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International Conference on Research Reactors: Safe Management and Effective Utilization

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RACE-T Experimental Activities
An overview of the subcritical measurements preliminary to the accelerator coupling experiment

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Presentation Content

- Preamble
- RACE-T generalities
- Fission rates radial traverses
- Subcritical level measurements
- Special Devoted Instruments
- Conclusions

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Preamble

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- The objective of the European Integrated Project EUROTRANS of the EURATOM 6th Framework Program is to bring answers to the high level nuclear waste transmutation in ADS. The EUROTRANS experimental activities have been joined into the ECATS domain, namely Experiment on the Coupling of an Accelerator, a spallation Target and a Subcritical blanket.
- The RACE-T experiment, formerly named TRADE, is part of ECATS. The experimental campaign was held in the period 2004–2006 in the TRIGA RC-1 reactor, operated by ENEA at the Casaccia research center near Rome, in order to propose experimental techniques for absolute reactivity calibration at either startup or shutdown phases.
- RACE-T includes fission rate measurements (performed with a special instrumented fuel element), investigation of different subcritical configurations (with D/T generator in the core center), and development of special devoted instrumentation and acquisition systems.

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RACE-T Generalities

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- **Selected RACE-T campaign results**

  - **Characterization of the critical phase performed by fission rate traverses.**
  - **Evaluation of the applicability of various experimental techniques for assessing a subcritical level. Those techniques are based on:**
    - ✓ **The system response to a pulsed neutron source, in particular the Area-ratio method obtained by a D-T generator.**
    - ✓ **The system response to a Source Jerk (SJ), in particular the Inverse Kinetics method applied to a SJ obtained by a D-T generator.**
    - ✓ **The Source Multiplication technique.**
  - **Reactivity estimates were performed at different core locations and for three different “clean” (control rods withdrawn) subcritical core configurations, namely SC0 (~ -500 pcm), SC2 (~ -2500 pcm) and SC3 (~ -5000 pcm).**

RACE-T Generalities: Neutron Sources

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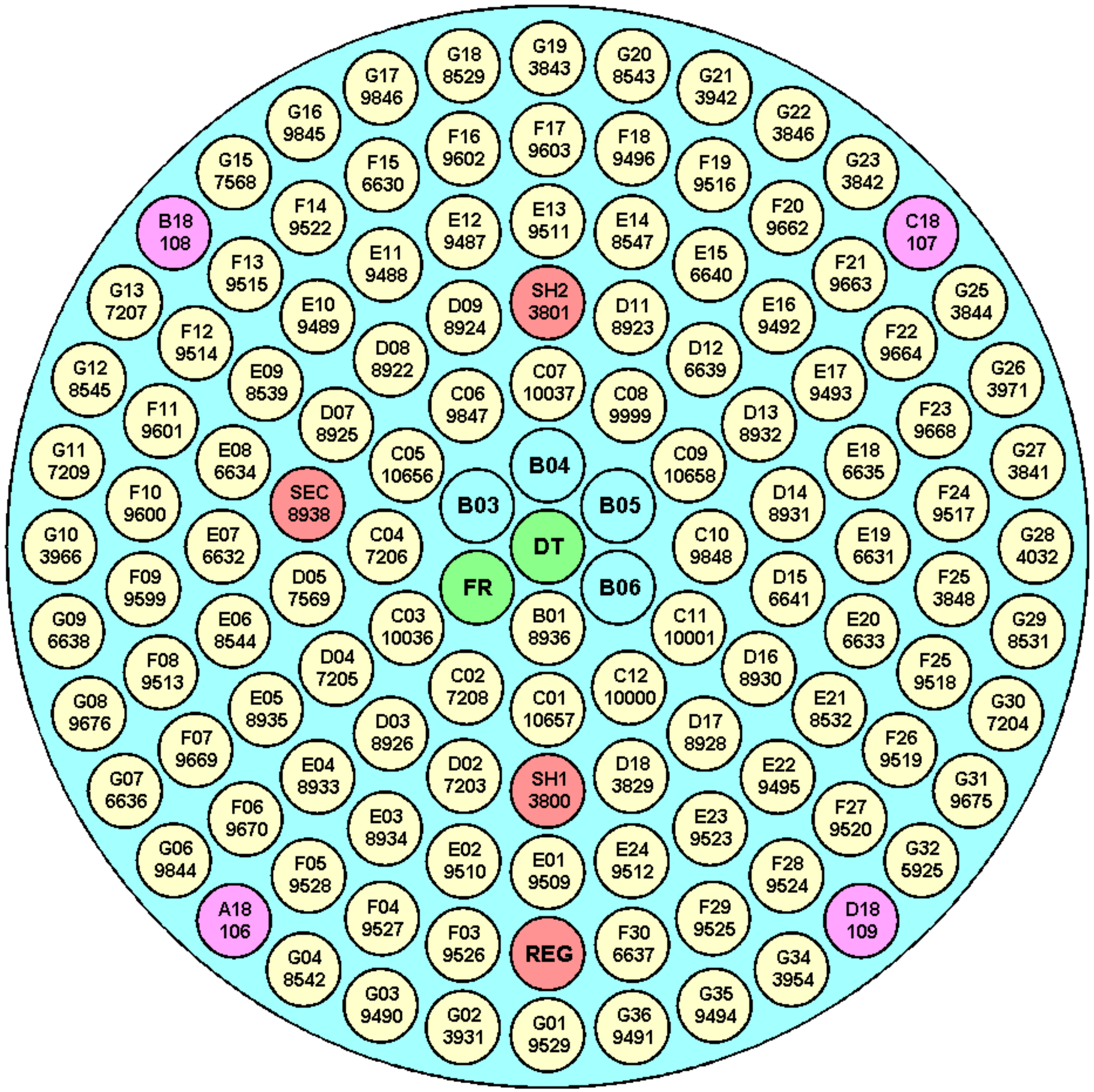
- **For the subcritical configurations, the reactor was coupled with the following neutron sources:**

  - **A pulsed deuterium-tritium neutron generator, accelerating deuterium ions onto a tritium target, and producing 14.1-MeV-neutron bursts with strength of 2x10^8 n/s at maximal frequency. The frequency range spanned from 1 to 50 Hz. The pulse duration was less than 1 μs. The neutron generator was located at the core center A01.**

  - **A Cf-252 source, with a strength of 0.4 Ci (1.5 · 10^6 n/s) , was used to perform Source Multiplication experiments using a Fast Rabbit (FR) location in the B02 position in ring B.**

RACE-T Generalities: Neutron Sources



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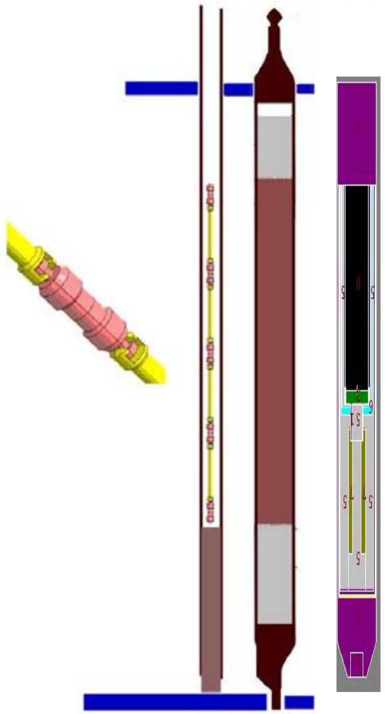

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Fission Rates: Radial Traverses

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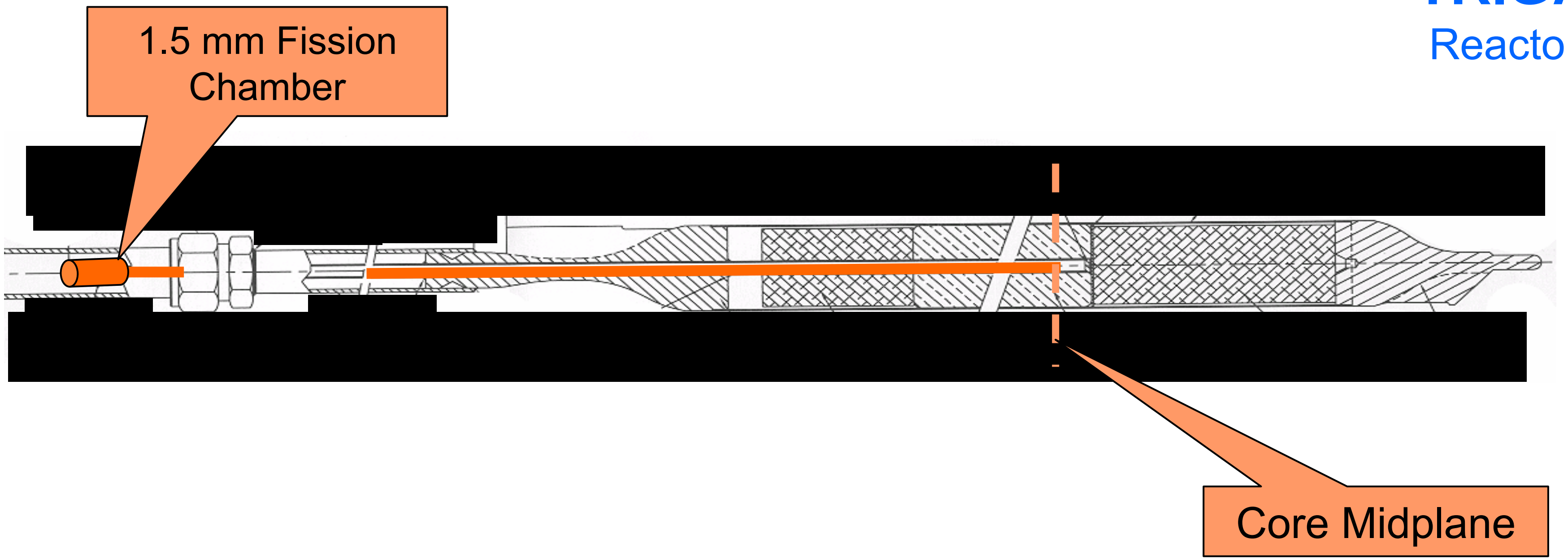
Special Instrumented Fuel Element with central channel of 4 mm internal diameter in order to host a fission chamber and investigate the fission rate inside the fuel.



Fission Rates: Radial Traverses

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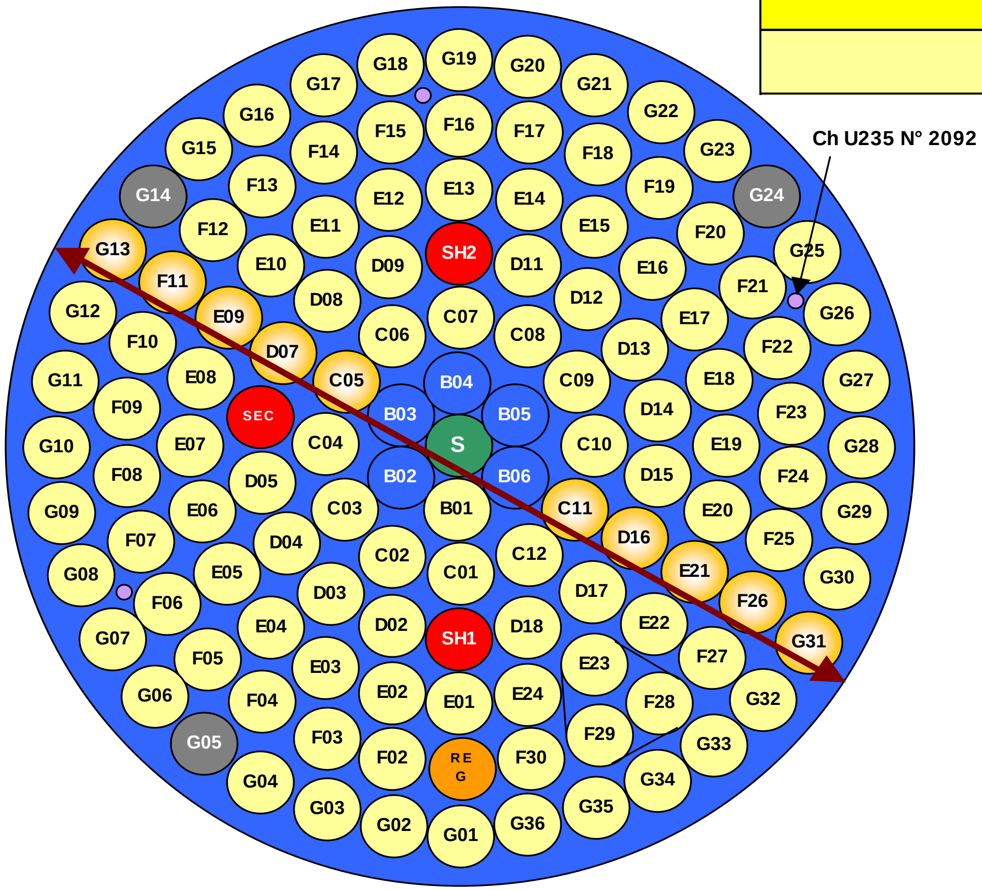
- **3 different loaded fission chambers:**
  - **^{235}U for thermal spectrum range**
  - **^{237}Np for intermediate spectrum range**
  - **^{238}U for fast spectrum range**
- **50 measures with SIFE displacement along a core traverse.**
- **Reactor power: 10÷80 W.**

Fission Rates: Radial Traverses

TRADE Exp Week 03-2004

STATE 3



- Fuel
- Graphite
- Water Hole
- FC — Fission chamber
- S — Source
- REG — Regulating Rod
- S. — Shim Rod 1 and 2 and Safety Rod

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Fission Rates: Radial Traverses

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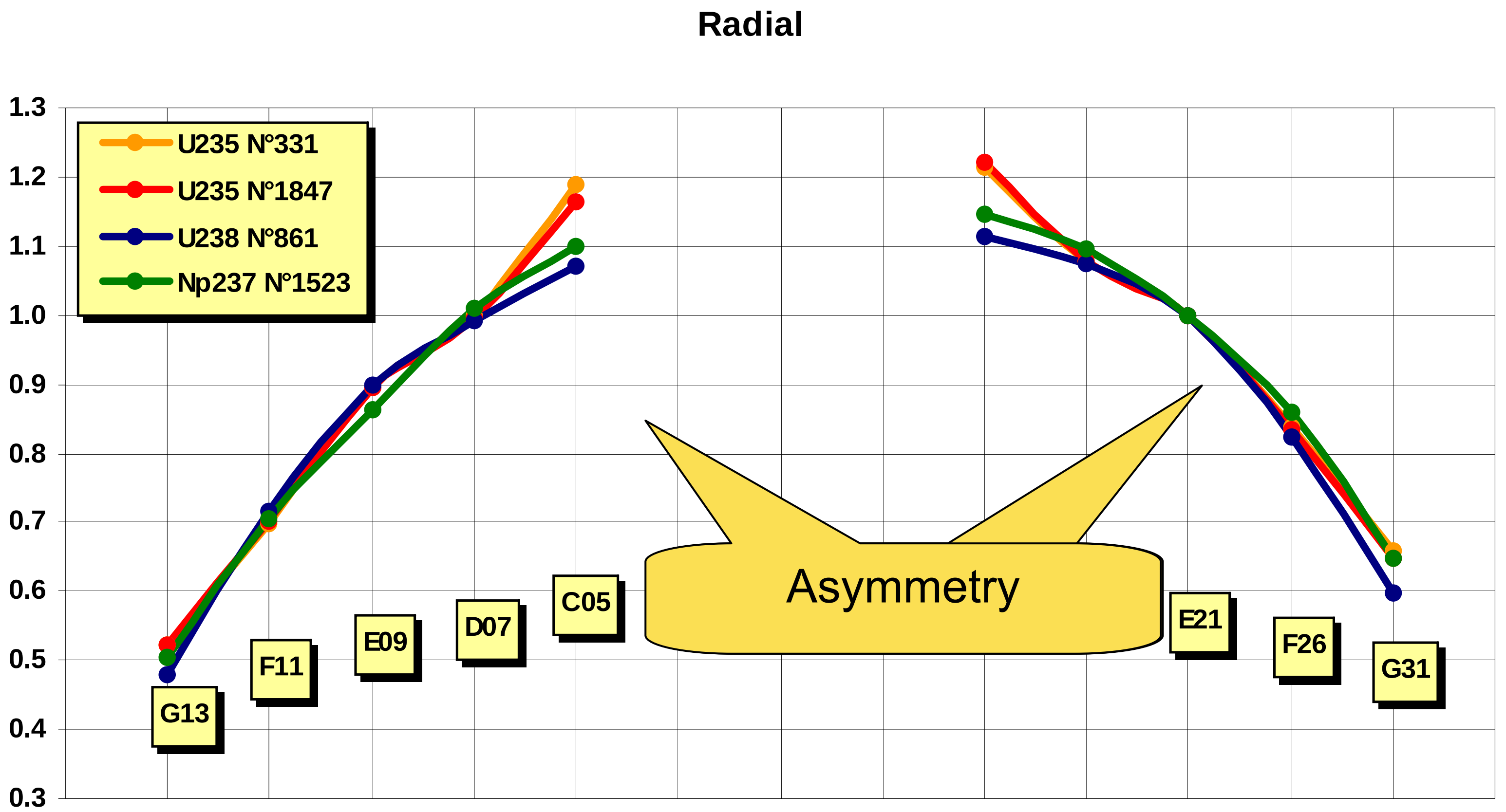

Fission Rates: Radial Traverses

TRADE Exp Week 03-2004

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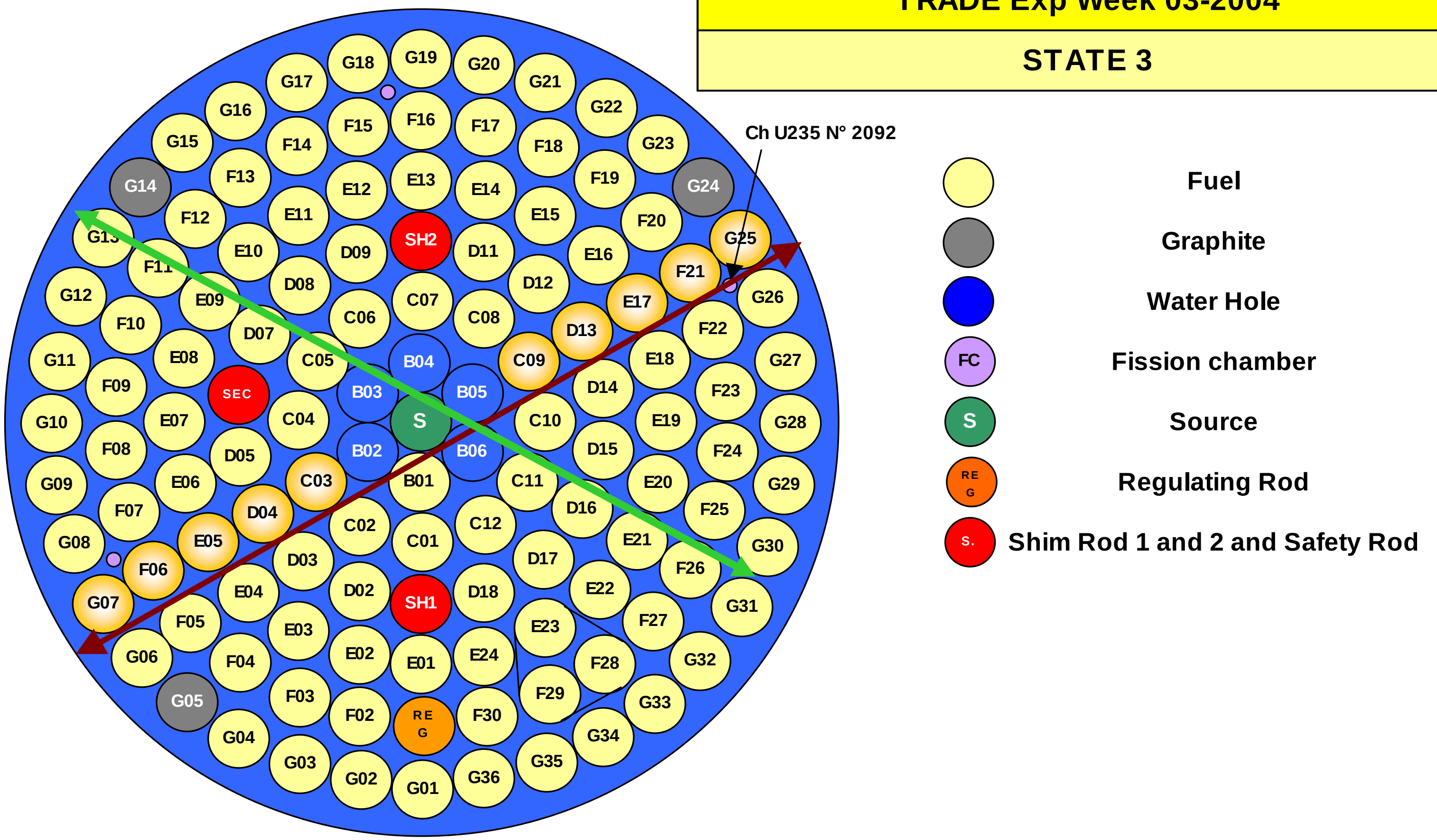

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Fission Rates: Radial Traverses

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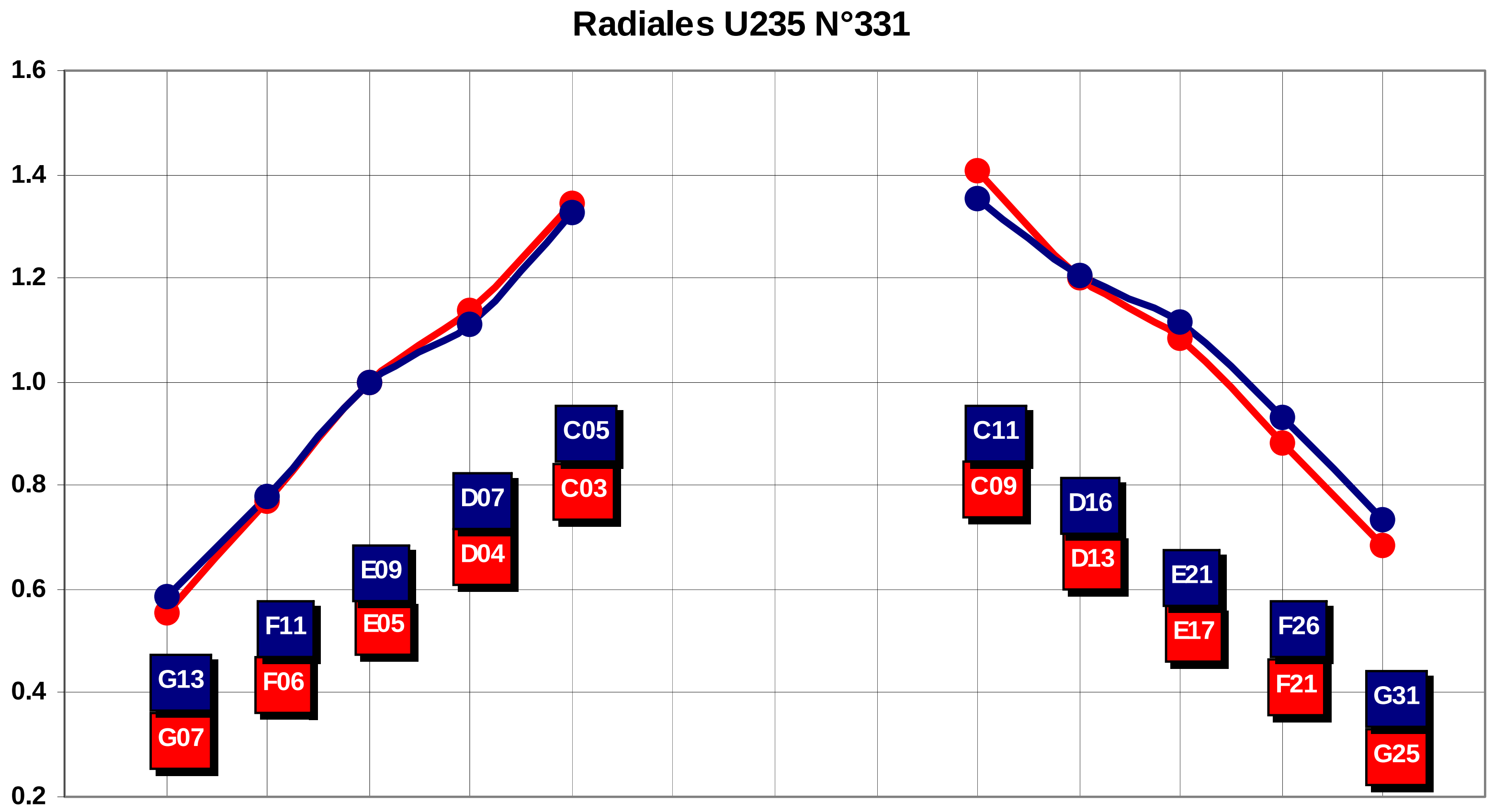

Fission Rates: Radial Traverses

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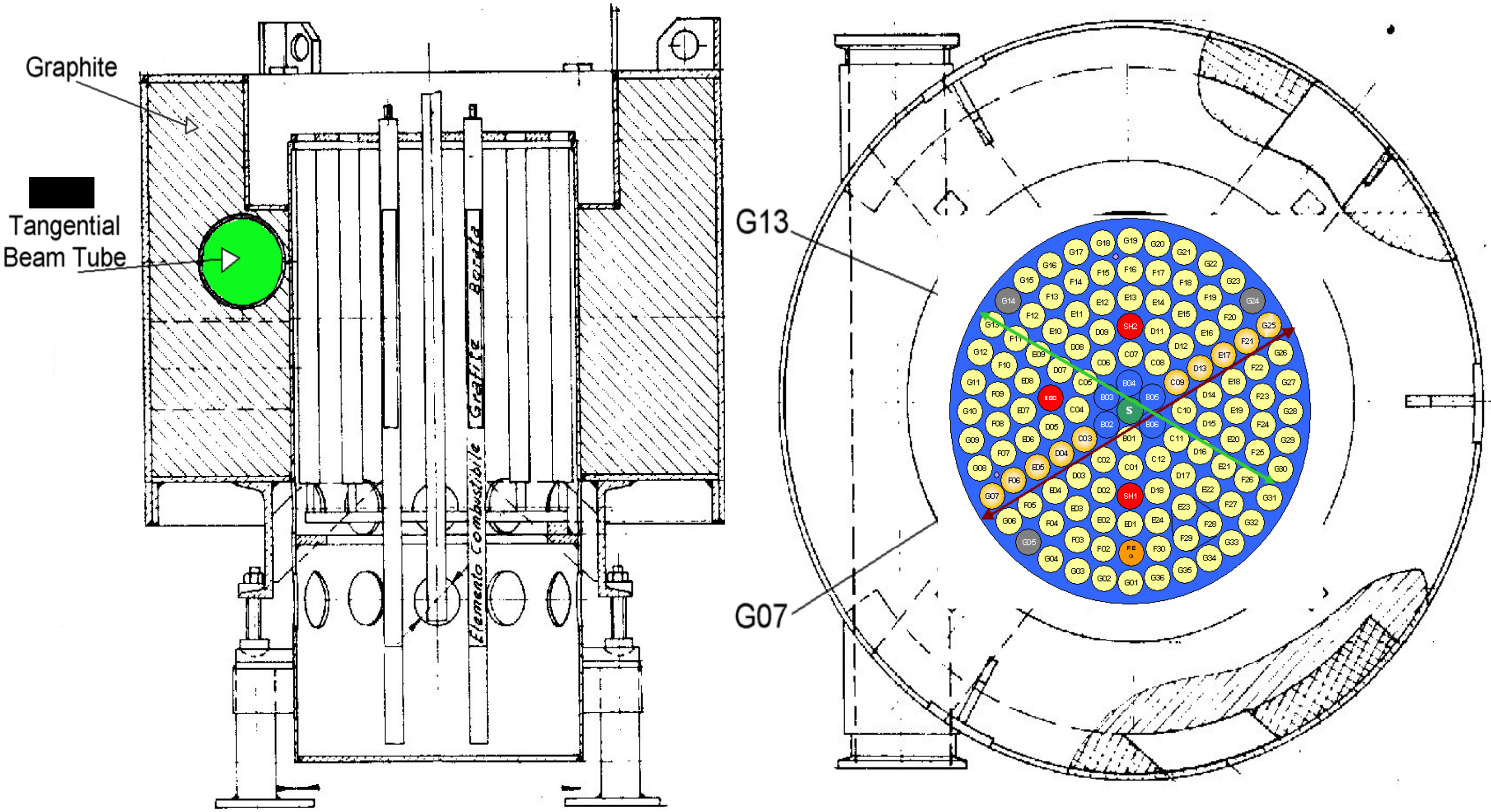

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Subcritical level measurements: core configurations

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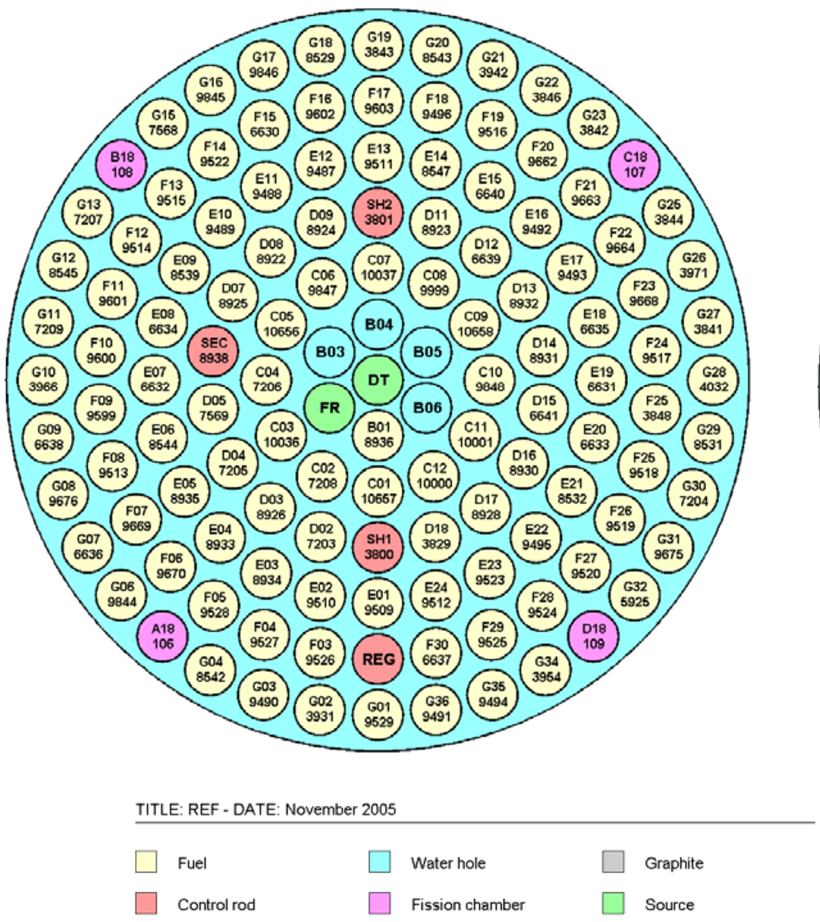
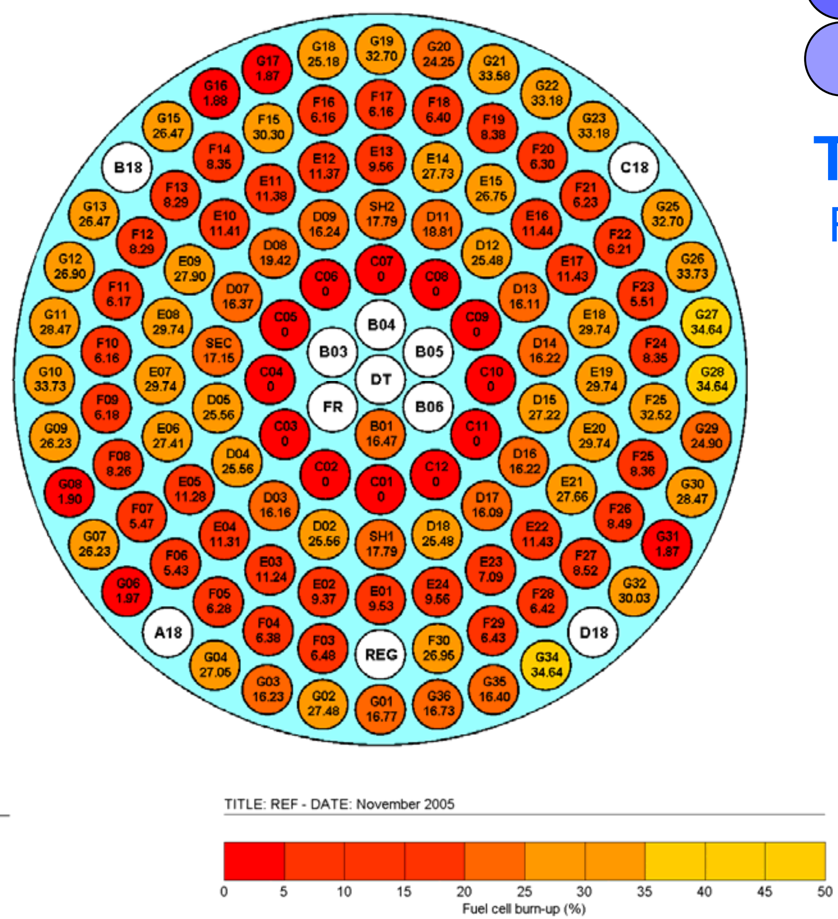
Reference critical (REG rod at 50% insertion)





Subcritical level measurements: core configurations

All Rods Out

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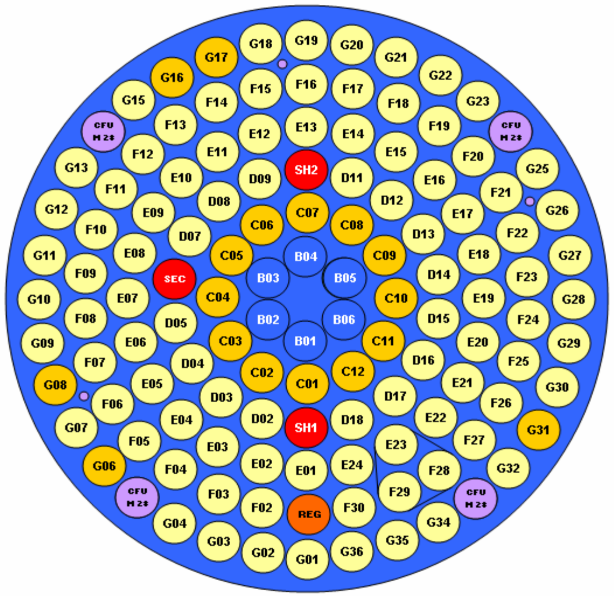
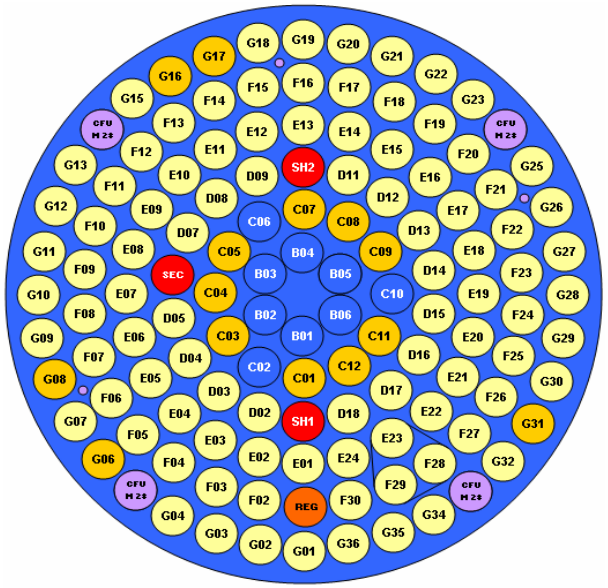
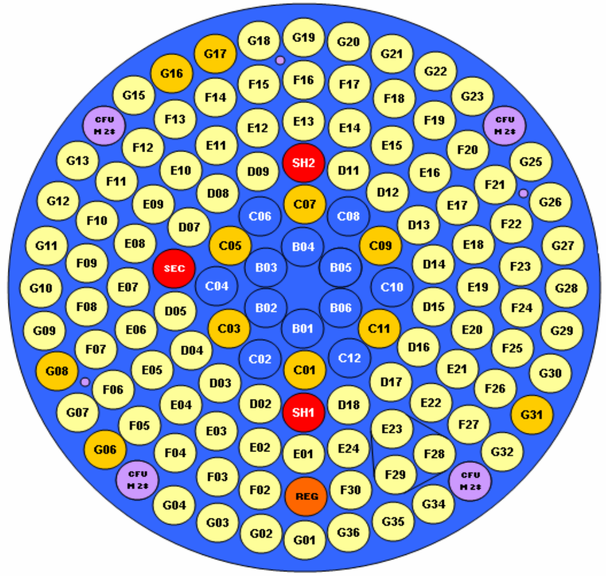


SC0
k=0.997



SC2
k= 0.977



SC3
k=0.959

Methods

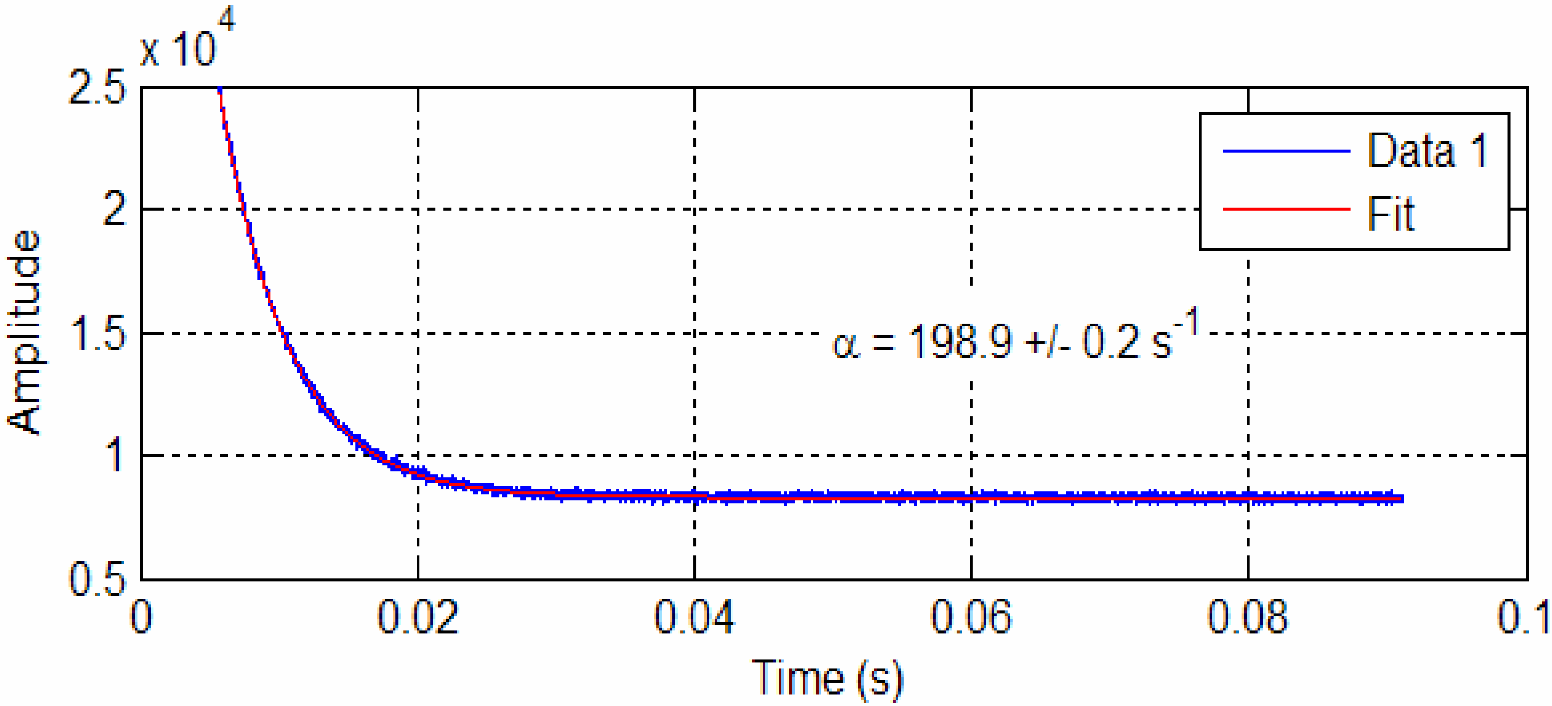
- Response to a pulsed neutron source
- Transient due to a source jerk
- Transient due to a rod drop
- Rationale of the source multiplication

Neutrons Generator

- D/T sealed tube, diameter 37 mm
- Emission: $2.0 \cdot 10^{8}$ $n \cdot s^{-1}$
- Max Pulsing Frequency: 50 Hz
- Pulse width < 5 µs
- Tube duration: 100 hours

Response to a Pulsed Neutron Source

- **Exponential-shaped decay function**
- **Experimental histogram obtained by means of the periodic pulse signal trigger**



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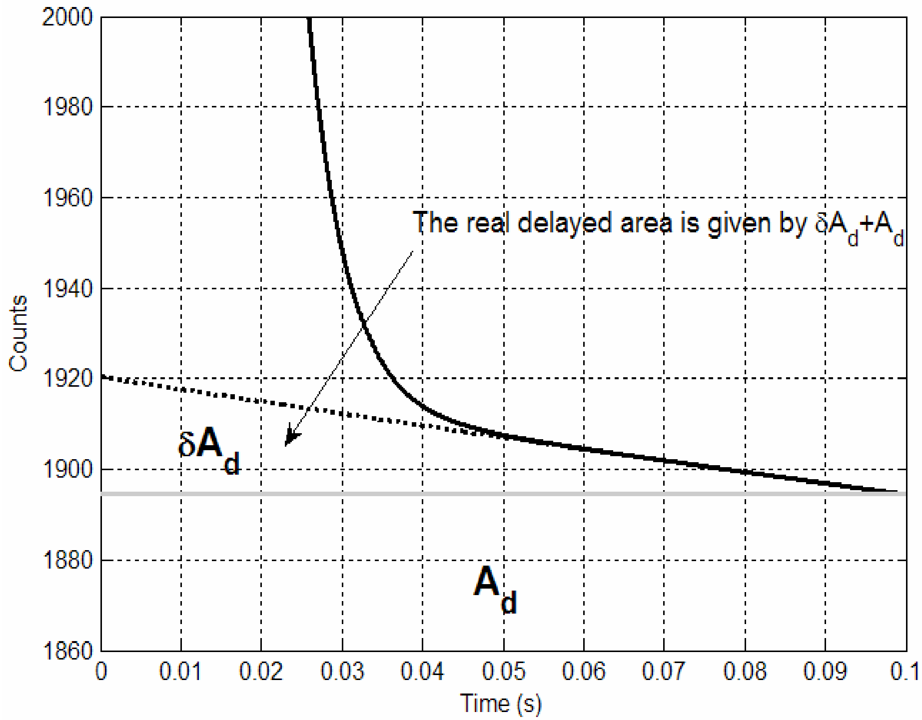
Response to a Pulsed Neutron Source

The area-ratio technique is more accurate and robust than the prompt neutron decay fitting technique.

$$\rho(\$) = \frac{\rho}{\beta} = -\frac{A_p}{A_d}$$



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Response to a Pulsed Neutron Source

- ***Prompt Decay Constant >*** **10 α_P**

$$\alpha_p T > 10$$

Configuration	T (ms)	α_p (/s)	α_p T
SC0	96.86	222.69	21.57
SC2	39.92	557.11	22.24
SC3	20.04	792.80	15.89

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Source Jerk

Standard

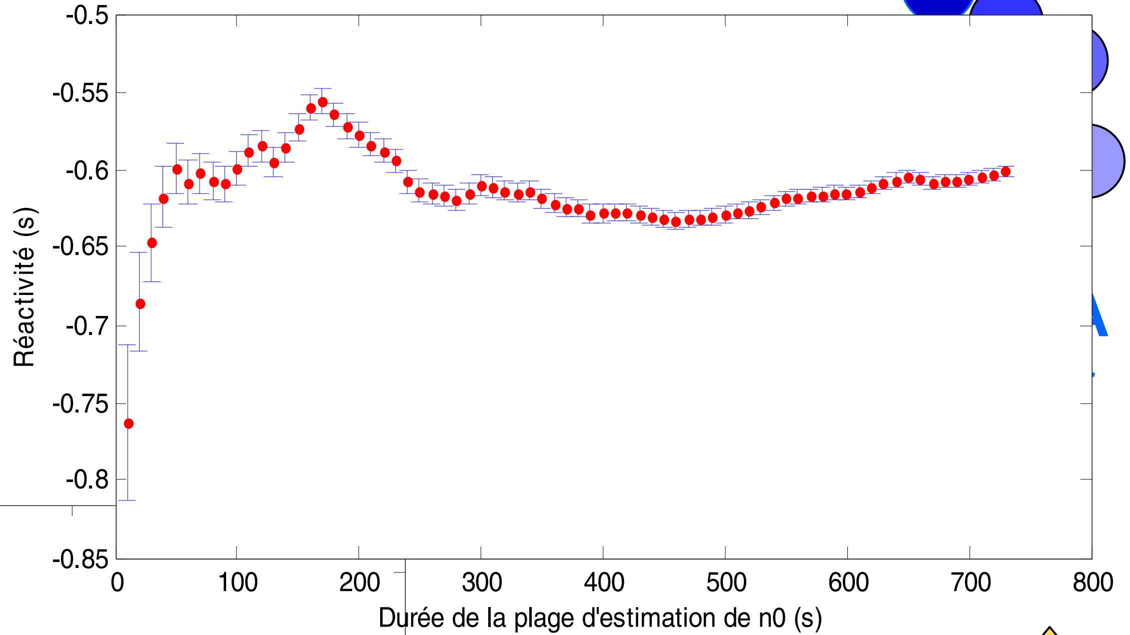
- Cf-252 as Fast Rabbit Shuttle
- Strength: 18.5 MBq → ~ 10^6 n·cm^{-2}

Neutron Generator

- Switch Off

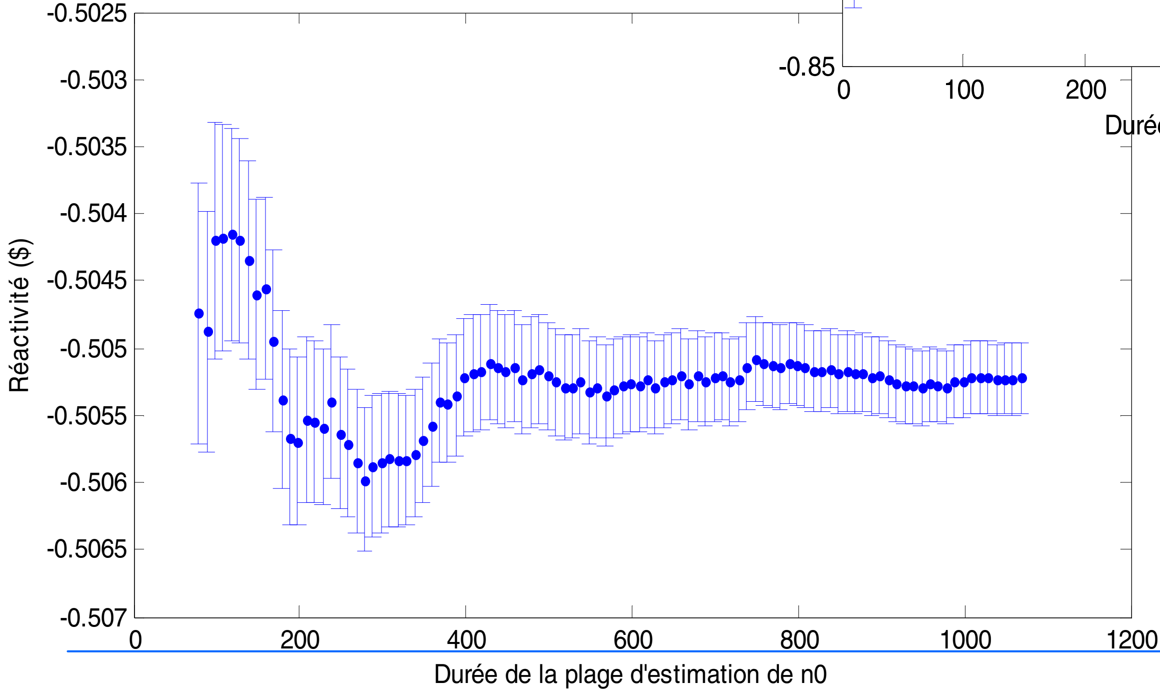
Subcritical level measurements

Source Jerk



Neutron Generator

Standard



Comparison with:

- PNS area-ratio method
- Source jerk method with Cf-252 source
- Source jerk method by switching off the neutron generator

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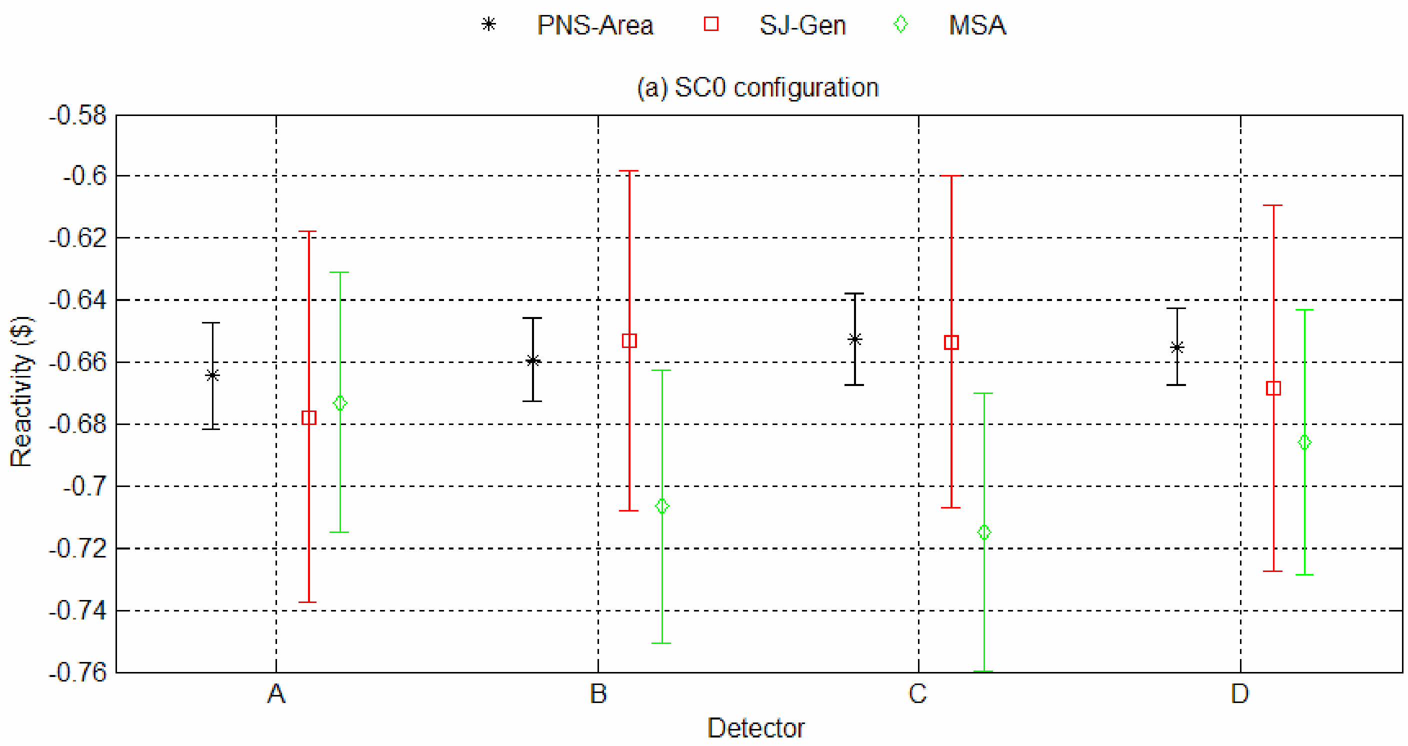
Detector Locations in Core
Rank of Sensitivities

PNS-Area	reactivity estimate spread < 1.22%.
SJ-Gen	reactivity estimate spread < 1.74%
SJ-Cf	the most sensitive to the detector locations - Cf-252 source is in B02 core (NGen in A00)

Subcritical level measurements: results

SC0 (~ -500 pcm)



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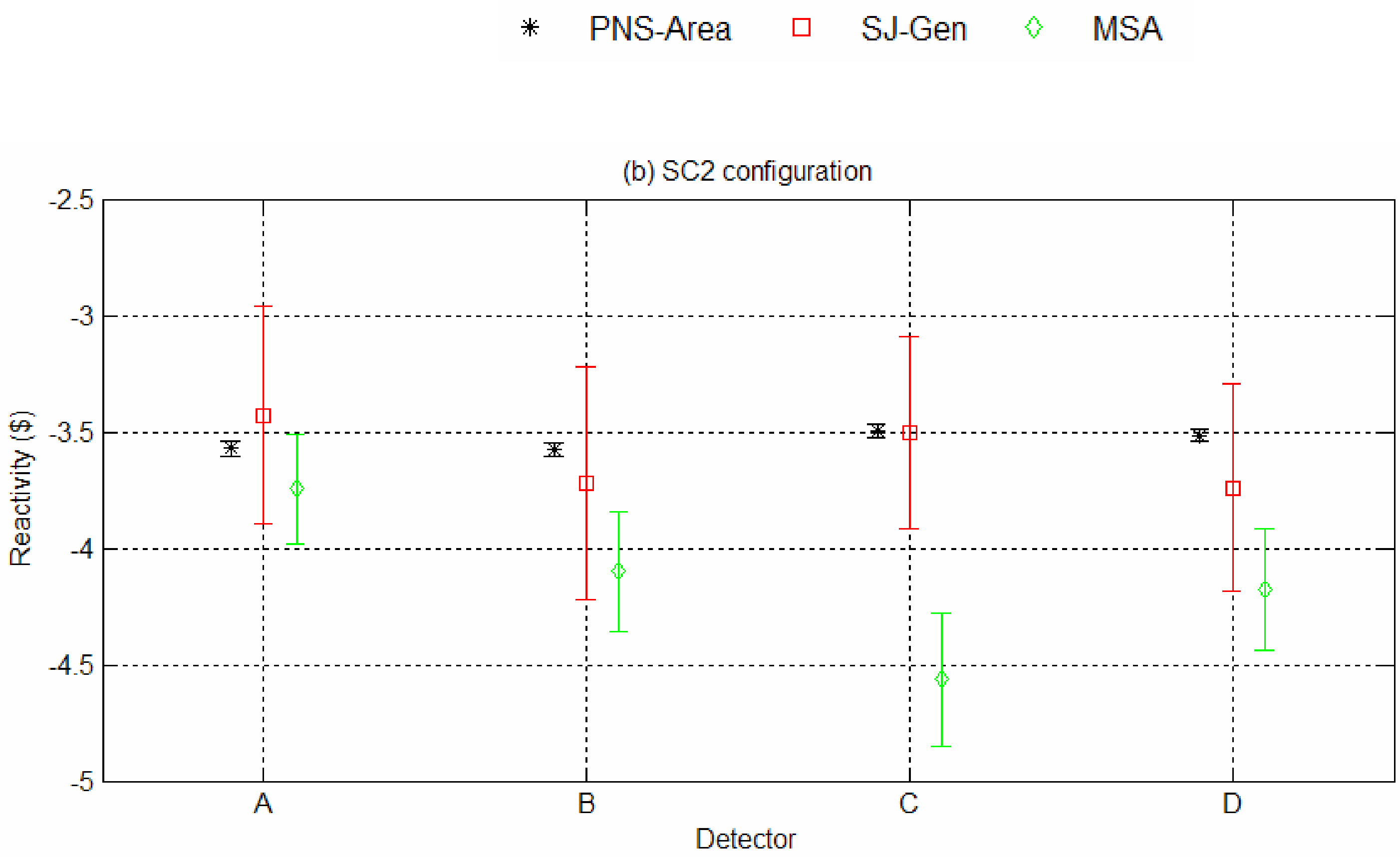
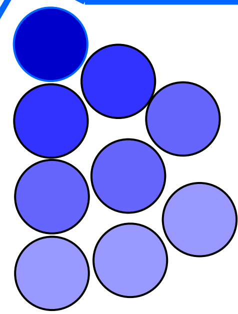
SC2 (~ -2500 pcm)


PNS-Area
SJ-Gen
MSA
(b) SC2 configuration
-2.5
-3
-3.5
-4
-4.5
-5
Reactivity ($)
A
B
C
D
Detector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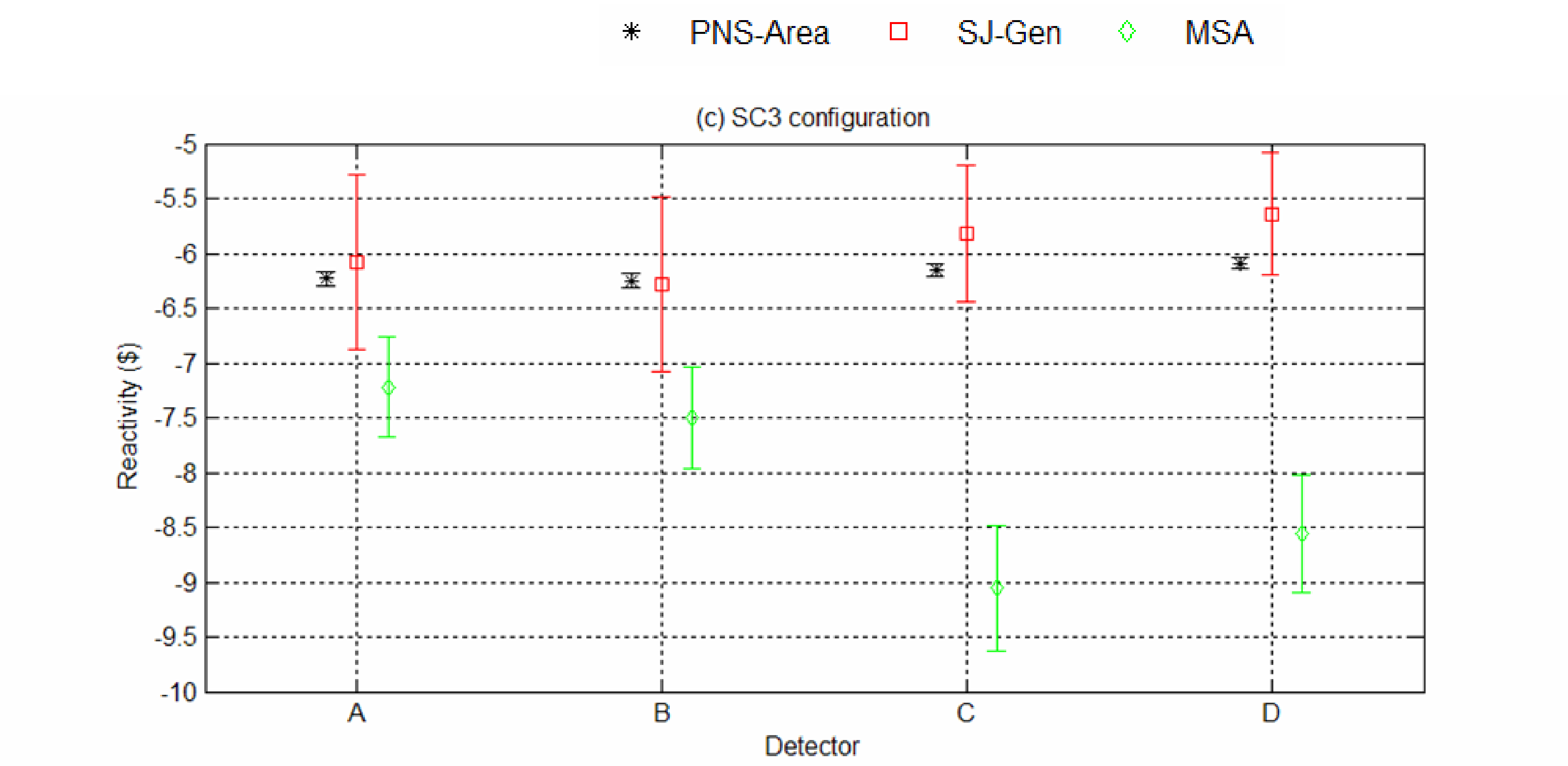
SC3 (~ -5000 pcm)



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Subcritical level measurements: Source Multiplication

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$$\rho_{MSA} = \frac{R_{REF}}{R} \rho_{REF}$$

The technique is the most detector location dependent

Discrepancies from the PNS-area estimates are

- SC0 1%-5%
- SC2 5%-19%
- SC3 16%-40%

Subcritical level measurements: Source Multiplication

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(a) PNS-Area reactivity estimates

Detector	Reactivity ($)		
	ρ	σ_ρ	σ_ρ/ρ
A	-0.6644	0.0078	1.17%
B	-0.6593	0.0062	0.94%
C	-0.6527	0.0068	1.04%
D	-0.655	0.0058	0.89%
Spread	-0.78%		

(b) MSA reactivity estimates

Detector	Reactivity ($)		
	ρ	σ_ρ	σ_ρ/ρ
A	-0.6730	-0.0210	3.12%
B	-0.7067	-0.0220	3.12%
C	-0.7149	-0.0223	3.12%
D	-0.6859	-0.0214	3.12%
Spread	-2.75%		

(c) SJ-Gen reactivity estimates

Detector	Reactivity ($)		
	ρ	σ_ρ	σ_ρ/ρ
A	-0.6060	-0.0204	3.36%
B	-0.6021	-0.0203	3.37%
C	-0.6071	-0.0204	3.36%
D	-0.6139	-0.0204	3.32%
Spread	-0.81%		

(d) SJ-Cf reactivity estimates

Detector	Reactivity ($)		
	ρ	σ_ρ	σ_ρ/ρ
A	-0.6107	-0.0204	3.33%
B	-0.6067	-0.0203	3.34%
C	-0.6119	-0.0204	3.33%
D	-0.6186	-0.0204	3.29%
Spread	-0.81%		

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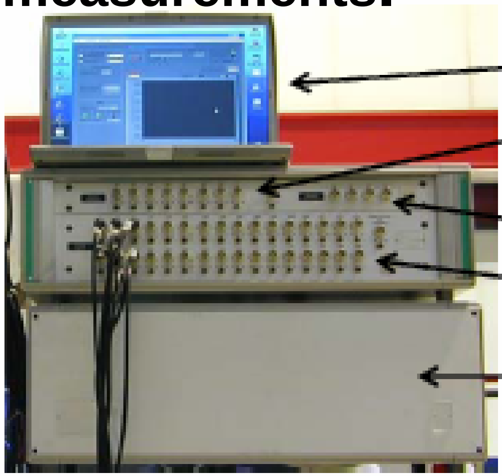
X-MODE

- Single system integrating all features needed for reactor measurements
- Data processing for online treatments and data reduction algorithms
- Precise time marking capability
  - Time marking acts as a triggerless acquisition mode
  - Each event detected is counted and marked
- Improvements of storage capabilities
  - Useful in a great number of measurements.



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Conclusions - PNS

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Reactivity Estimates

- Best performance in terms of uncertainties and insensitivity to spatial effects
- Consistent with the results found in MUSE
- Significant reduction in the uncertainties
- Uncertainties less than 1% for any sub-critical configuration (ρ in $)
- Independent of delayed neutron data
- Sensitivity to detector location ~ 1% - lower than in other methods.
- Area-ratio method is much less sensitive to spatial effects than the prompt decay fitting method
- Slight discrepancies in the reactivity estimates in core and reflector regions

Conclusions – Source Jerk

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Reactivity Estimates

- Pneumatically ejecting a Cf-252 source from the core
  - Too many runs to obtain adequate statistics
  - Stronger source → Shielding and handling problems
- Sudden shutdown of the neutron generator
  - inconsistencies in the beam source strength before the shutdown
- The method will be used in ADS for periodical monitoring by analyzing beam trips (planned or un-planned)
  - source strength will be fairly high and more consistent
  - uncertainties should be less than in RACE-T

Conclusions – MSA

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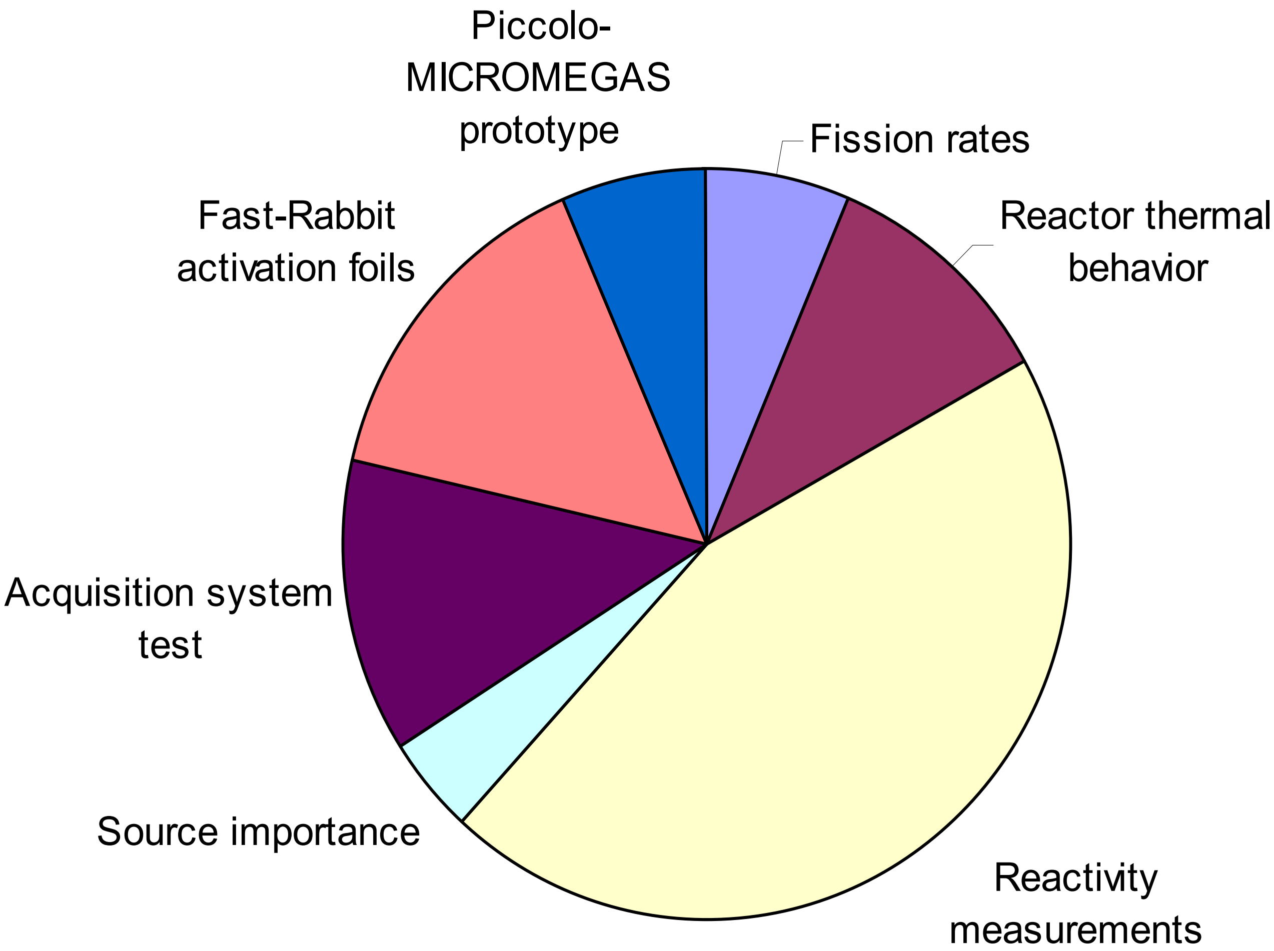
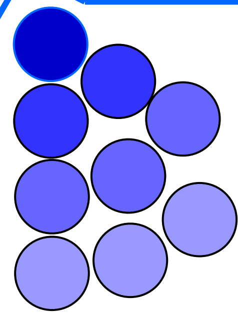
Reactivity Estimates

- Requires corrections with calculations
  - source importance
  - detector efficiencies
- Large inconsistencies without corrections
  - in RACE-T (as in MUSE) differences (from the area-ratio method) of up to 47% (SC3)

RACE-T Experiments





Sharing of 50 Work-Weeks over 2,5 Years Reactor

General Conclusions

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- **RACE-T experiments have allowed the testing of different techniques to measure the subcritical level in ADS.**

- **Coherently with the outcomes from MUSE, the PNS Area-ratio method seems to be the most stable for what concerns the spatial effects, even if such stability has to be supported by theoretical and numerical confirmations.**

- **Inverse Kinetics/Source Jerk technique provided reactivity estimates always in excellent agreement with those obtained by the Area-ratio technique, although a discrepancy between PNS Area-ratio and Inverse Kinetics/Source Jerk results can be clearly be observed when increasing the subcriticality level.**

- **The above mentioned theoretical and numerical confirmations will be obtained, hopefully, thanks to a computational benchmark, recently endorsed by IAEA, focused on the evaluation of the correction factors to be applied to the PNS Area-ratio and MSA results.**

Pre-TRADE benchmark site

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Main Meeting
Coordinated Research Project "Analytical and Experimental Benchmark Analyses of Accelerator Driven Systems (ADS)"
Embedded Meeting
Collaborative Work "Low Enriched Uranium (LEU) Fuel Utilization in Accelerator Driven Sub-Critical Assembly Systems ADS)"
Date: 12 - 16 November 2007
Meeting Venue
Conference Room
ENEA's Headquarters – Rome – Via Giulio Romano, 41

http://www.triga.enea.it/TRIGA/Eng/IAEA_Benchmark.htm