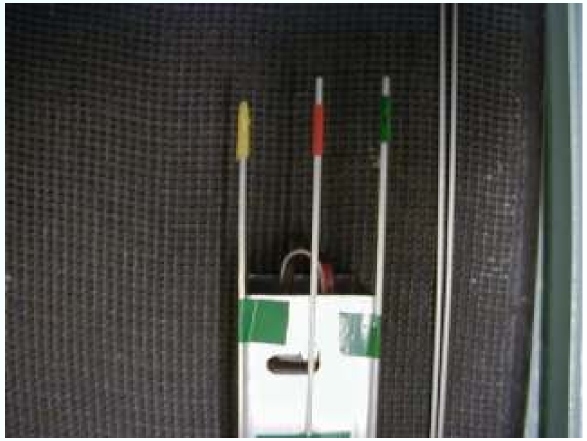


Fig. Optical fiber covered by Al tube

✧ **<u>Main characteristics</u>**

➢ Li: Scintillation material (obtained by ^{6}Li (n, α) reaction)

➢ ZnS: Convertor material

➢ Size: Compound of (LiF+ZnS -> 1:1) optimized mixture in 0.5 mm thickness and 1 mm diameter

Neutron Multiplication (k-source)

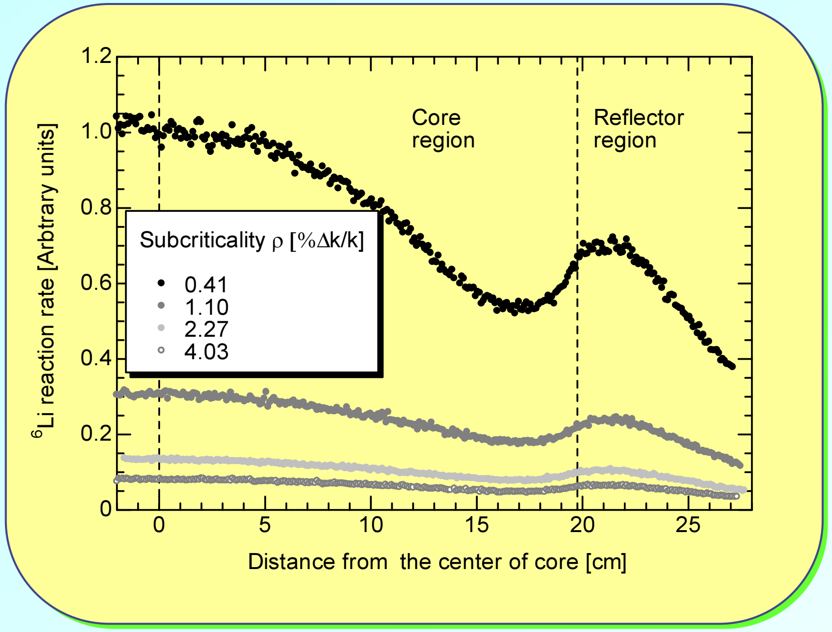


Fig. Axial Li reaction rates by optical fiber detection system varying subcriticality

$$M = \frac{F+S}{S}$$

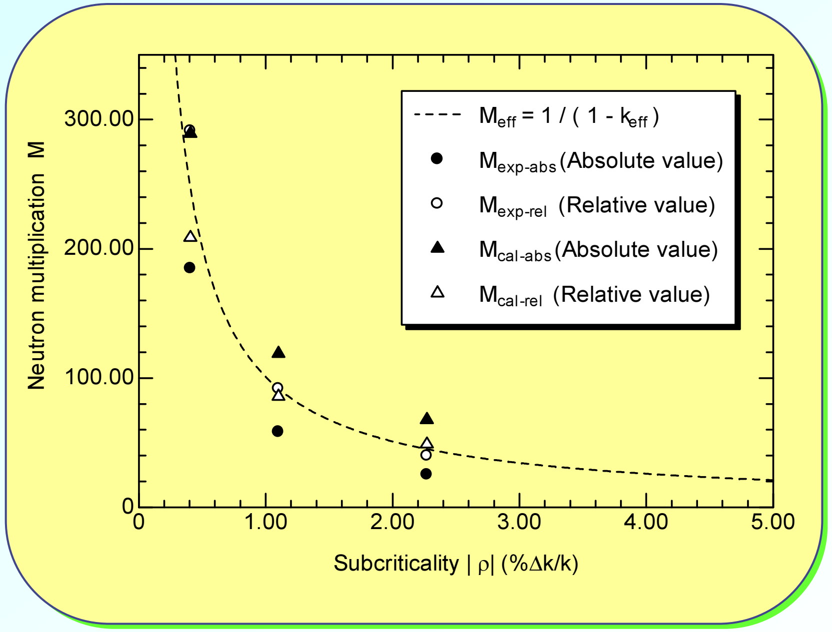
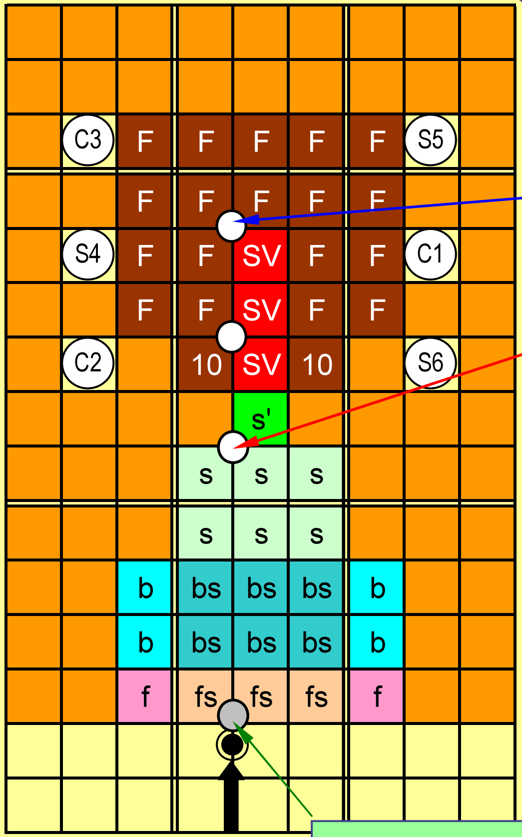


Fig. Neutron multiplication by Area ratio method applied to Li reaction rates

Principle of an attachment at top in optical fiber

- LiF (ZnS): ^{6}Li (n, α) reaction for thermal neutrons => 1/v distribution of X-sec in thermal energy region
- ThO_2 (ZnS): ^{232}Th fission reaction for fast neutrons => Threshold reaction in 9 MeV for neutrons
- F: Total number of neutrons by nuclear fission reactions
- S: Total number of neutrons generated by outer source

Neutron Decay Constant



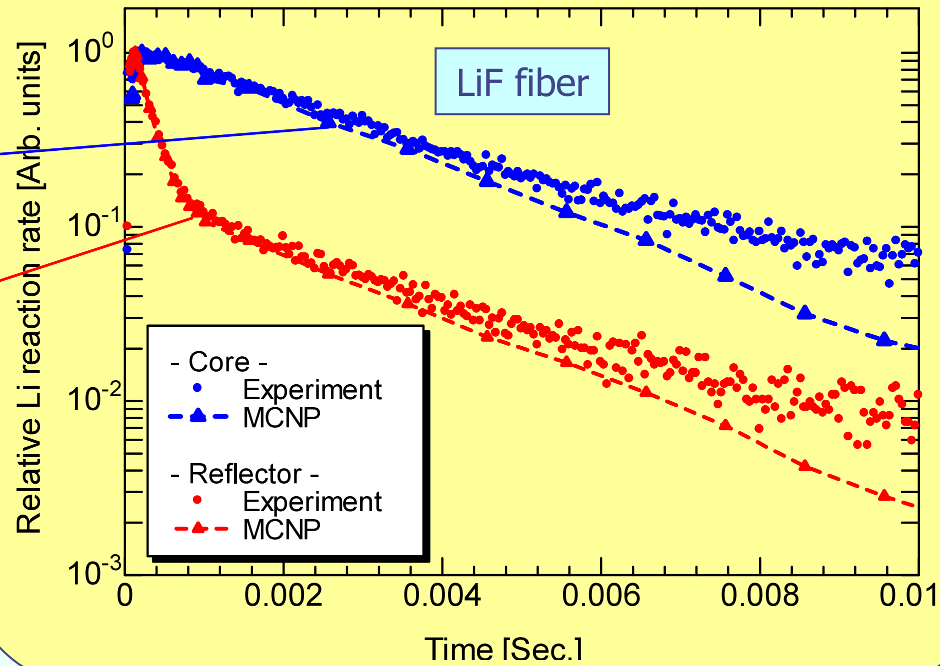


Fig. Measured neutron decay behavior by optical fiber detector system.

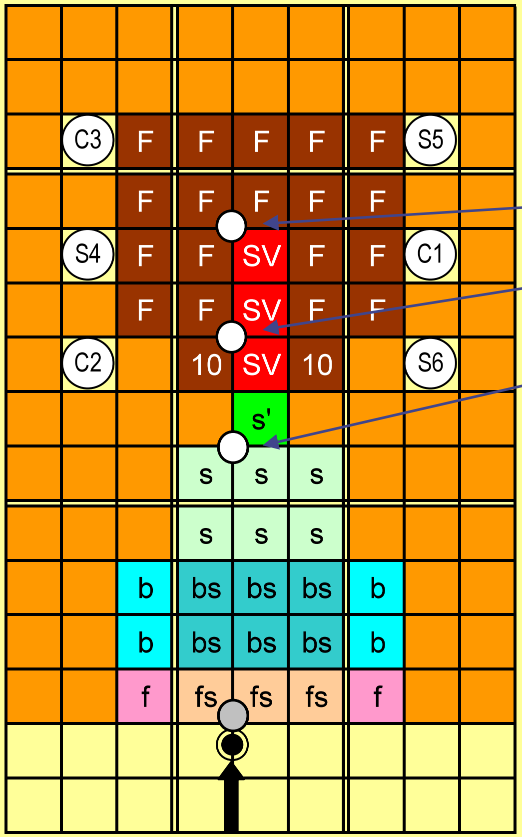
ThO_2 (or Al, ZnS, LiF) fiber: Monitoring outer source neutrons

<u>Pulsed neutron method (PNM)</u>

✓ Good evaluation of subcriticality at both core and reflector positions

✓ Examination of validity of methodology and position dependency

Pulsed Neutron (PN) Method



○: LiF Optical fiber
●: ThO_2 optical fiber

Table Comparison of measured subcriticality by pulsed neutron method varying detector positions

MCNP	Fiber #1 (%Δk/k)	Fiber #2 (%Δk/k)	Fiber #3 (%Δk/k)
0.97±0.03	0.99±0.01	0.96±0.01	0.99±0.01
1.83±0.03	1.88±0.02	2.15±0.02	1.78±0.02
2.55±0.03	2.55±0.03	3.12±0.03	2.42±0.02
3.45±0.03	3.40±0.03	3.25±0.03	3.63±0.04
6.24±0.03	5.89±0.06	6.54±0.07	6.87±0.07
7.41±0.03	7.55±0.08	8.18±0.08	8.64±0.09
10.38±0.03	10.24±0.10	12.28±0.12	11.93±0.12

Neutron Noise (NN) Method

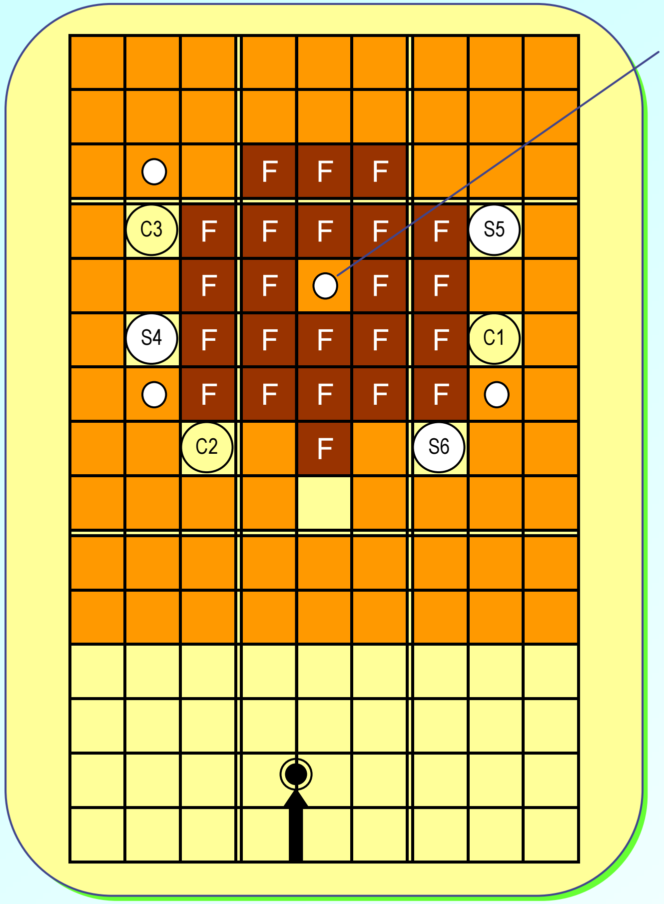


Fig. Top view of KUCA A-core

Table Comparison of measured neutron decay varying Feynman and Rossi-α methods (pulsed period 20 ms)

Subcriticality (%Δk/k)	Reference* α (1/sec)	Feynman** α (1/sec)	Feynman*** α (1/sec)	Rossi (1/sec)
0.50±0.01	266±2	253±1	285±1	263±1
0.99±0.01	369±3	373±2	383±1	368±2
1.58±0.02	494±3	495±3	508±1	500±5
2.07±0.02	598±4	601±4	631±2	599±7

*: Reference a was obtained using pulsed neutron method
**: Stochastic Feynman-α
***: Deterministic Feynman-α

Note that these data were provided by Dr. Y. Kitamura of JAEA

Neutron Source Multiplication (NSM) Method

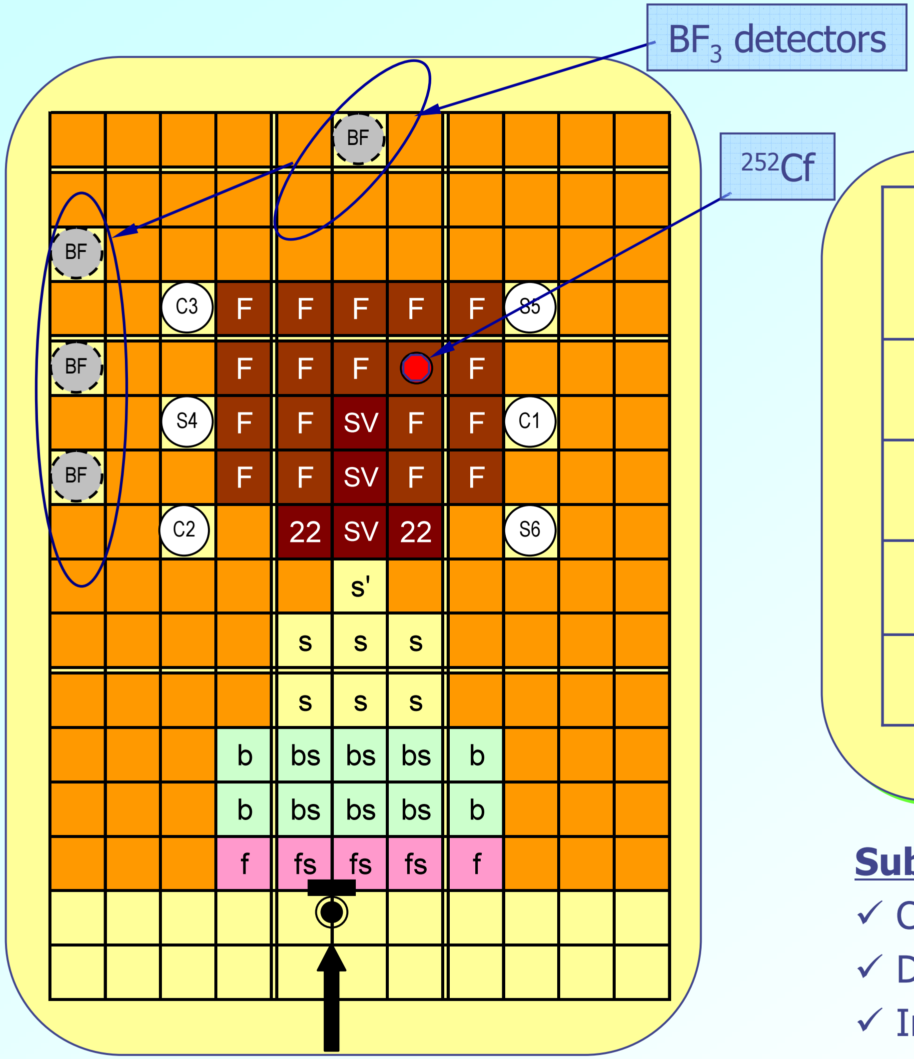


Table Comparison of measured subcriticality with calculated ones (with JENDL-3.3).

Ref. Exp. value (%Δk/k)	MCNP (%Δk/k)	Higher-mode SM method (%Δk/k)
0.72±0.06	0.69 (4.2%)	0.67 (6.9%)
2.72±0.22	2.88 (5.9%)	2.52 (7.4%)
5.96±0.45	6.44 (7.5%)	5.19 (12.9%)
8.66±0.69	10.46 (20.8%)	7.09 (18.1%)

( ): Relative difference, Cal. error: 0.03%Δk/k

Subcriticality (Source Multiplication method)

✓ Confirmation of measurement technique
✓ Detector position dependence
✓ Improvement of precision and methodology

IAEA Benchmark Problems

- **Phase 1: Static experiments (14 MeV D-T neutrons)**
  Reaction rate distribution, Neutron spectrum, Reactivity
- **Phase 2: Kinetic experiments (14 MeV D-T neutrons)**
  Neutron multiplication, Subcriticality measurement methods
  (Rossi-α, Feynman-α, Pulsed neutrons and
  Neutron source multiplication (NSM) methods)
- **Phase 3: Static and Kinetic experiments (150 MeV protons)**
  Above topics, γ-ray distribution, Power monitoring, etc.

✓ Fuel: HEU, Thorium, NU
✓ Reflector: Polyethylene, Graphite, Aluminum, Beryllium
✓ Core: Any combinations of Fuel & Reflector

Summary

- Confirming the detection system using a unique optical fiber:
  - ✓ Multiplication M using reaction rate distribution
    (vs. one point reactor approximation)
  - ✓ Neutron decay constant α and Subcriticality ρ
    → Good evaluation of subcriticality

- IAEA benchmark problems (Phase 2):
  Subcriticality using PN, NN and NSM methods, confirming
  - ✓ Detector position dependence
  - ✓ Each measurement technique