Introduction to ADSR

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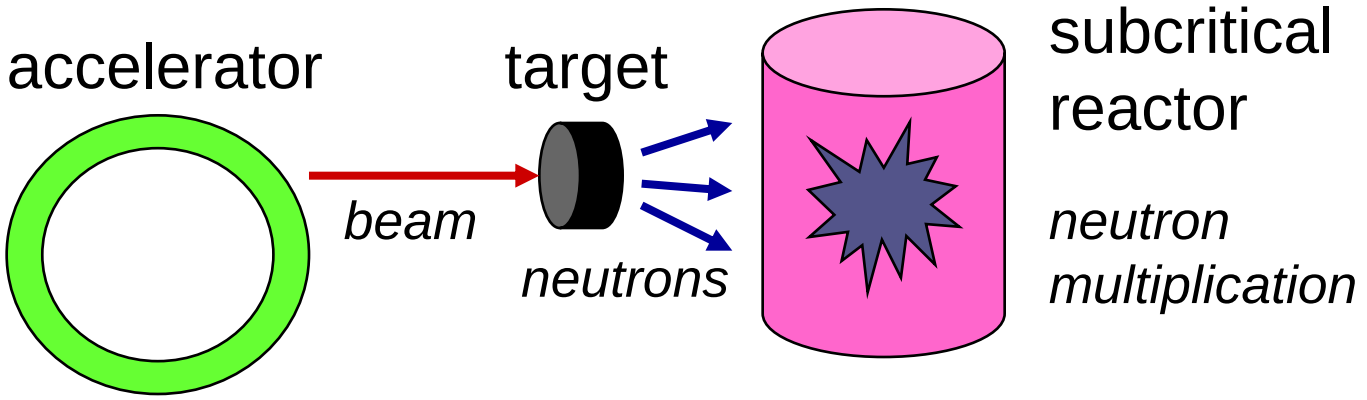
- Concept and Purpose, Basics of ADSR
- ADSR projects and studies
- ADSR studies at KURRI: KART Project

ADSR : Concept and Purpose

ADSR=Accelerator Driven Subcritical Reactor

(ADS = Accelerator Driven System)

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



ADSR : Subcritical Reactor

Subcritical Reactor

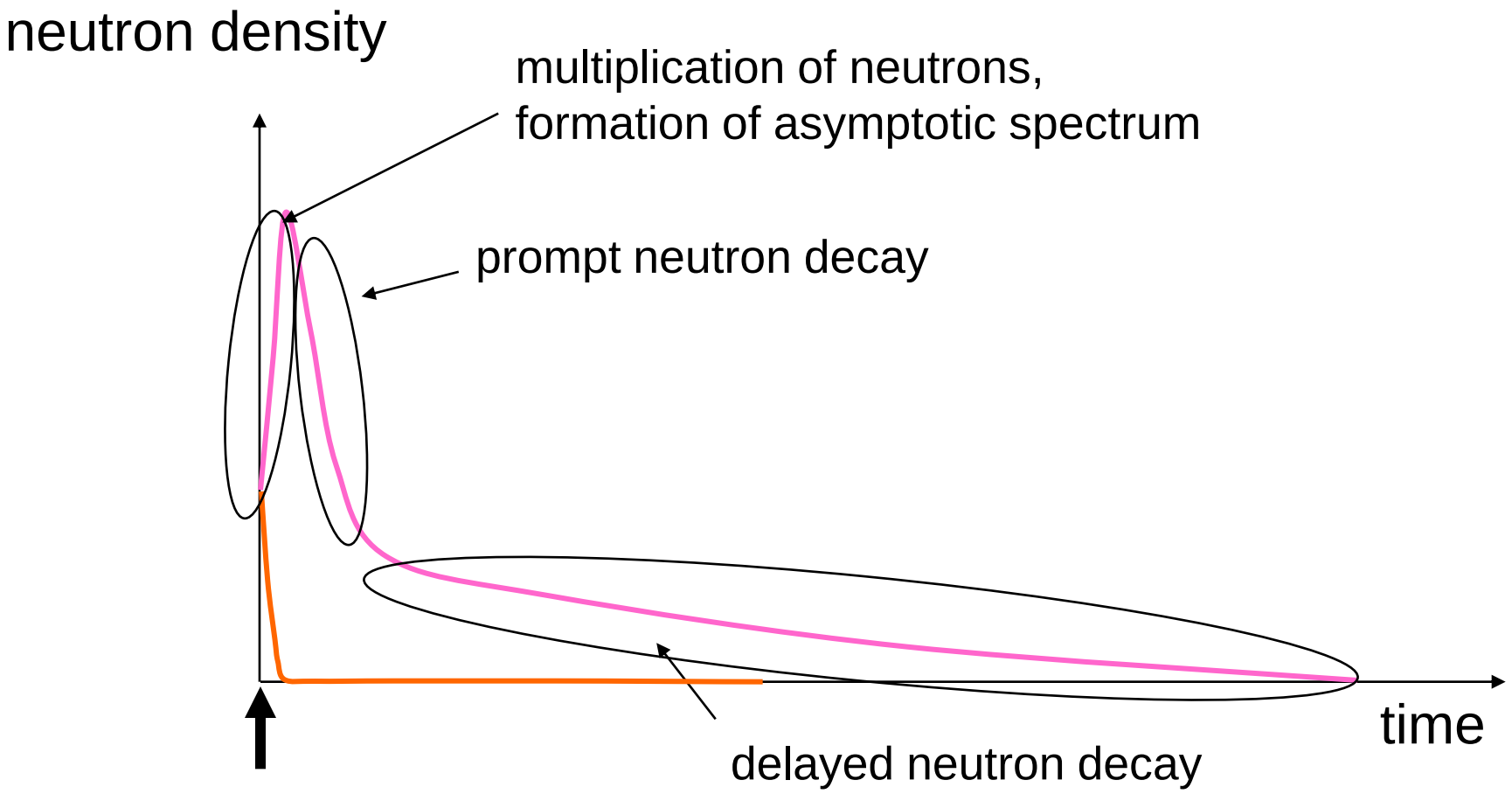
- nuclear reactor with fuel material not sufficient to sustain the fission chain reaction

(neutron production by fission) < (neutron loss by absorption & leakage)

- neutron population in the reactor fades away with time, unless there is no continuous supply of neutrons (i.e. no external neutron source)

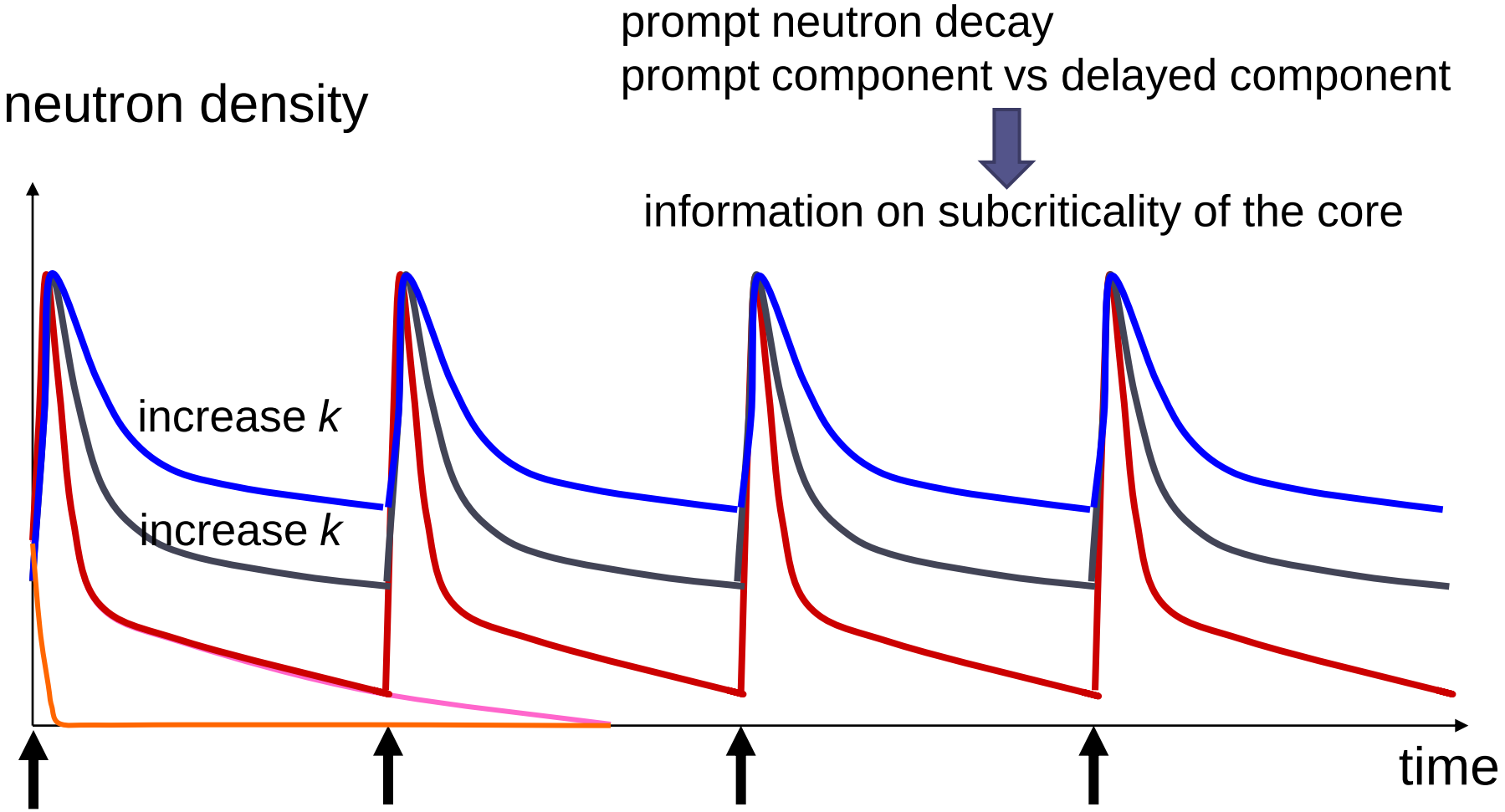
- neutrons supplied from external source is multiplied in the reactor ; the magnitude of the multiplication is determined by parameter *k*, the "multiplication factor" which indicates how "close" the reactor is to the critical state.
  - ✓ k=1 when the reactor is critical; k<1 for a subcritical reactor
  - ✓ neutrons supplied will be multiplied by 1/(1-k)

Neutron Multiplication in a Subcritical Reactor

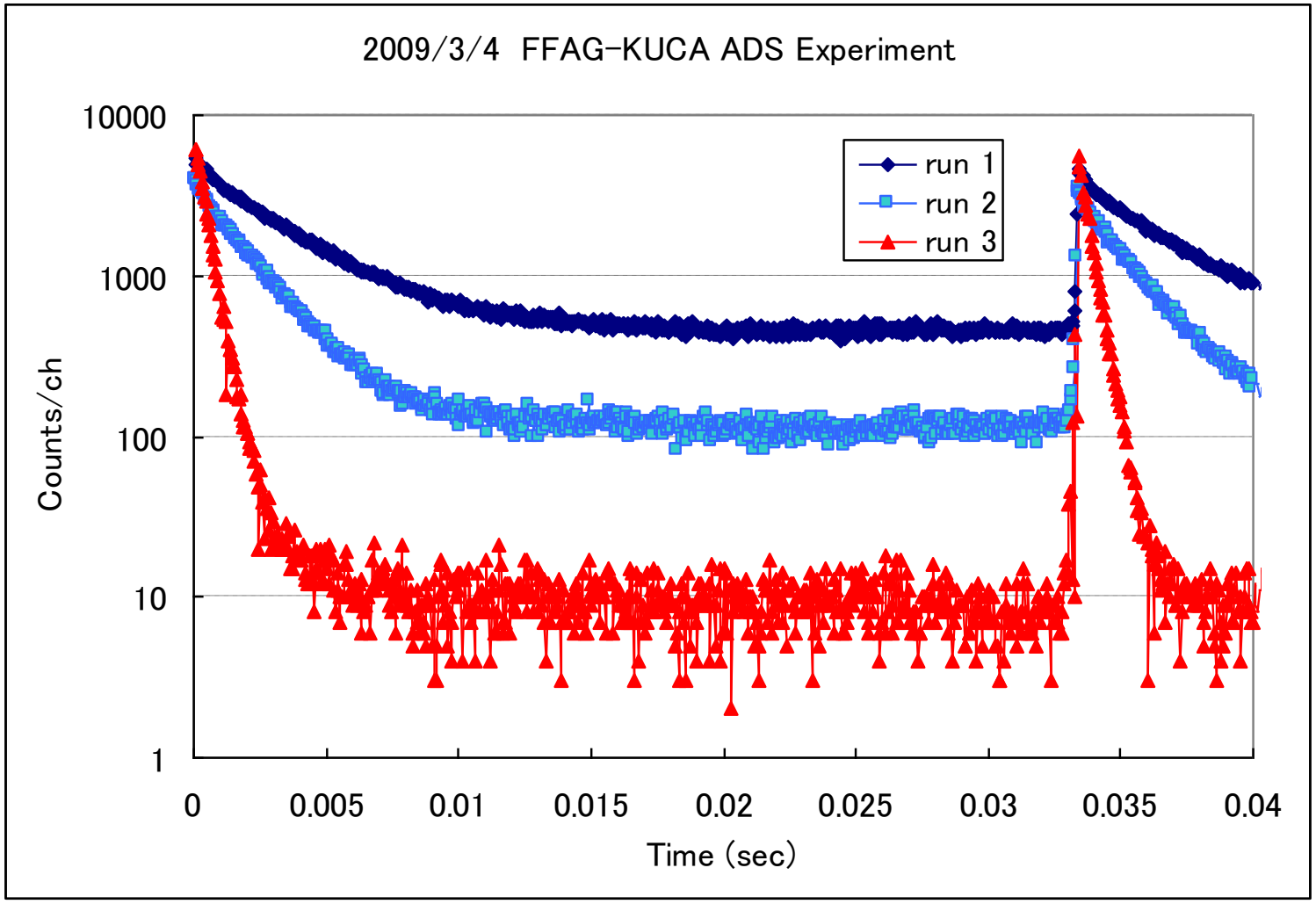


Neutron Multiplication in a Subcritical Reactor

prompt neutron decay
prompt component vs delayed component



Neutron Multiplication in a Subcritical Reactor



ADSR : why interesting ?

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

ADSR : Purpose ?

➢energy production by nuclear fission :

if [energy required for accelerator] < [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 minor actinides (Np, Am, Cm, etc.) and long-life fission products (LLFPs: Tc-99, I-129 etc.), high-hazardous fission products (Sr-90, Cs-137, Rh, Pd etc) in the spent nuclear fuel waste → ADSR as **nuclear transmutation / incineration facility**

ADSR-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 TEF-P & TEF-T (JAEA、Japan)
- **KART (FFAG+KUCA, Kyoto Univ., Japan)**

Activities related to ADSR

- 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)

EUROTRANS : XT-ADS

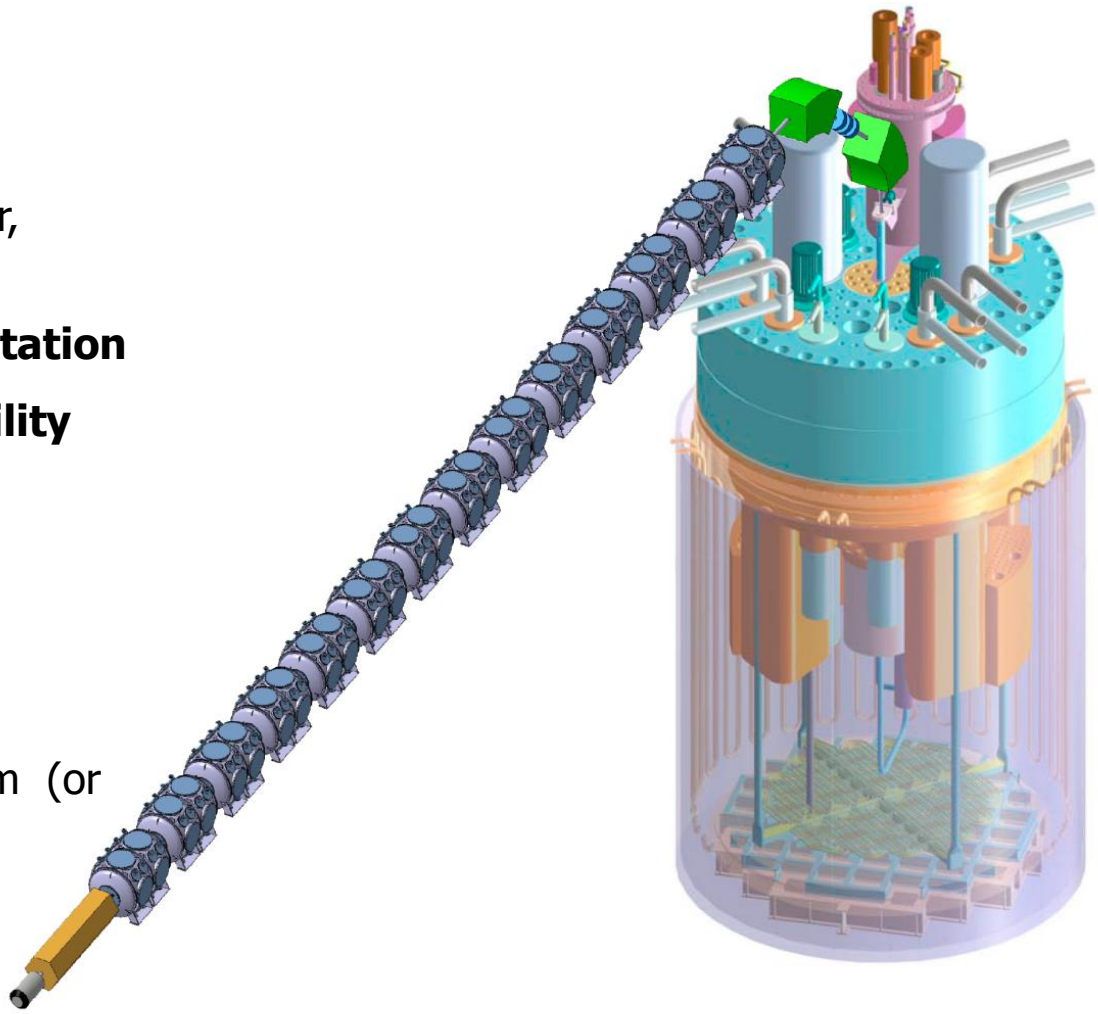
XT-ADS (ADS prototype)

Goals:

- **Demonstrate the concept** (coupling between accelerator, spallation target & reactor),
- **Demonstrate the transmutation**
- **Provide an irradiation facility** and an EFIT test bench

Features:

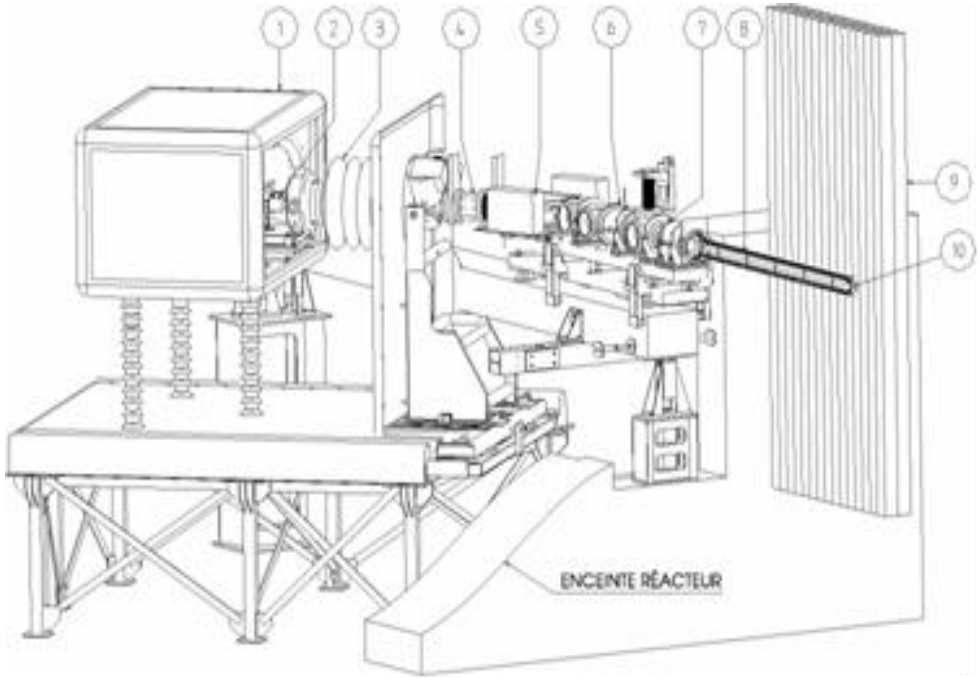
- 50 - 100 MWth power
- keff around 0.95
- 600 MeV, 2.5 mA proton beam (or 350 MeV, 5 mA)
- Conventional MOX fuel
- Pb-Bi Eutectic coolant



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

GENEPI + VENUS (GUINEVERE)

GENEPI Accelerator
(D-T neutrons)



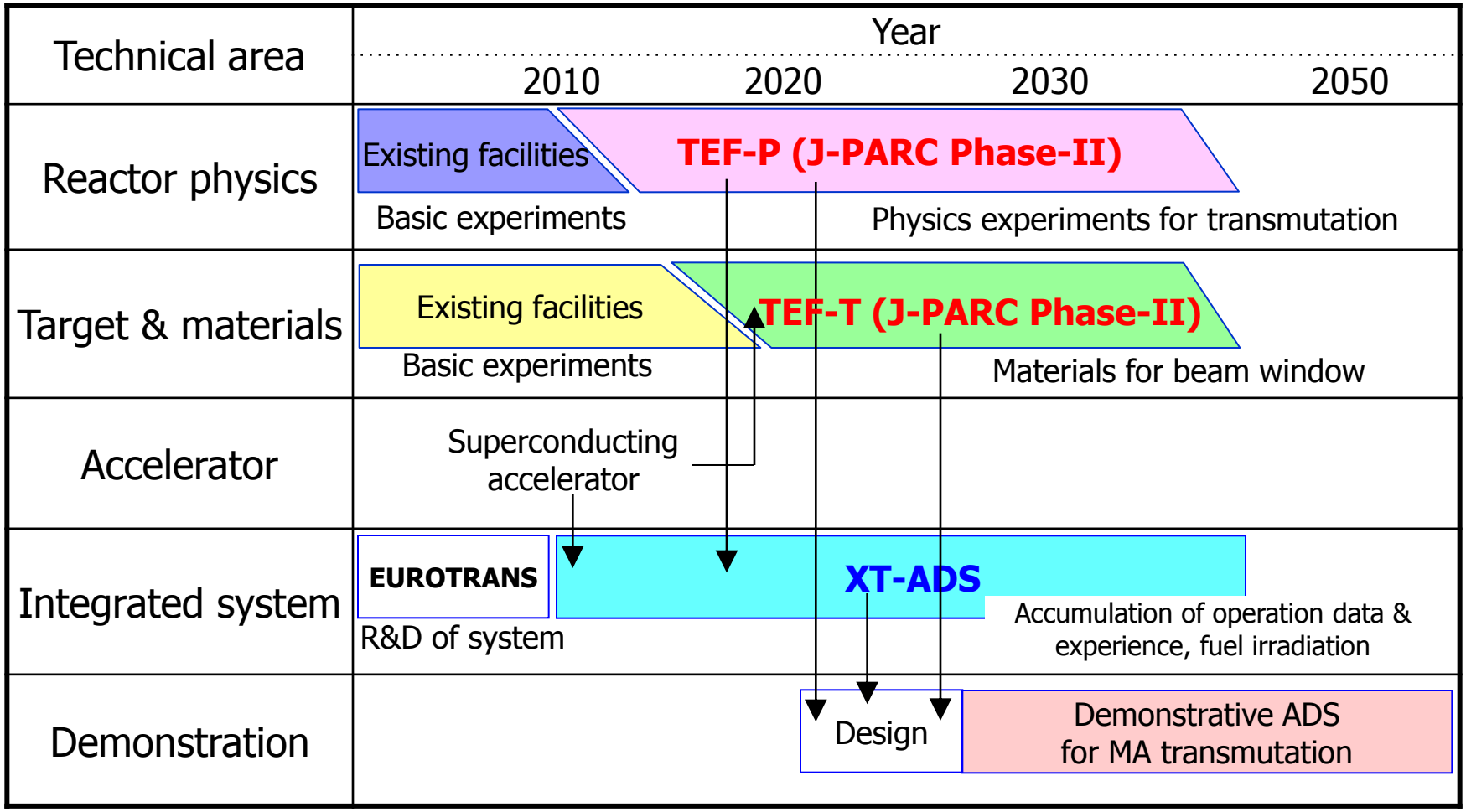
1) High Voltage Head, 2) duoplasmatron,
3) accelerator tube, 4) quad Q1,
5) magnet, 6) quad Q2,
7) quad Q3, 8) quad Q4 + T2 part,
9) MASURCA tube, 10) target

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

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

Proposal of International Road Map for ADS (JAEA-Japan)

- 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

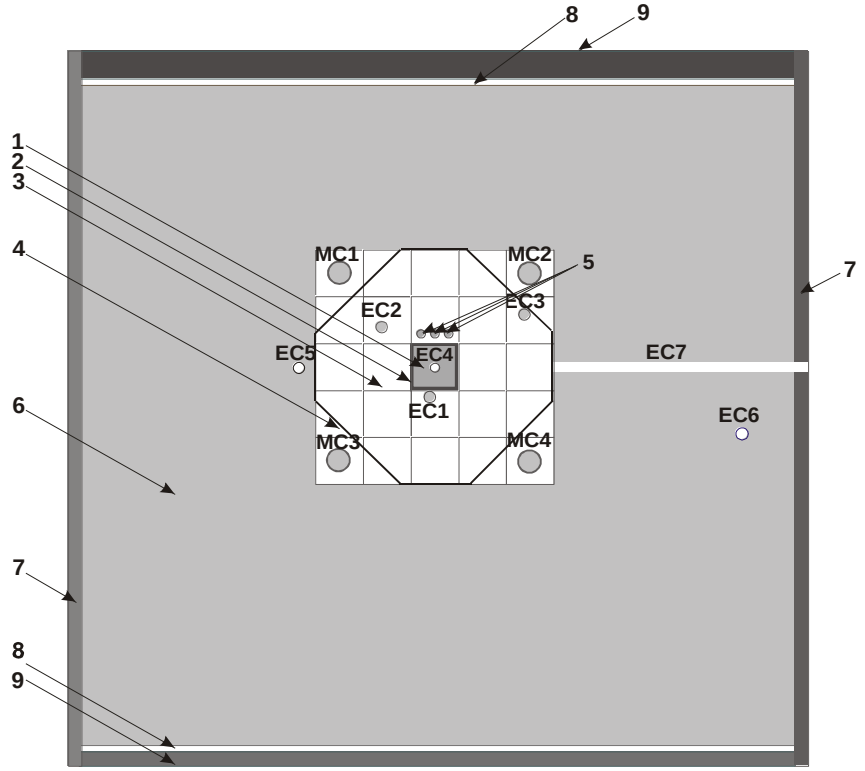
IAEA Benchmark Studies

YALINA (Belarus) (supported by ANL, US)

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

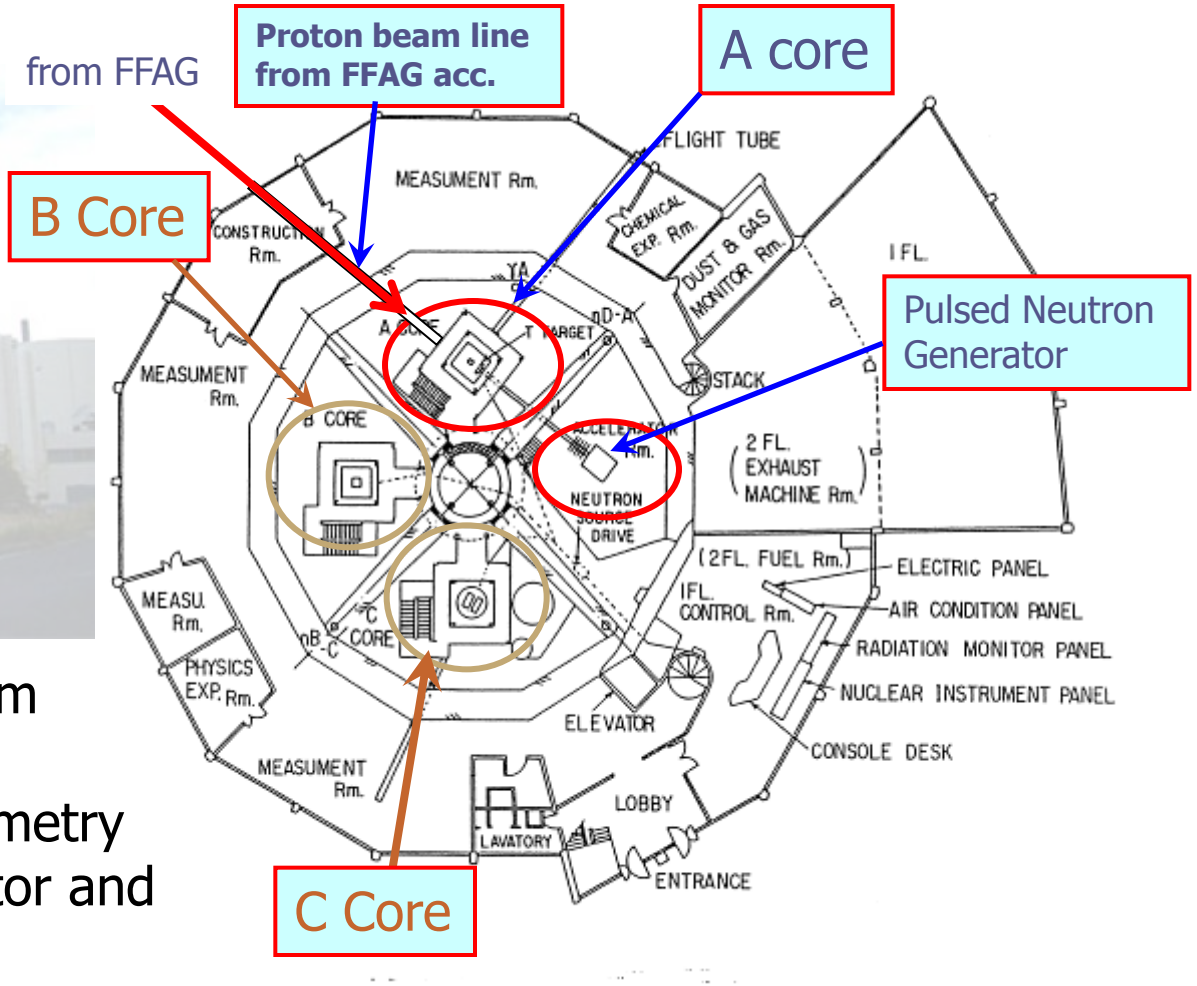
X-Y cross-section of the YALINA-Thermal assembly, (65 mm < Z < 280 mm)

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)

KUCA (Kyoto Univ. Critical Assembly)



- Three cores in reactor room
- Wide variety of material composition and core geometry
- Combined use of accelerator and subcritical core

KUCA : Basic Exp. on ADSR using (D,T) 14 MeV Neutrons

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

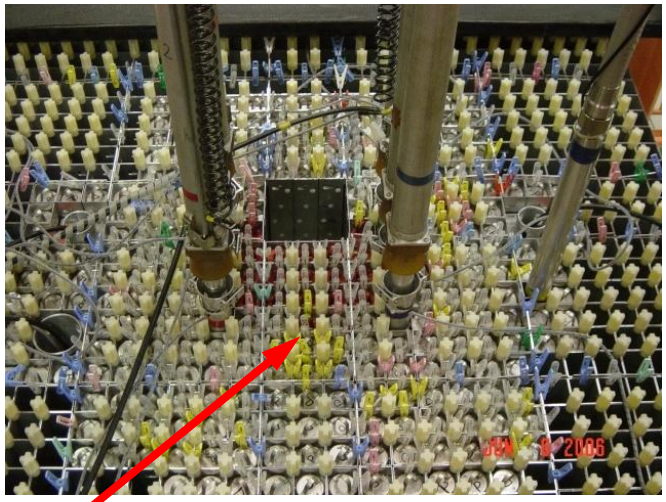


Fig. KUCA A-core

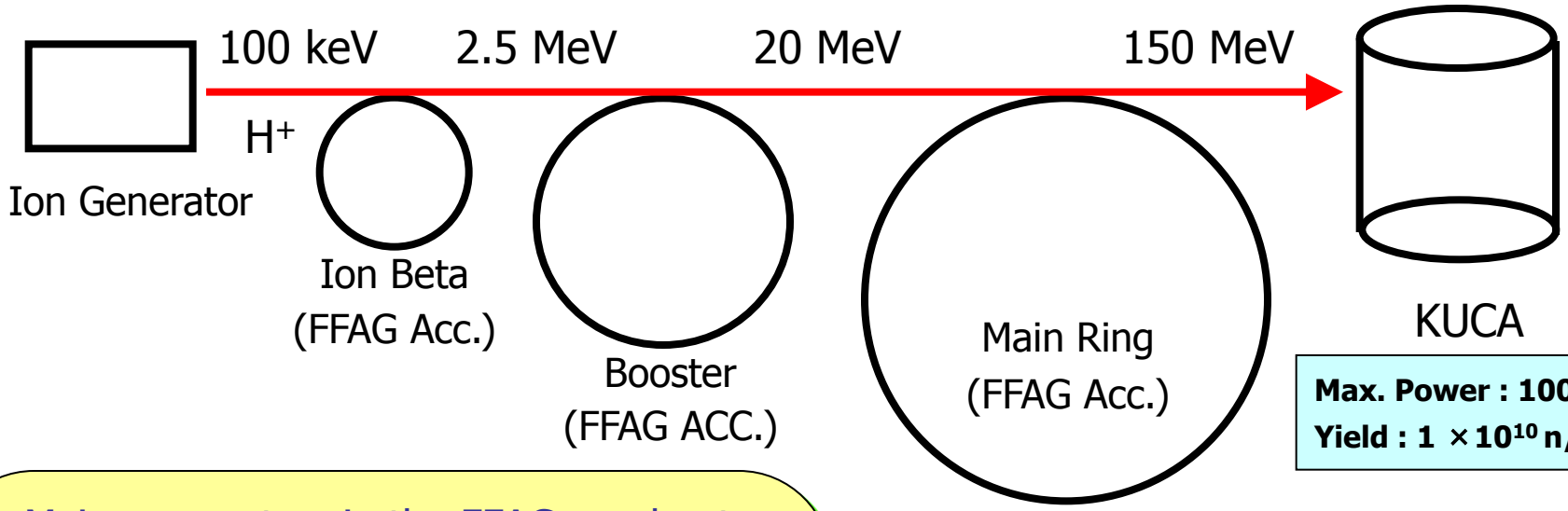
Tritium Target

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%

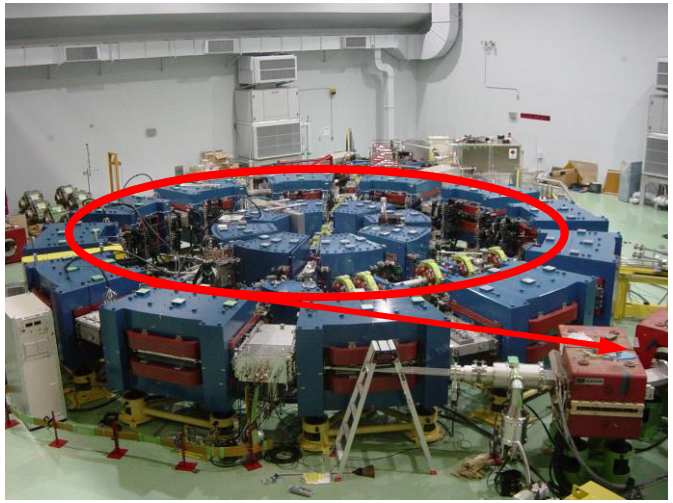
Image of KART ADSR by FFAG complex + KUCA



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

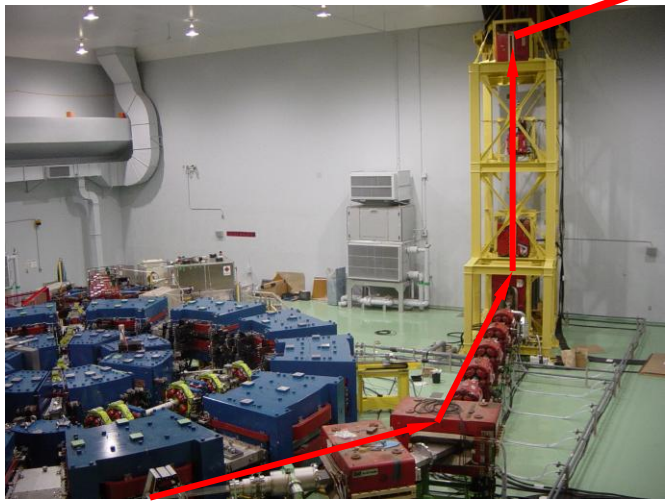
KART (FFAG + KUCA)

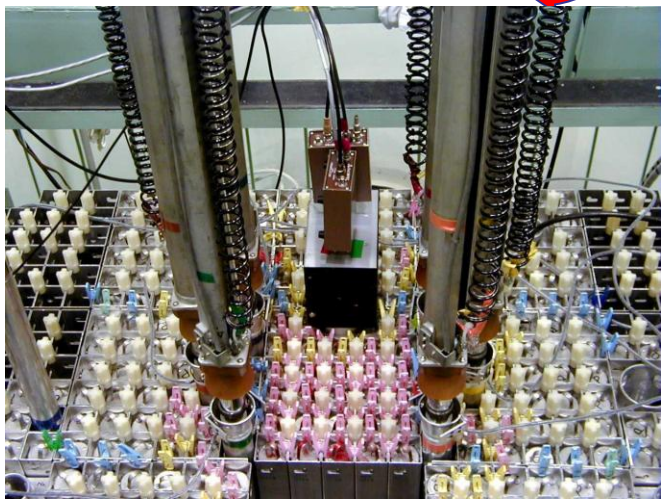


FFAG Accelerator

KUCA A core

150 MeV Proton Beam Line





FFAG-KUCA ADSR experiment : First Data

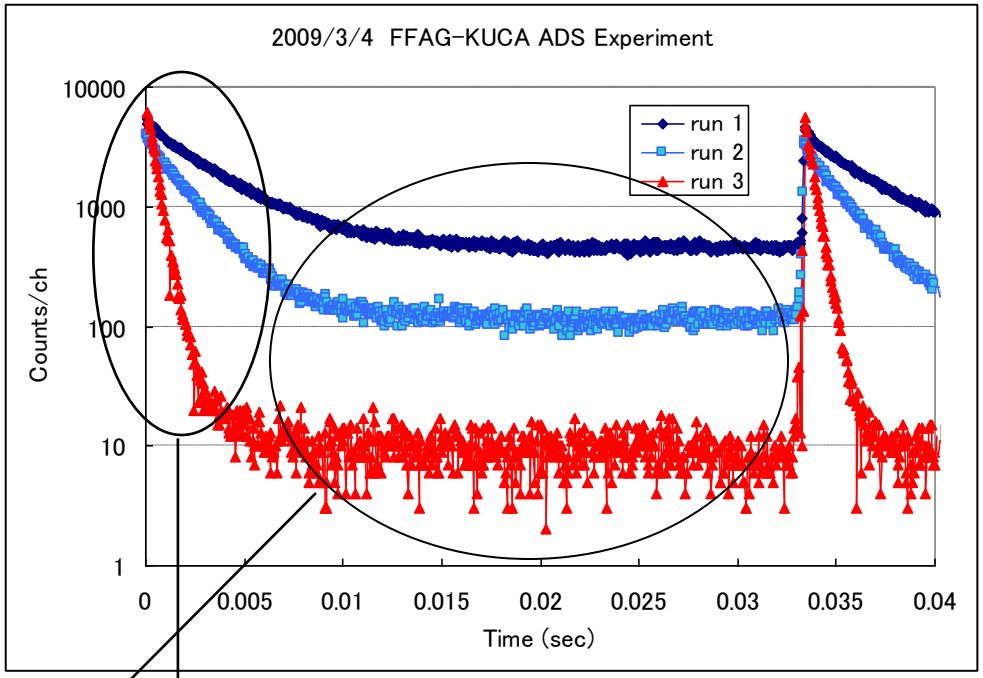
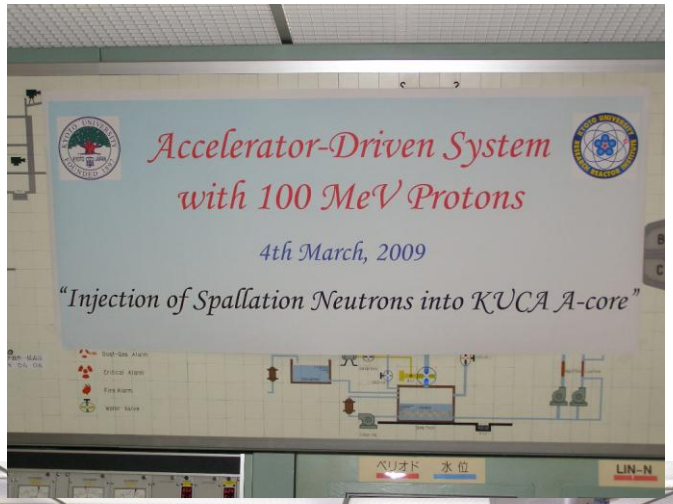


Fig. Time series of neutrons

prompt neutrons

Delayed neutrons



Reaction Rate Distribution (In wire, Axial direction)

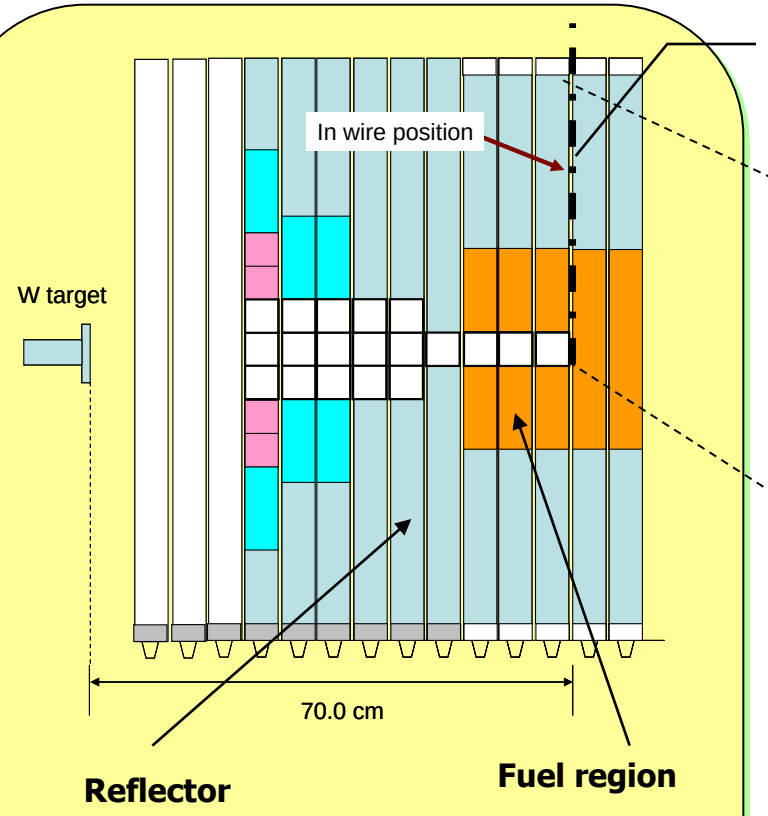


Fig. Side view of ADS core in KUCA A-core

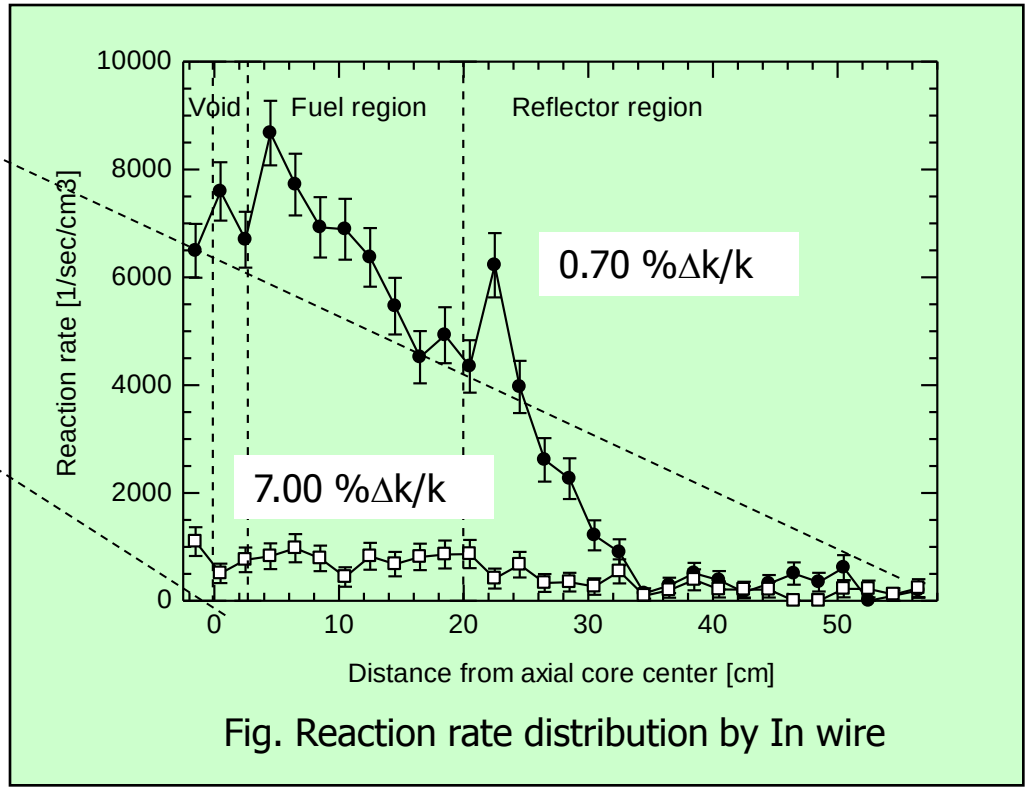


Fig. Reaction rate distribution by In wire

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: the only existing facility for ADSR experiments with proton + subcritical core
- many activities on spallation target studies : spallation reaction mechanism, heat removal
- further studies in reactor physics and reactor design required ; definition and measurement of multiplication factor and kinetic parameters
- validation and verification of ADSR design methodology and related nuclear data required for future development

Thank you for your attention.