What is "ADSR" ?

- a brief introduction -

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Contents

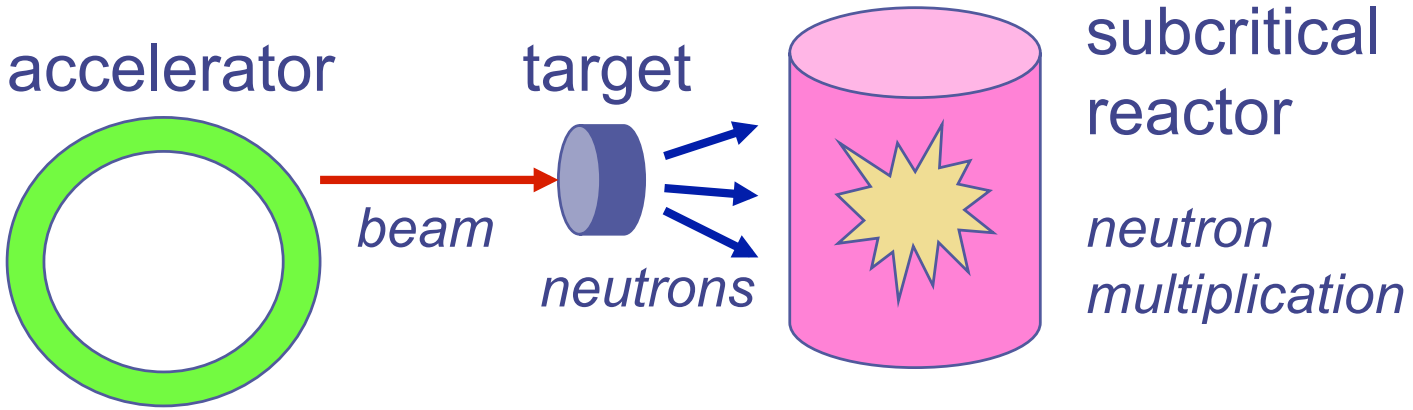
- Concept and purpose of ADSR
- ADSR projects and studies
- ADSR studies at KURRI

ADSR : Concept and Purpose

ADSR=Accelerator Driven Subcritical Reactor

(ADS = Accelerator Driven System)

- Proposed by E. O. Lawrence in the 1950s; revisited through proposal by Dr. C. Rubbia as "Energy Amplifier"
- combination of accelerator and nuclear reactor
- subcritical reactor with external neutron source provided by the use of accelerator

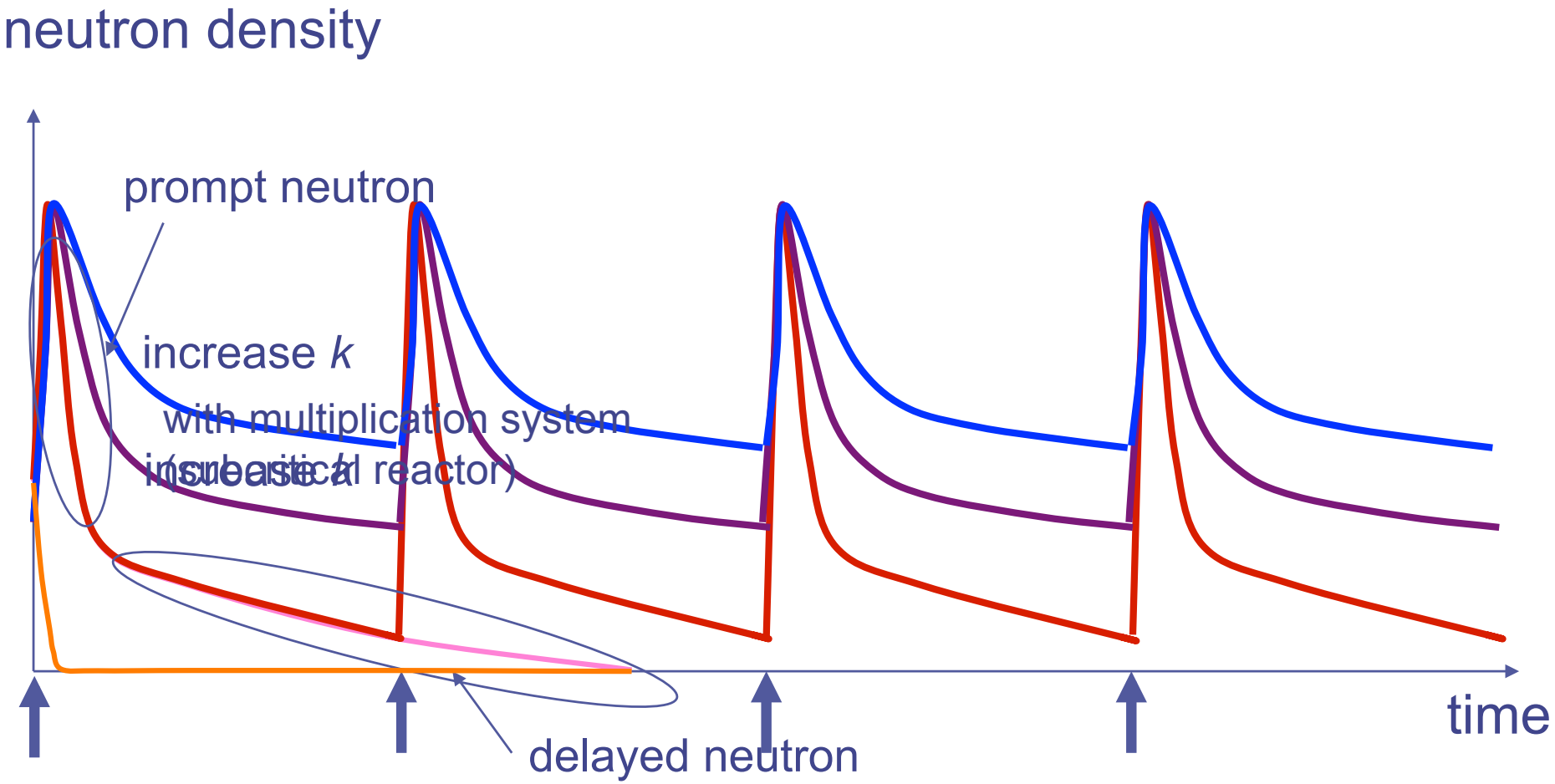


ADSR : Concept and Purpose

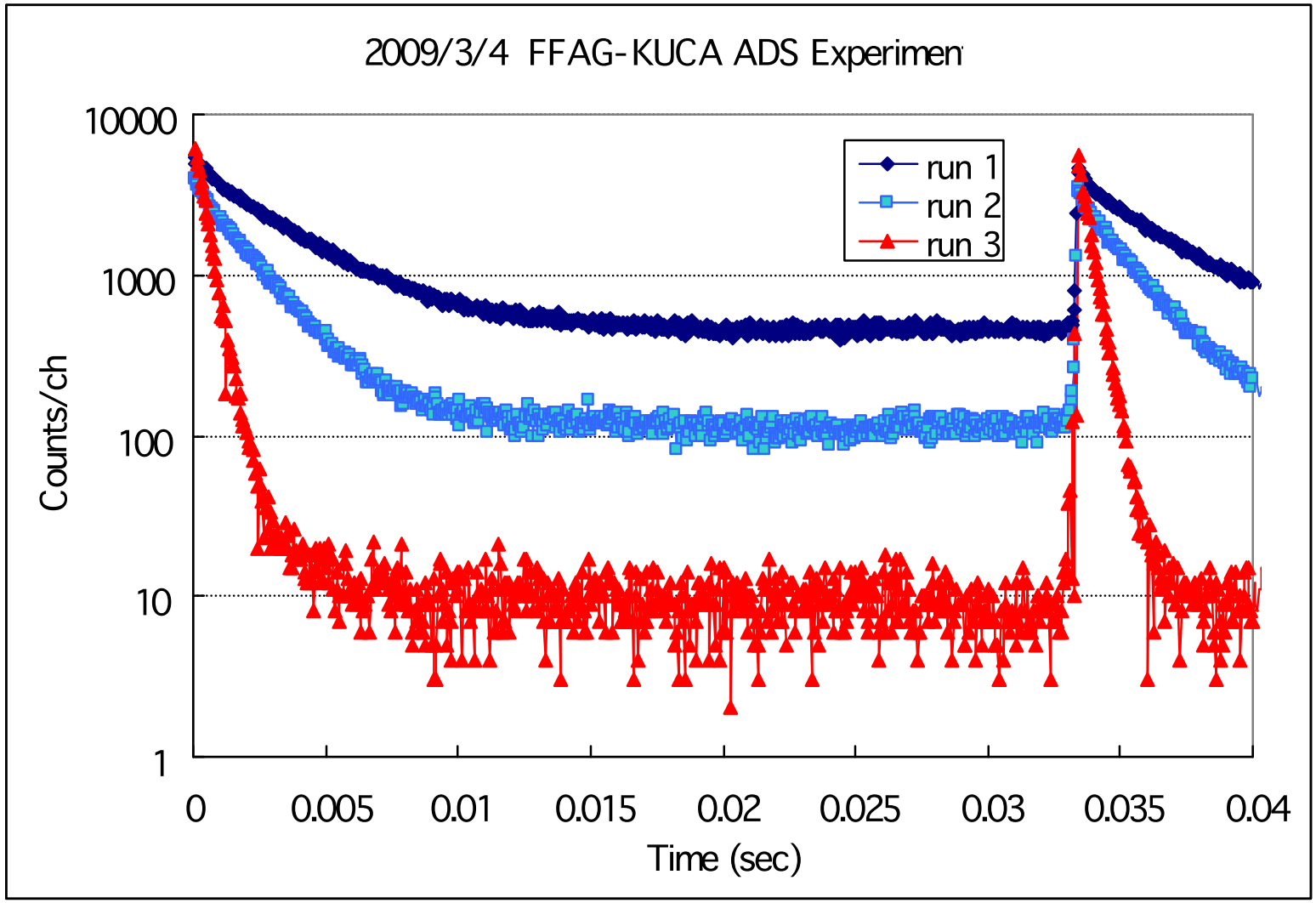
Subcritical Reactor

- nuclear reactor with fuel material not enough to sustain the fission chain reaction
- neutron population within the reactor fades away with time, unless there is no supply of neutrons (i.e. no external neutron source)
- neutrons supplied from external source is multiplied in the reactor ; the magnitude of the multiplication is determined by parameter *k*, the "multiplication factor" which indicates how "far" the reactor is away from the critical state.
- $k=1$ when the reactor is critical; $k<1$ for a subcritical reactor
- neutrons supplied will be multiplied by $1/(1-k)$

Neutron Multiplication in a Subcritical Reactor



Neutron Multiplication in a Subcritical Reactor

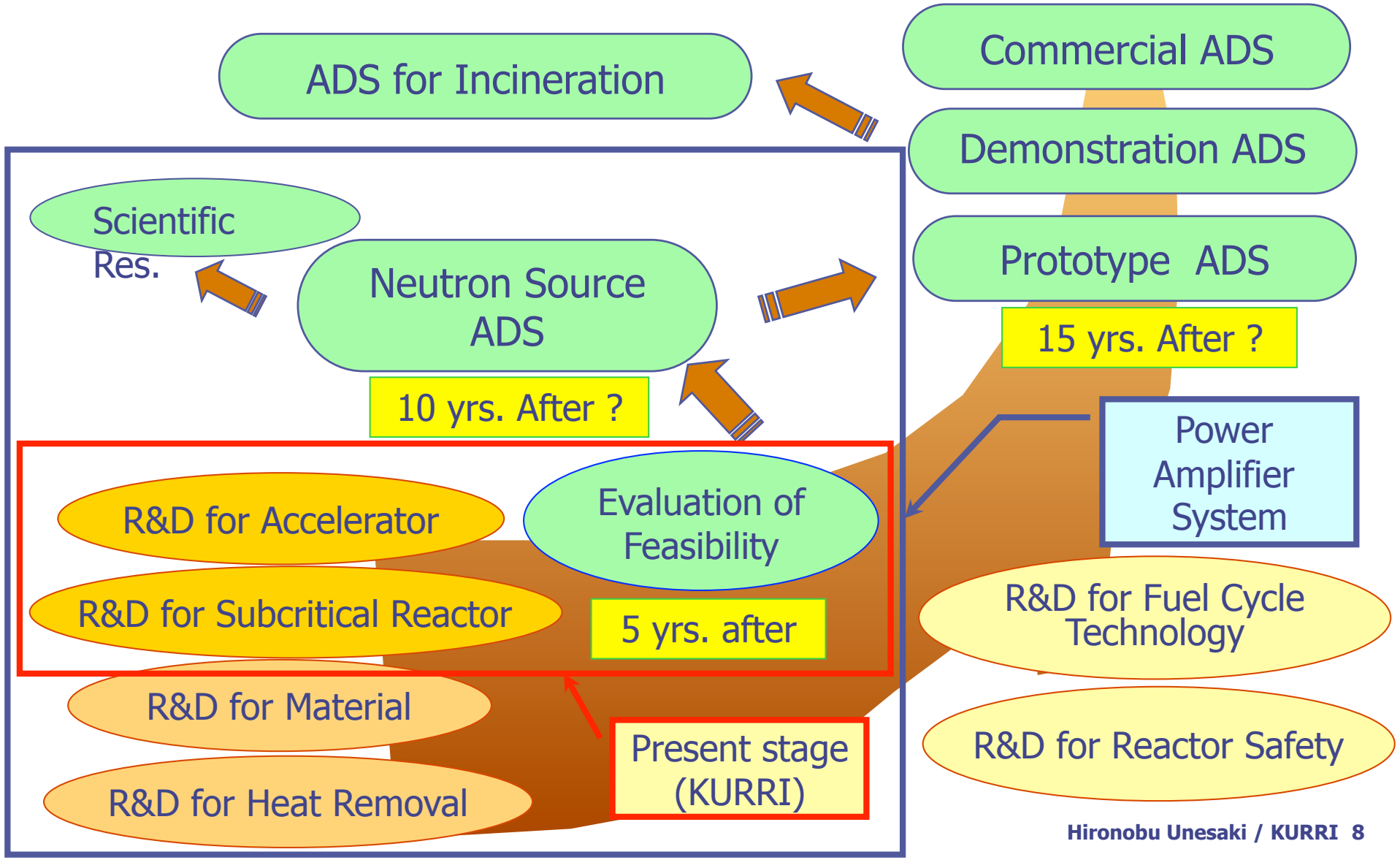


ADSR : Concept and Purpose

Combined system of accelerator and subcritical reactor for generation and use of neutron in the reactor; the neutrons are generated through creation of neutron by bombarding the target with charged particle beam from the accelerator followed by the amplification of neutron through nuclear fission in the reactor core

- energy production by nuclear fission : if [energy required for acclerator] < [energy produced in the reactor core], the system could be considered as "energy amplifier" → ADSR as **energy source**
- use of multiplied neutrons for R&D → ADSR as **neutron source**
- specific use of multiplied neutrons for nuclear transmutation and incineration of MAs (Np, Am, Cm, etc.) and LLFPs（Tc-99, I-129 etc.), high-hazardous FPs (Sr-90, Cs-137, Rh, Pd etc) → ADSR as **transmutation / incineration facility**

Road Map of ADS Program in KURRI



ADSR : why interesting ?

- complex system with different technologies (accelerator science + nuclear reactor science + nuclear physics + reactor engineering)
- behaviour of subcritical system well understood for En<14 MeV (DT neutron) but not many information with high-energy neutron source
- definition of parameter k in source-driven subcritical system : differs from multiplication factor k for critical system and needs experimental confirmation of the proposed theories
- enchanced flexibility of core design, which can cope with non-conventional fuel design (with MAs and FPs)

ADSR : why interesting ?

- spallation target technology ; generation of maximum amount of neutrons per injected beam intensity and safe removal of generated heat
- accelerator technology ; enhancement of beam stability and system efficiency
- nuclear physics ; investigation of spallation reaction and high-energy reaction cross section
- reactor engineering ; investigation of reactor controll system and safety system design

ADS-related Projects and Experiments

- EUTROTRANS Programme
  (14 countries, 2005/4-2010/4)
  → Design of Experimental ADS facility (XT-ADS)
- TRADE (TRIGA＋DT source, Italy) (discontinued)
- RACE-T（TRIGA＋DT source, Italy）(Pre-TRADE?)
- MUSE: DT source + Fast Reactor Critical Assembly
- SNS (ORNL, US) : spallation neutron target
- YALINA（DT source, Belarus → "Booster"）
- GUINEVERE（Pb-cooled FR＋DT source, Belgium）
- J-PARC (JAEA、Japan)
- KART (FFAG+KUCA, Japan)

Activities related to ADS

・Pb-Bi spallation target verification – MEGAPIE（by PSI, Switzerland：international collaboration）

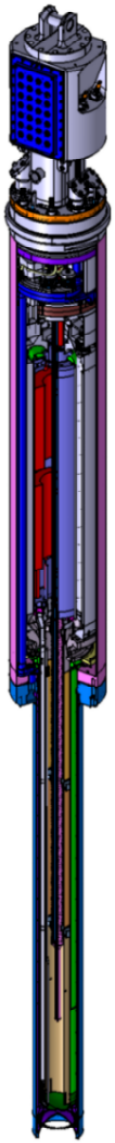
・High Power Proton accelerator for ADS – EUROTRANS (EU)

・Accelerator reliability and stability studies – Spallation neutron source (SNS, ORNL, US), J-PARC (JAEA, Japan)

・Spallation Target and Heat Removal – MYRRHA (Belgium)（by SCK・CEN, ADS for irradiation experiment）

・Subcritical Reactor Design – XT-ADS (EUROTRANS), Venus-1 (China), GUINEVERE (Belgium),KART (Japan)

MEGAPIE target



Target Head Feedthroughs

Target Shielding

Expansion Tank

Main EMP Flowmeter

12 Pin Heat Exchanger

Bypass EMP Flowmeter

Upper Target Enclosure

Main Guide Tube

Central Rod Heaters and Neutron Detectors

Bypass Flow Guide Tube

T91 Lower Liquid Metal Container

LBE Leak Detector

Lower Target Enclosure

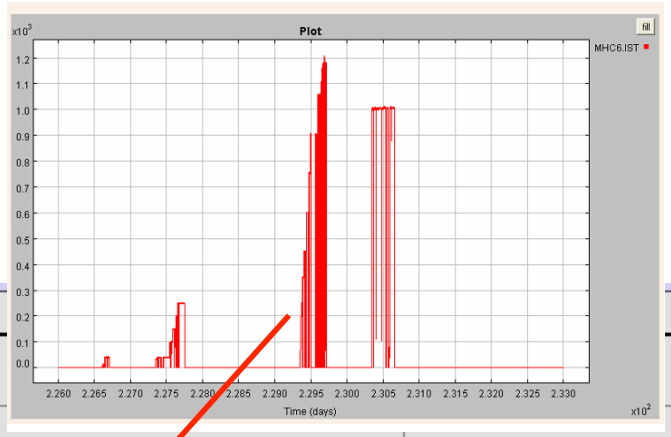
APIE Target

gn parameters

ı energy:	575 MeV
ı current:	1.74 mA
ın life:	1 year of operation (6000 mAh)
ɛt/coolant:	Lead-bismuth eutectic
/olume:	88 l
ɛd surface:	16 m^2
sited Heat:	650 kW
Γ range:	230-380° C
flow velocity:	~1.2 m/s
ı window:	T91 steel
ɔw Temperature:	330-380° C
ıtion Damage:	20-25 dpa

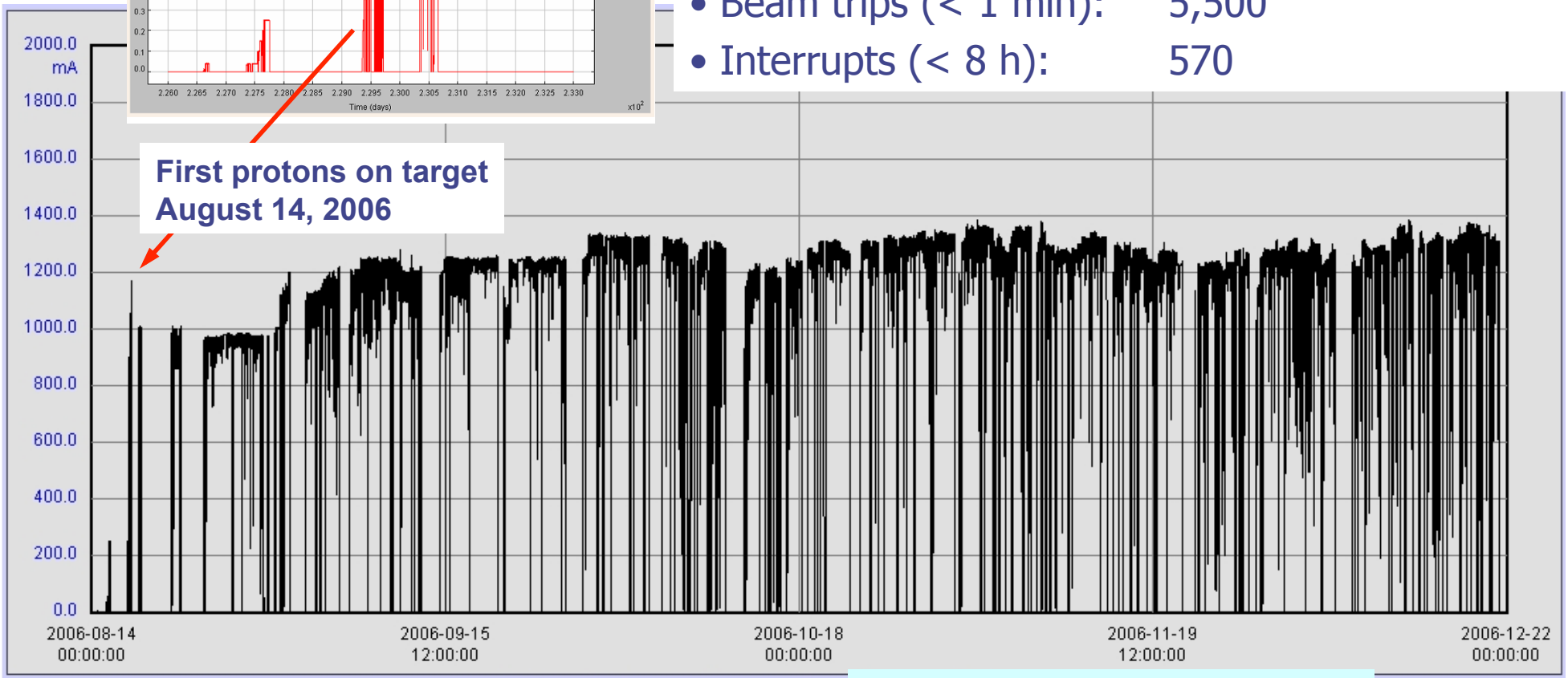
(From F. Groeschel, PSI, Swiss)

MEGAPIE experiment



On beam: August 14 – December 21, 2006

- Accumulated charge: 2.8 Ah
- Peak current: 1,400 μA
- Beam trips (< 1 min): 5,500
- Interrupts (< 8 h): 570



(From F. Groeschel, PSI, Swiss)

EUROTRANS Programme

- **EUROpean research programme for the TRANSmutation of high level nuclear waste in an Accelerator Driven System**
- EU FP6 programme (2005 - 2009)
- 31 research agencies & industries, 16 universities
- Expands the EU FP5 project PDS-XADS (2001 - 2004)
- 5 Domains (DM1=Design, ...)

Main GOAL of the EUROTRANS programme

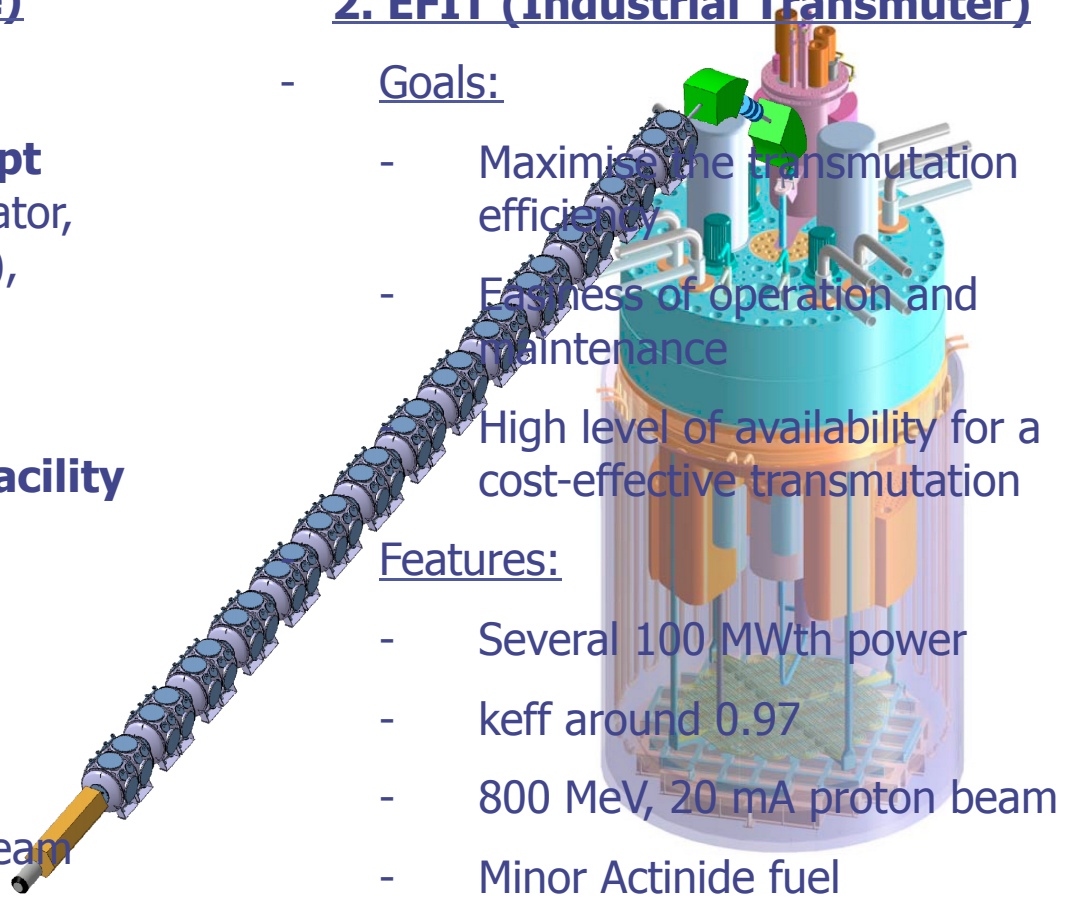
- Advanced design of a 50 - 100 MWth e**X**perimental facility demonstrating the technical feasibility of **T**ransmutation on an **ADS (XT-ADS, short-term realisation)**
- Generic conceptual design (Several 100 MWth) of a **E**uropean **F**acility for **I**ndustrial **T**ransmutation **(EFIT, long-term realisation)**

(From J. L. Biarrote, CNRS, France)

EUROTRANS Facilities

1. XT-ADS (ADS prototype)

- Goals:
  - **Demonstrate the concept** (coupling between accelerator, spallation target & reactor),
  - **Demonstrate the transmutation**
  - **Provide an irradiation facility** and an EFIT test bench
- Features:
  - 50 - 100 MWth power
  - keff around 0.95
  - 600 MeV, 2.5 mA proton beam (or 350 MeV, 5 mA)
  - Conventional MOX fuel
  - Pb-Bi Eutectic coolant



2. EFIT (Industrial Transmuter)

- Goals:
  - Maximise the transmutation efficiency
  - Easiness of operation and maintenance
  - High level of availability for a cost-effective transmutation
- Features:
  - Several 100 MWth power
  - keff around 0.97
  - 800 MeV, 20 mA proton beam
  - Minor Actinide fuel
  - Pb coolant (gas as back-up solution)

(From J. L. Biarrote, CNRS, France)

EUROTRANS activities: accelerator R & D

High-power proton CW beams

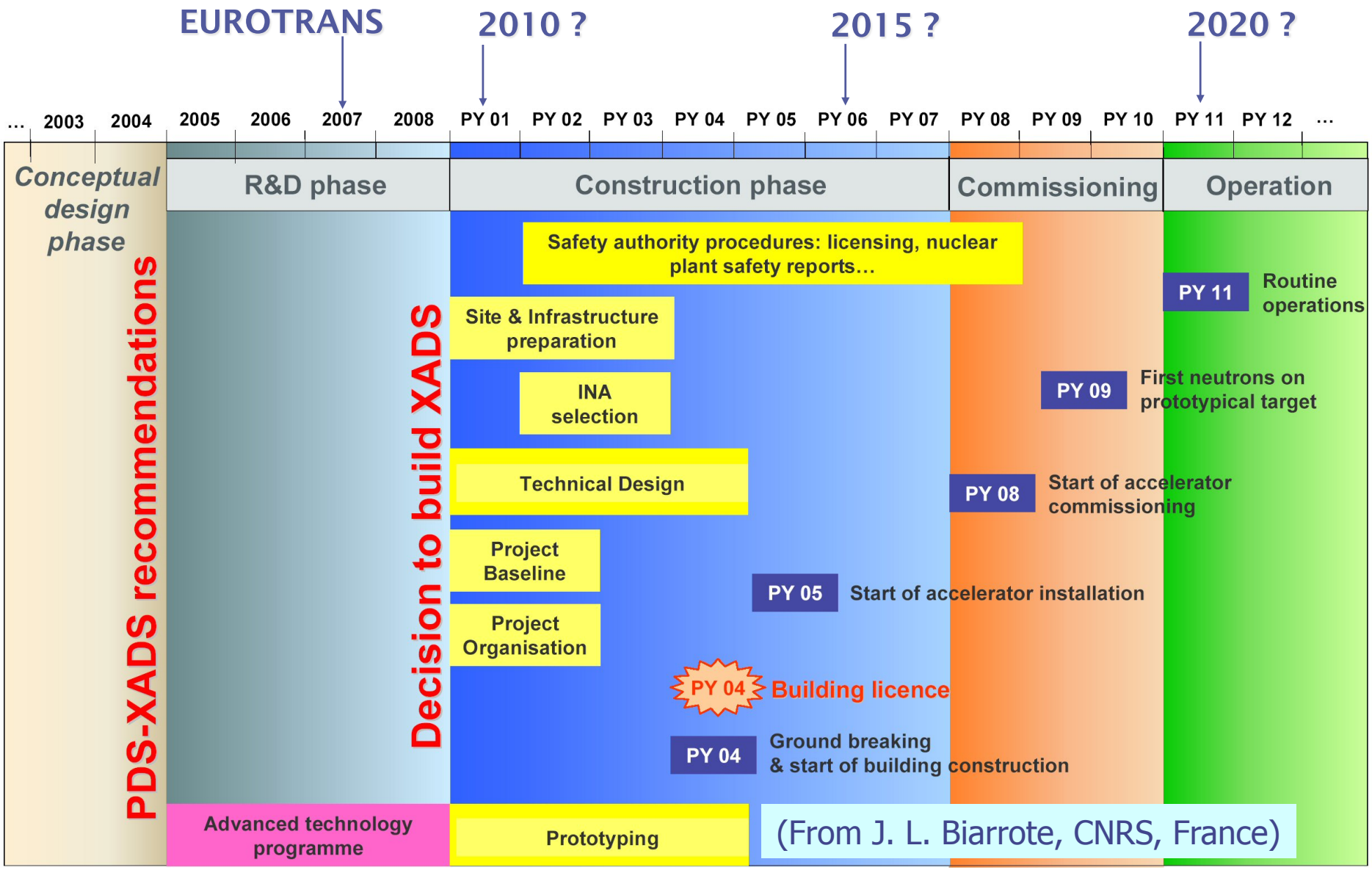
Table 1 – XT-ADS and EFIT proton beam general specifications

	XT-ADS	EFIT
Maximum beam intensity	2.5 – 4 mA	20 mA
Proton energy	600 MeV	800 MeV
Beam entry	Vertically from above	
Beam trip number	< 20 per year (exceeding 1 second)	< 3 per year (exceeding 1 second)
Beam stability	Energy: ± 1 %, Intensity: ± 2 %, Size: ± 10 %	
Beam footprint on target	Circular ∅ 5 to 10 cm, "donut-shaped"	An area of up to 100 cm² must be "paint-able" with any arbitrary selectable intensity profile
Beam time structure	CW, with 200 μs zero-current holes every 10^{-3} to 1 Hz, + pulsed mode capability (repetition rate around 50 Hz)	

Extrememely high reliability is required !!!

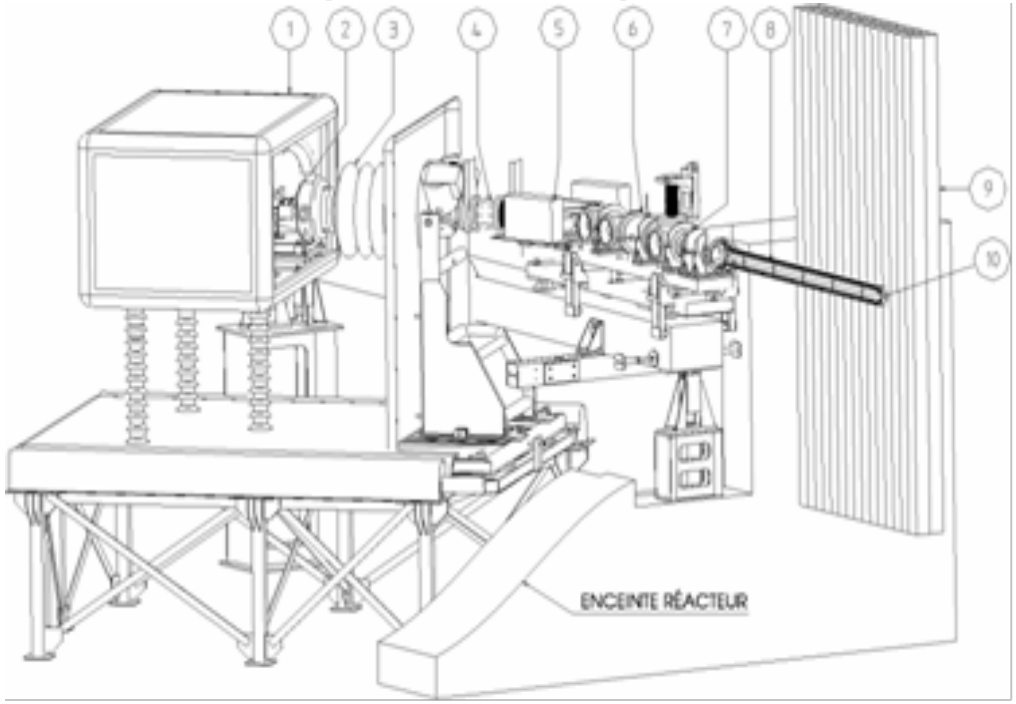
(From J. L. Biarrote, CNRS, France)

Beyond EUROTRANS



VENUS and GENEPI Acc. (GUINEVERE)

GENEPI Accelerator
(D-T neutrons)



1) High Voltage Head, 2) duoplasmatron,
3) accelerator tube, 4) quad Q1,
5) magnet, 6) quad Q2,
7) quad Q3, 8) quad Q4 + T2 part,
9) MASURCA tube, 10) target

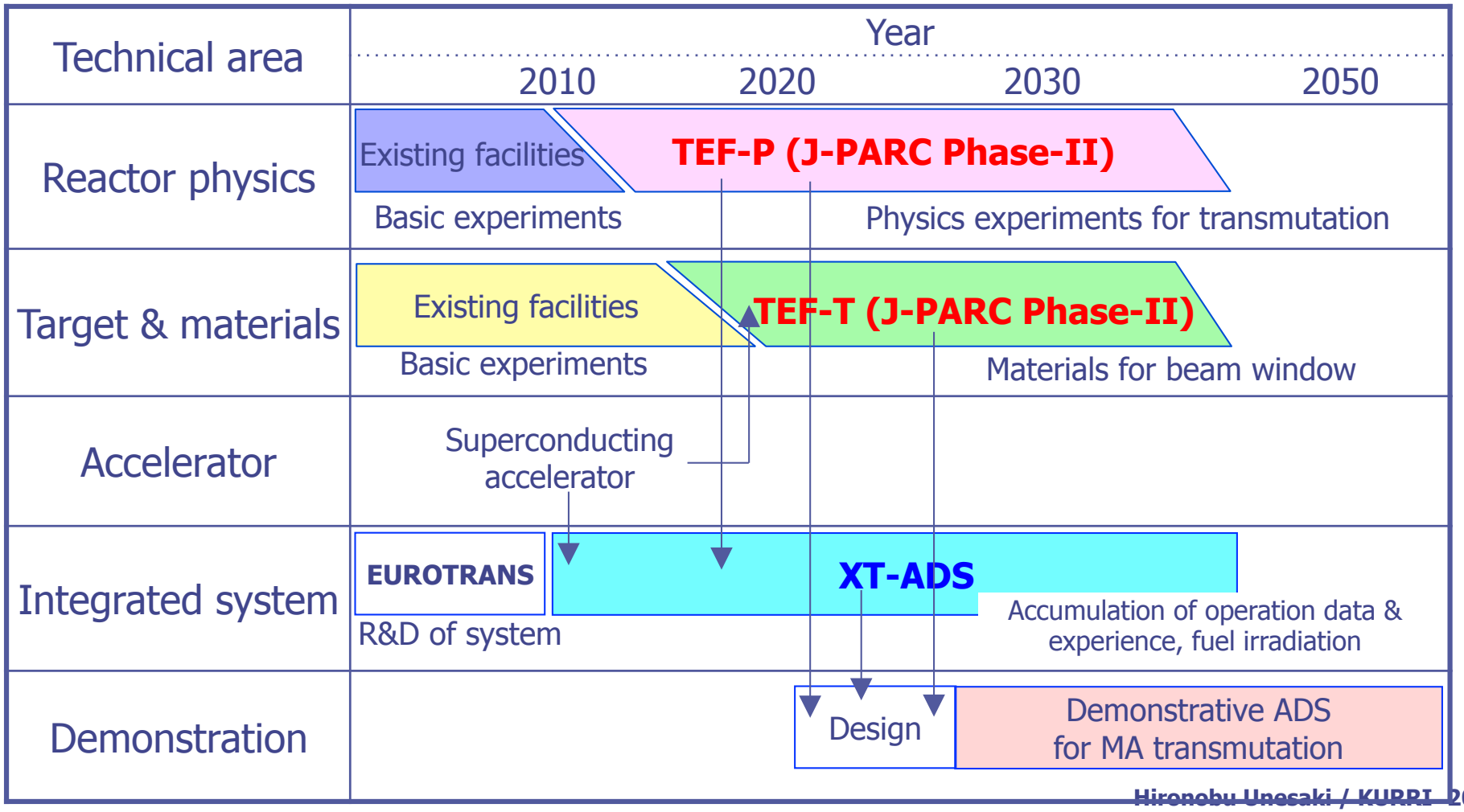
VENUS is a very flexible water moderated zero power facility used for accurate measurement in view of code validation

Fig. Subcritical Core @ VENUS

(From P. Schuurmans, SCK·CEN, Beligium)

Proposal of International Road Map for ADS（JAEA･Dr. Oigawa）

- International common roadmap can be established by **coupling TEF and XT-ADS** as complementary facilities.



Activities at IAEA CRP

- **IAEA CRP** meetings

"Research Coordination Meeting of the Coordinated "Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS),"

Purpose: international collaboration for verification and improvement of analysis methodology and nuclear data of ADS consisting of spallation target and subcritical multiplication system

18 countries, 43 participants

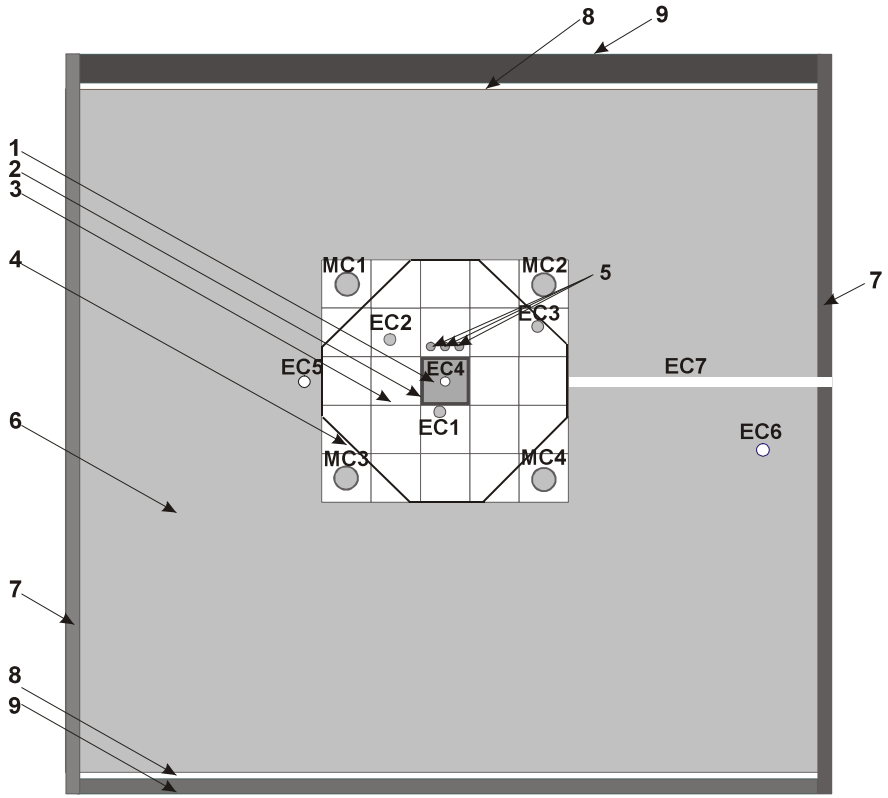
IAEA Benchmark Studies

YALINA (Belarus) (supported by ANL, US)

- YALINA - Thermal Benchmark
- YALINA - Booster Benchmark (Conversion of HEU to LEU)

X-Y cross-section of the YALINA-Thermal assembly, (65 mm < Z < 280 mm)

1 - Lead (Pb) target
2 - Stainless steel frame
3 - Core
4 - Outer boundary of fuel loading
5 - Holes for location of B_4C rods
6 - Graphite reflector
7 - Organic glass sheet
8 - Cadmium layer
9 - Upper and bottom plates made of steel with low content of carbon
EC1 - EC3, EC4 - experimental channels
MC1 - MC4 - measuring channels
EC7 radial
EC8 axial experimental channels in reflector



(From A. Kiyavitskaya, Belarus)

YALINA - Facilities

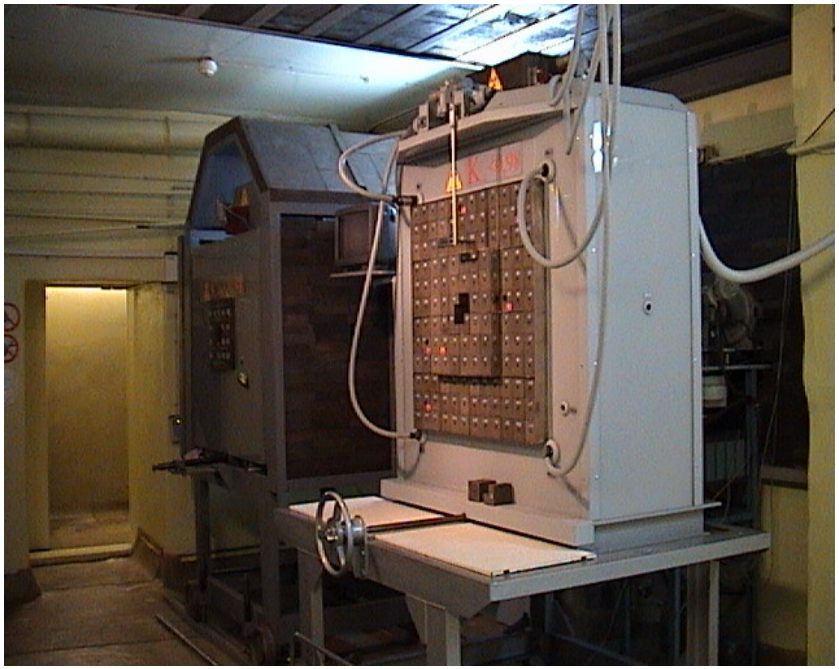


Fig. Subcritical facility YALINA: YALINA-Thermal (behind) and YALINA-Booster (front)

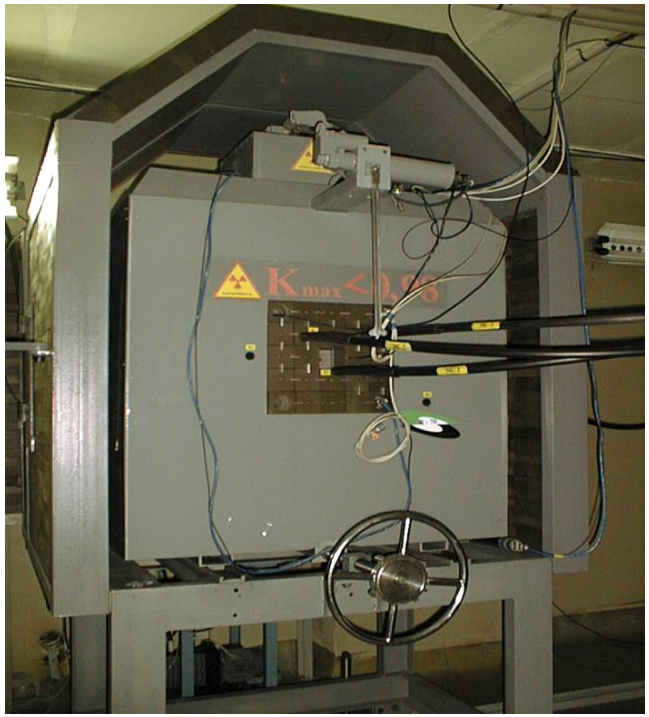


Fig. General view of YALINA-Thermal assembly

(From A. Kiyavitskaya, Belarus)

KUCA : Basic Exp. on ADS with 14 MeV Neutrons

✧ **Critical Assembly**
- Highly-enriched Uranium
- Polyethylene Reflector & Moderator
- Thermal neutron field
- Zero power reactor (Ave. mW order)

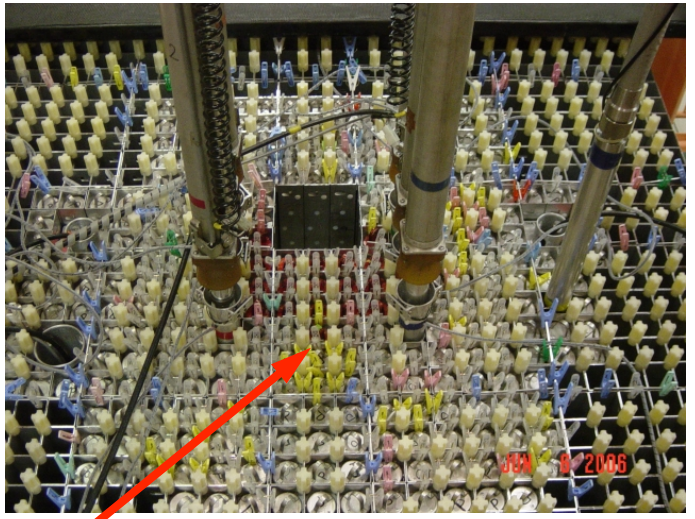


Fig. KUCA A-core

Tritium Target

14 MeV Neutrons

Fig. Cockcroft-Walton type Accelerator and Tritium Target

✧ **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} n/s, Intensity: 0.5 mA
- HV: 180 keV, Duty ratio: Max. 1%

KUCA A core

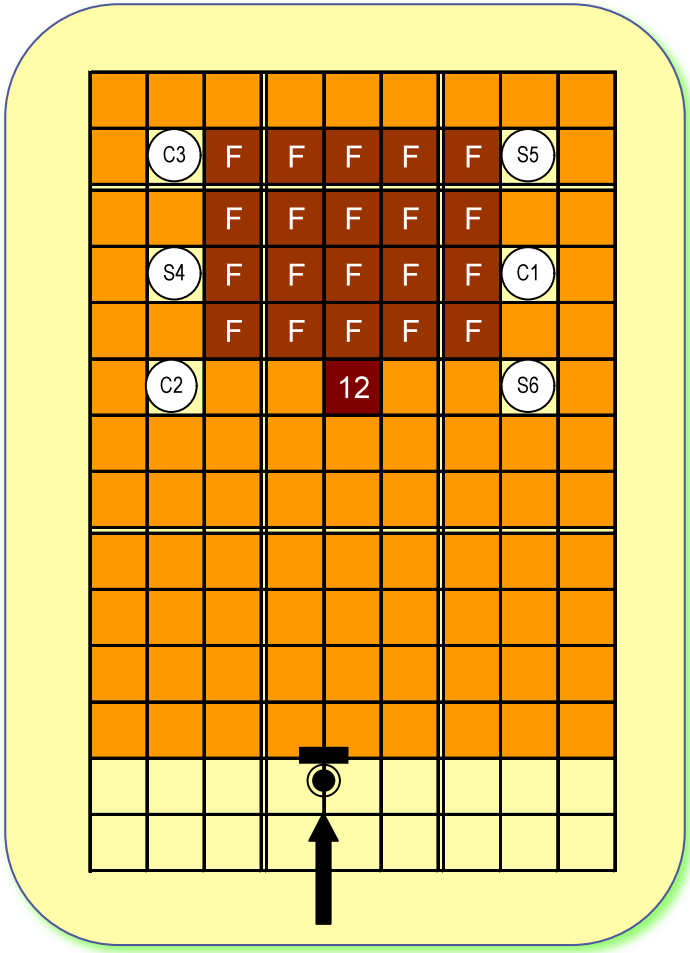


Fig. KUCA A-core (Reference core)

- KUCA A-core -

A solid-moderated and -reflected core

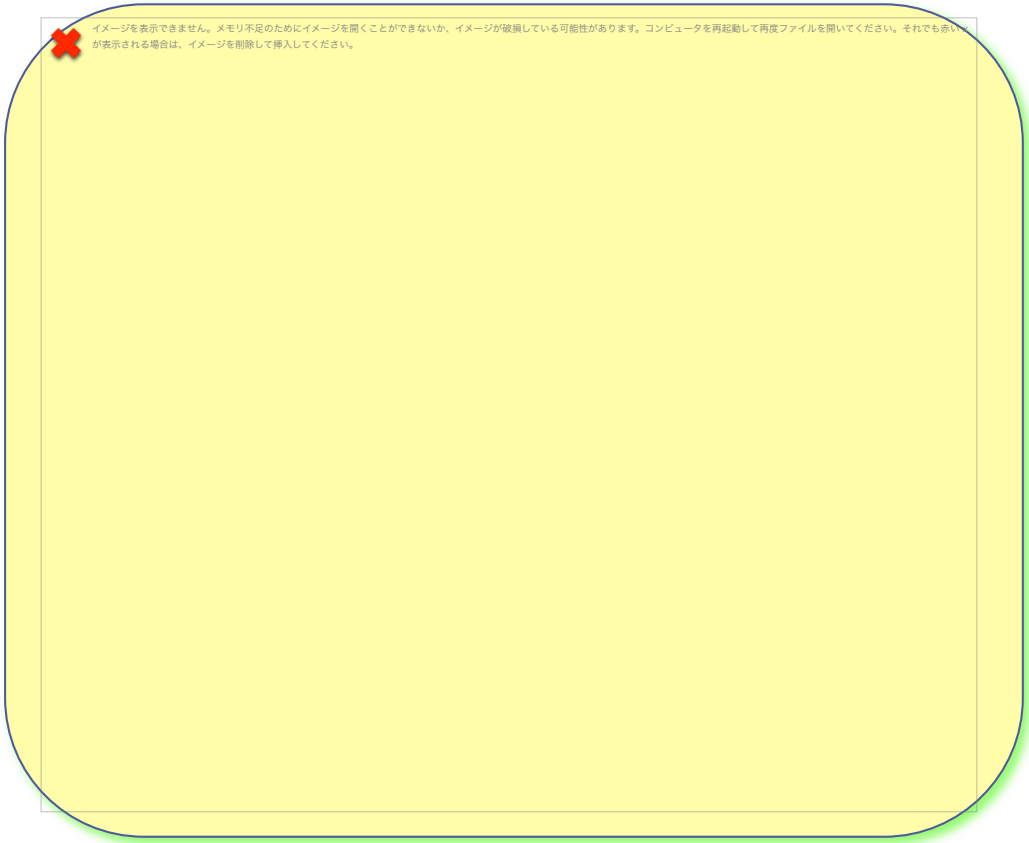


Fig. Image of KUCA A-core and fuel assembly loaded

Static Experiments (Phase 1)

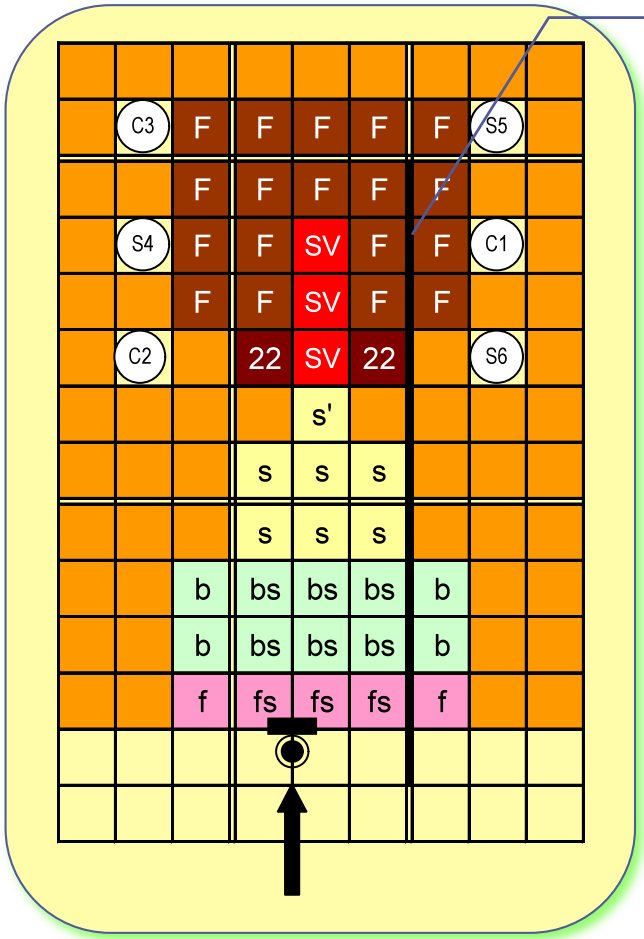


Fig. Neutron guide core

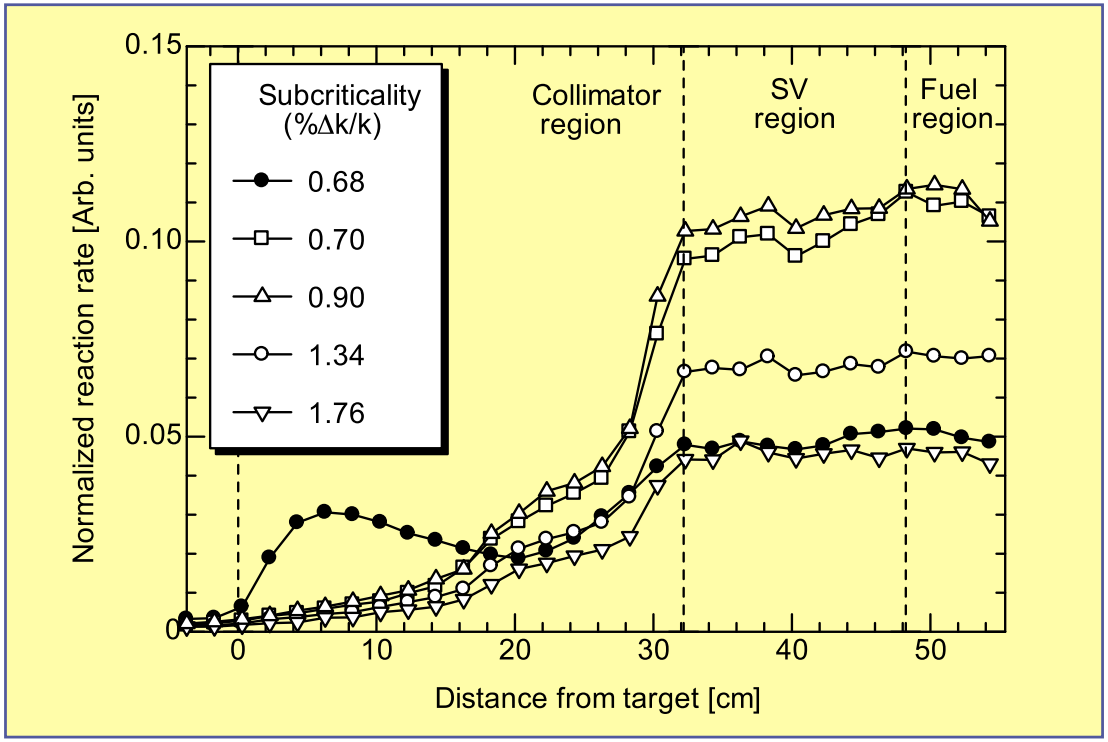


Fig. Measured Indium reaction rate distribution.

Reaction rate distribution (Foil activation method)

- ✓ Measure ^{115}In (n, γ) ^{116m}In (Exp. error: 5%)
- ✓ Examine effects on subcriticality & core configuration
- ✓ Optimize neutron guide and beam duct size

Kinetic Experiments (Phase 2)

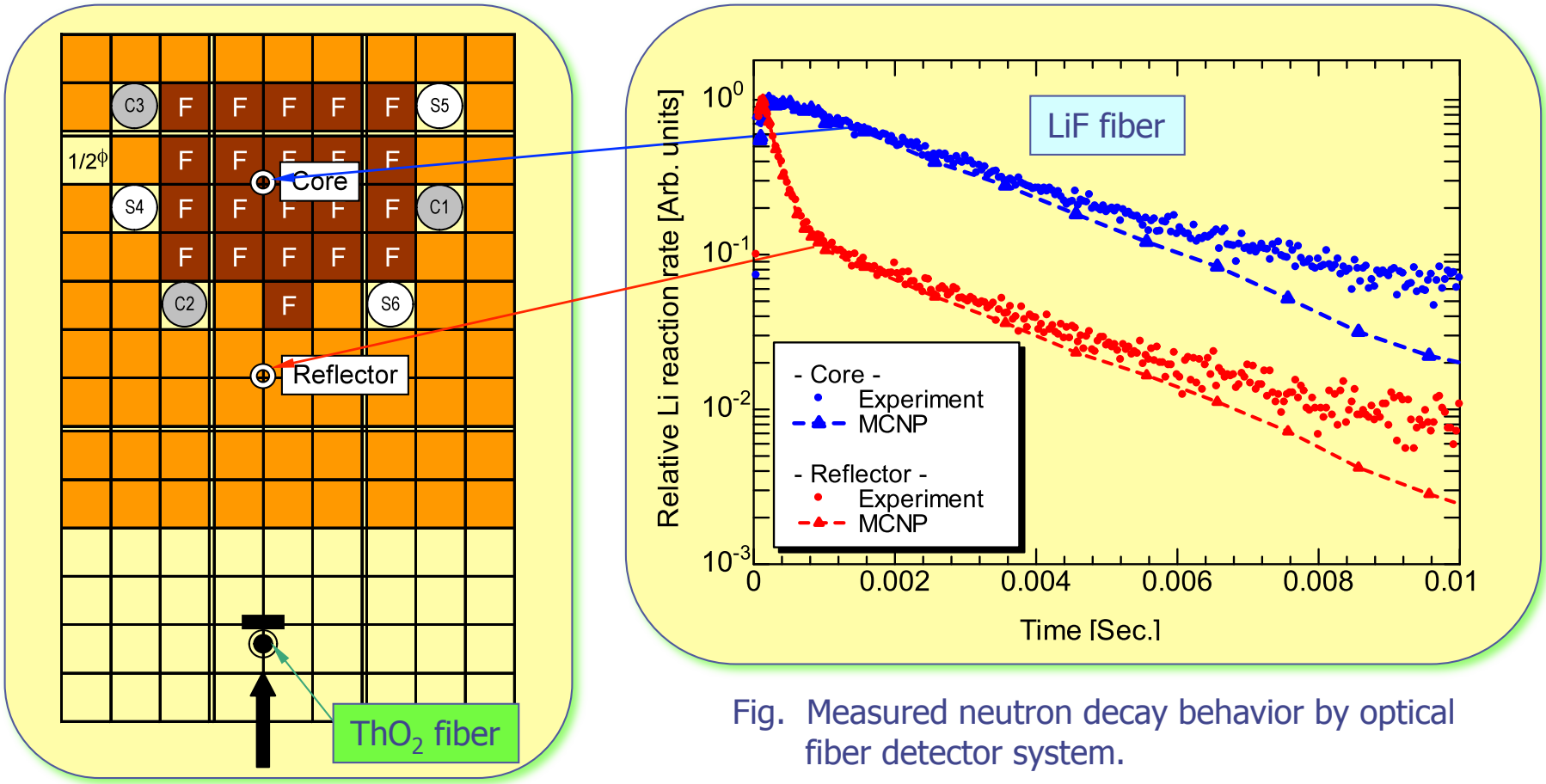
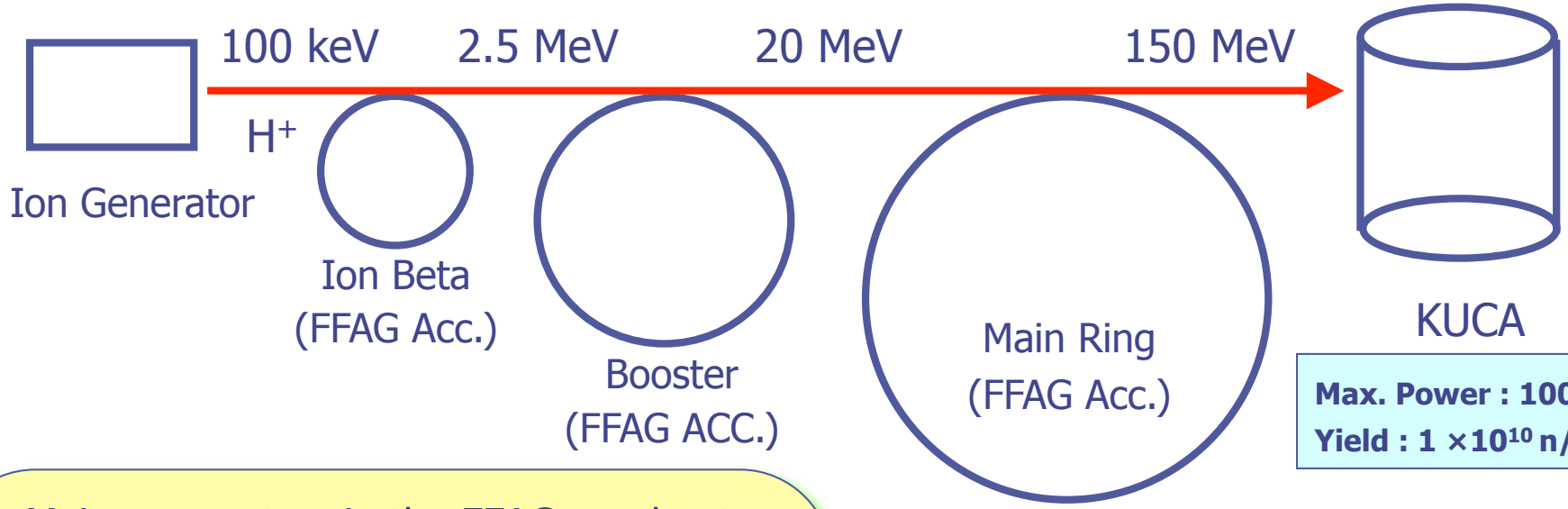


Fig. Measured neutron decay behavior by optical fiber detector system.

Pulsed neutron method (PNM)

- ✓ Good evaluation of subcriticality at both core and reflector positions
- ✓ Examination of validity of methodology and position dependency

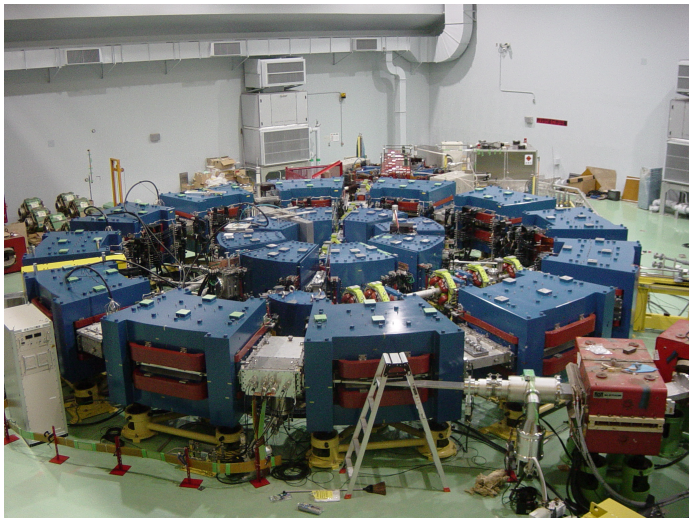
Image of ADS by FFAG Accelerators



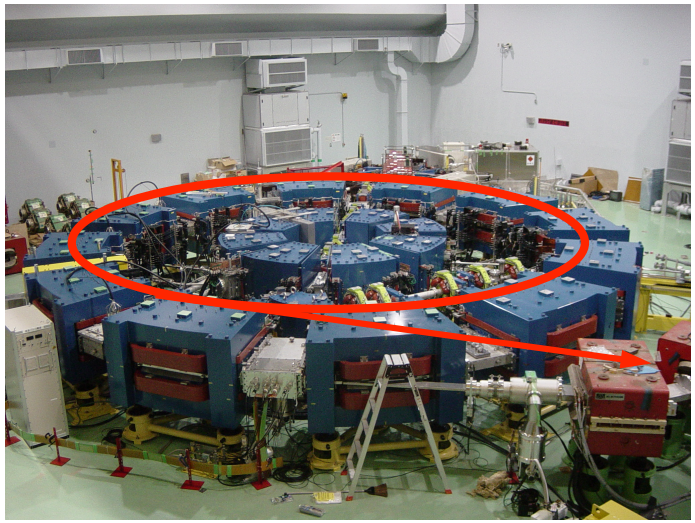
Max. Power : 100 W
Yield : 1 ×10¹⁰ n/s

Main parameters in the FFAG accelerator

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



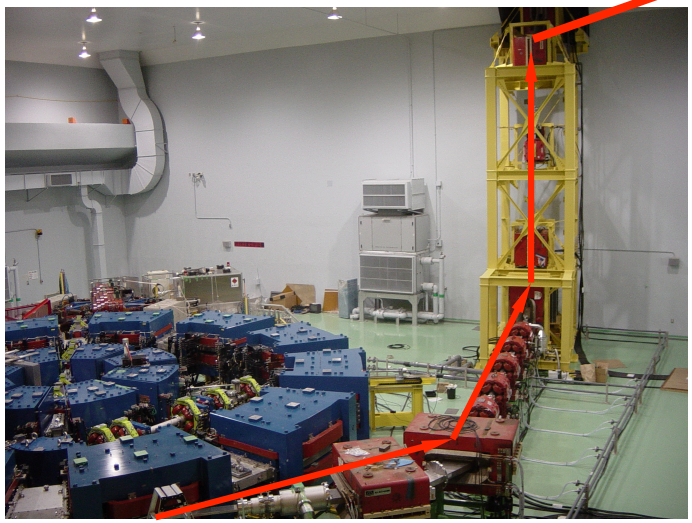
KUCA A-core & FFAG Accelerator

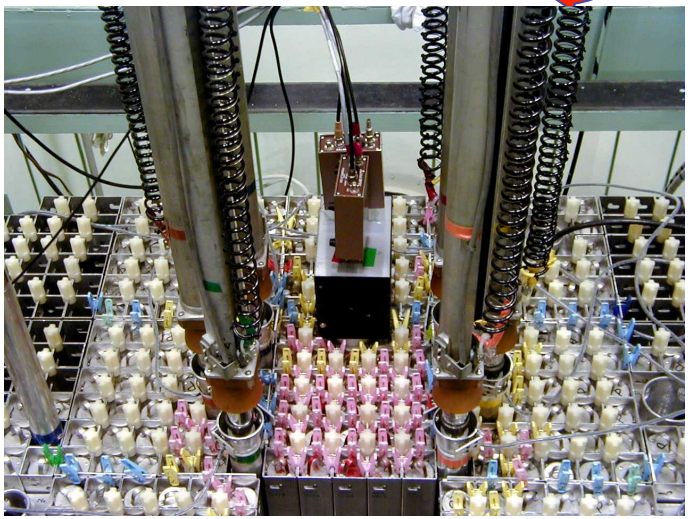


FFAG Accelerator

KUCA A core

150 MeV Proton Beam Line





FFAG-KUCA ADSR experiment : First Data

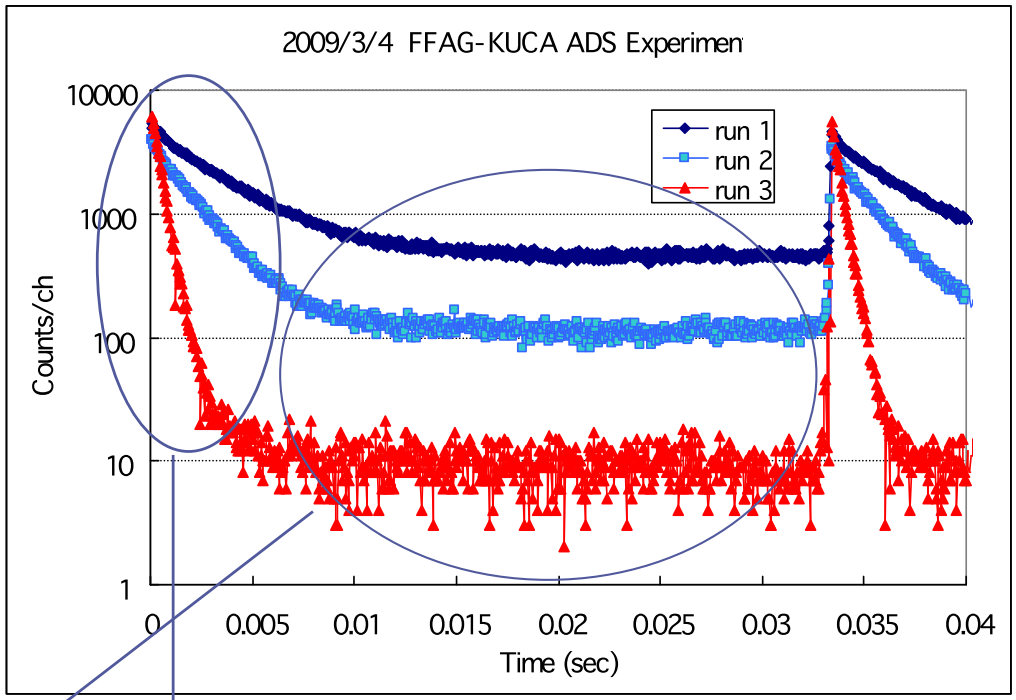
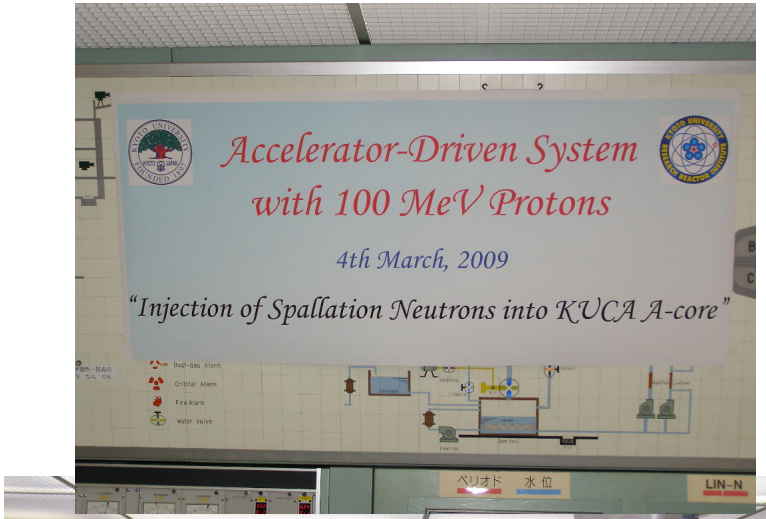


Fig. Time series of neutrons

prompt neutrons showing rapid decay

Delayed neutrons in core



Reaction Rate Distribution (In wire, Axial direction)

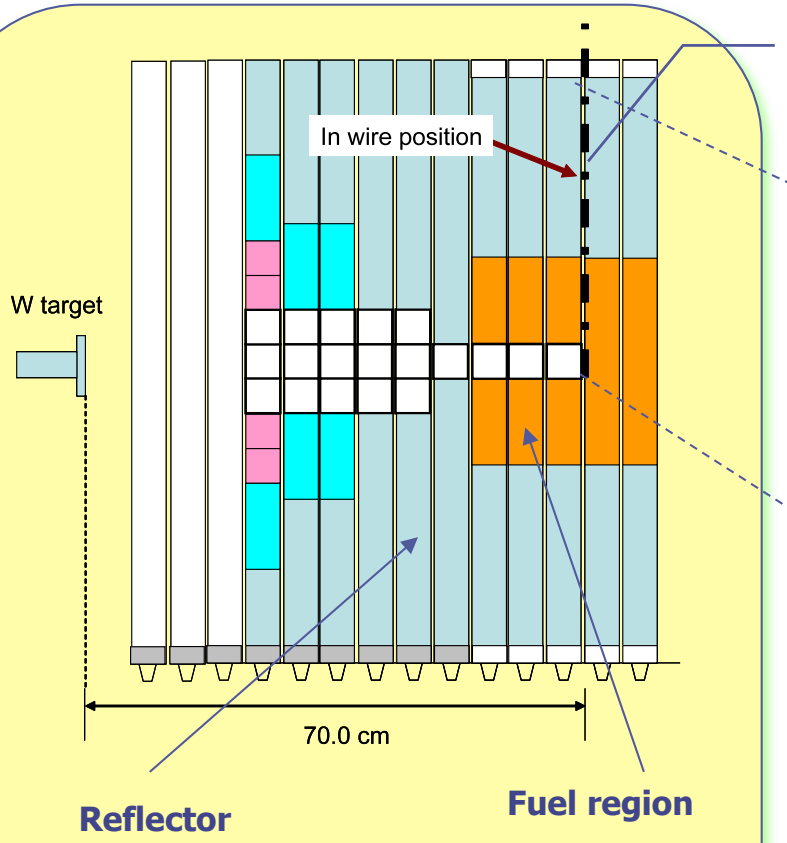


Fig. Side view of ADS core in KUCA A-core

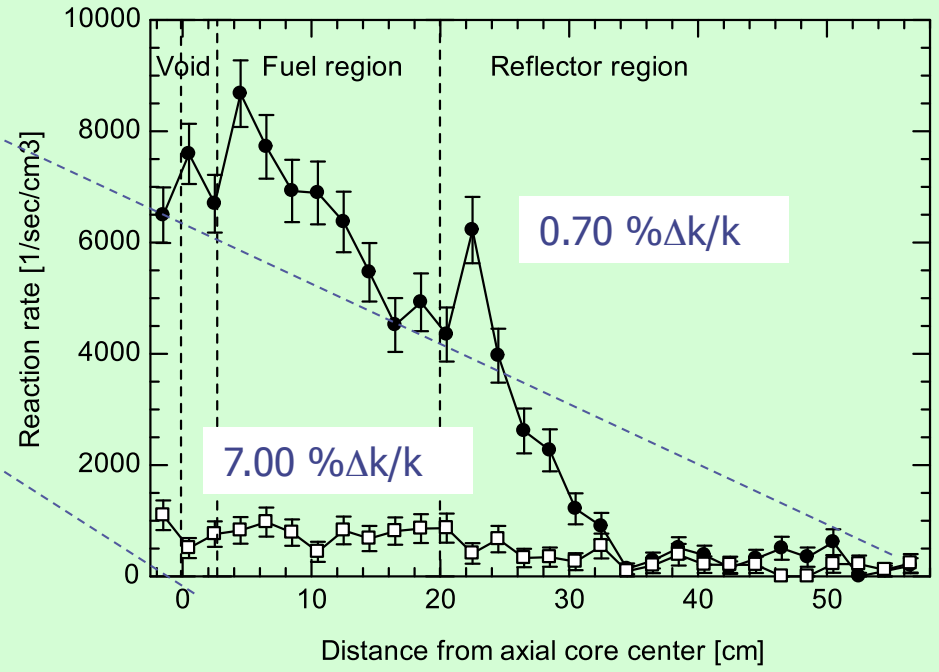


Fig. Reaction rate distribution by In wire

Reaction rate distribution

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

Summary of current status on ADSR research

- many activities on ADS development at Europe (through OECD/ NEA and IAEA) ; EUROTRANS programme
- increased interest from IAEA Benchmark community to KART (FFAG-KUCA) results for 100 MeV proton
- many activities on spallation target studies : spallation reaction mechanism, heat removal
- further studies in reactor physics and reactor design required ; definition of *k*-source and kinetic parameters,
- validation and verification of ADSR design methodology and related nuclear data