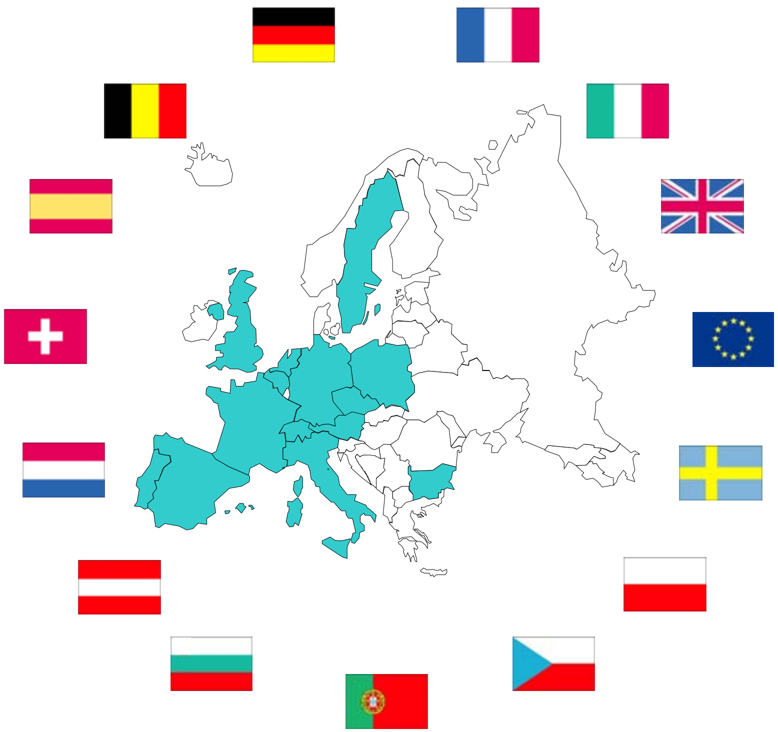
IP-EUROTRANS DM2 ECATS

The RACE Low Power experiments :

Proposal of experimental program



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2nd ECATS/RACE Progress Meeting
Texas A&M, April 10, 2006

Presentation Lay-out

- Project structure
  - The task 2.1.1 "RACE LP Experiments" in the IP EUROTRANS Structure
  - Objectives of DM2/WP2.1/Tas2.1.1
- Proposed experimental program
  - "Reactivity measurements"
  - "Experiments in support of transient behavior studies"
  - "Complementary/Preparatory experiments"
- Requests – Recommendations
- Conclusions

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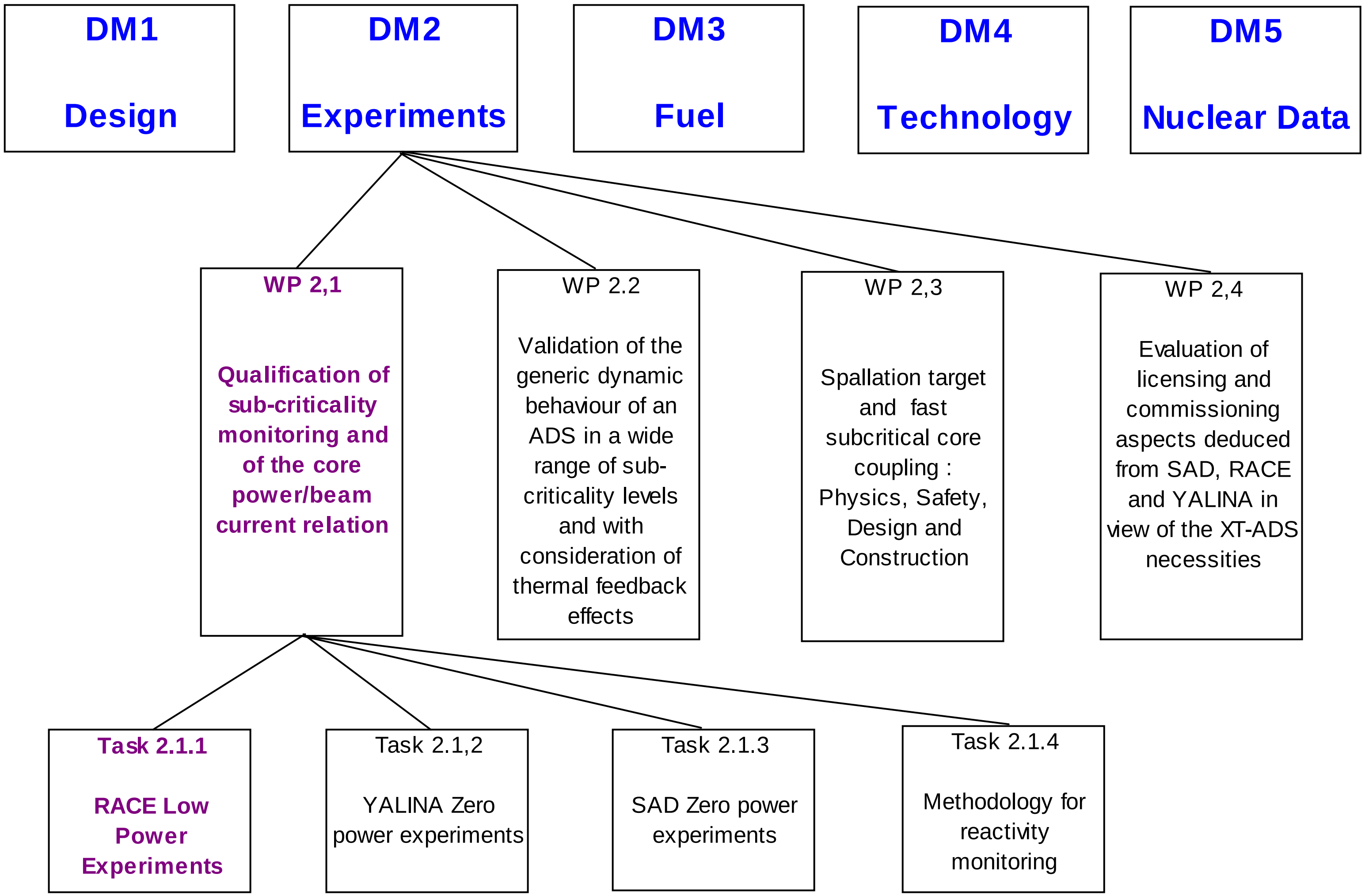
IP EUROTRANS Structure



Objectives of DM2 ECATS

- Qualification of sub-criticality monitoring,
- Validation of generic dynamic behaviour of an ADS in a wide range of sub-critical levels, sub-criticality safety margins and thermal feedback effects,
- Validation of the core power / beam current relationship,
- Start-up and shut-down procedures, instrumentation validation and specific dedicated experimentation,
- Interpretation and validation of experimental data, benchmarking and code validation activities etc.,
- Safety and licensing issues of different component parts as well as that of the integrated system as a whole.

Objectives of WP 2.1

- **Qualification of sub-criticality monitoring,**
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Content of the task 2.1.1

The task 2.1.1. "RACE LP Experiments" consists of 5 sub-tasks :

- Zero power RACE-T Experiments
- **In pile instrumentation, measurement devices, experimental techniques and data acquisition system for the RACE-LP experiments**
- **Support to the transient behavior assessment of the TRIGA-reactors**
- **Current to power experiments in RACE-LP**
- RACE-Low Power Experiments interpretation

Objectives of the task 2.1.1

- **To contribute to the definition of a final and experimentally proven methodology for the reactivity monitoring in an ADS**

- **To prepare the High Power phase**

  - to consolidate the thermal hydraulic features of TRIGA reactors up to 100 kW

  - to validate calculation tools for transient analysis on the RACE LP critical core in the range 30-100 kW

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The RACE LP experiments should contribute, at different levels, to all the objectives of DM2

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Proposed experimental program

It has been elaborated by the partners involved in task 2.1.1

- **D. Villamarin (CIEMAT); M. Carta, R. Rosa (ENEA)**
- **M. Schikorr (FZK); C-M Persson (KTH); P. Baeten (SCK)**
- **G. Imel (DOE); M.S. Chenaud, G. Granget, C. Jammes, F. Mellier (CEA)**

It includes :

- **experiments for reactivity measurement (in the TRIGA reactors),**
- **experiments in support of transient behavior studies of TRIGA cores**
- **"peripheral" experiments (necessary to properly achieve the program)**

and takes advantage of the experience gained during MUSE, TRADE, RACE-T

"Reactivity measurements"

Initial calibration of the reactivity

- the Reference method currently used in critical reactors,
- the PNS based methods (direct method),
- the Source Jerk technique (alternative solution to PNS technique).

Continuous monitoring of the reactivity

- investigation of the current to power relation

Management of normal events

- current to power measurements with regular beam trips

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These measurements should be carried out for three different subcritical configurations (k_{eff} =0.995, 0.97, 0.95)

At least four detectors available (U235 preferably)

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Initial calibration of the reactivity

Reference method – Basis (1/2)

This method will be used as a reference

- principle of the method is to deduce the reactivity from the counting rates on detectors located in or out of the core (CR_{SC})

- reactivity of the subcritical configuration is obtained by applying the ASM method (PK assumption)

$\rho_{SC\,1} = (\rho_{ref} * CR_{ref})/CR_{SC\,1}$; $\rho_{SC\,2} = (\rho_{SC\,1} * CR_{SC\,1})/CR_{SC\,2}$; $\rho_{SC\,3} = ...$

(ρ_{ref}, CR_{ref}) obtained by the way of a rod drop experiment from critical state

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Initial calibration of the reactivity

Reference method – Basis (2/2)

- results are corrected to take into account spatial and spectrum effects (MSM method)

- corrections are calculated

- final uncertainties in the range 5-8%
(ρ_{ref} : 3-5%, CR : 0.5%, f_{MSM} : 3%, β_{eff} : 3-5%)

- very attractive method (but no so easy to properly apply !)

- required experimental conditions easy to manage in a TRIGA reactor

- short duration experiments

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Initial calibration of the reactivity

Reference method – Implementation

- rod-drop such as reactivity inserted in the range 0.4-0.7 $,

- all absorber rods (regulator, shim, safety) should be entirely withdrawn,

- subcritical configurations obtained by removing subassemblies from internal rings (see RACE-T),

- subassemblies removed should be with fresh fuel,

- knowledge of kinetics parameters λ_i, β_i necessary

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Initial calibration of the reactivity

PNS based technique

- direct method

- one experiment, several analysis methods

  - fitting techniques
  - area method

- all techniques deeply investigated during MUSE

- during TRADE/RACE-T, only the area method was used (full investigation of the method; report to be published very soon)

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Initial calibration of the reactivity

PNS based technique

- final uncertainties are expected to be lower than 5%

- full analysis and interpretation of RACE-T results is planned

- knowledge of kinetics parameters β_{eff} , Λ necessary

Objectives of the experiments in RACE LP

- extend the experimental database,
- master the technique and the analysis methodology before the HP phase (this technique will be the new reference method during this phase),
- make progress on uncertainty issue.

Full analysis and interpretation of RACE LP results is planned

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Initial calibration of the reactivity

PNS based technique – Implementation

- target at the centre of the core
  (best configuration for analysis and interpretation issues)

- these experiments could be also performed with a DT source

Online reactivity monitoring

Current to power experiments

$$-\rho = c\varphi^* \frac{S}{R}$$

S → External neutron production

R → Detector response

- Continuously controled

$c\varphi^*$:

- Initially determined by reactivity calibration measurements based on PNS techniques

- Regularly checked

Measurements with and without reactivity changes

- Determination of the precision and robustness of the method (modifications of accelerator operating parameters - current intensity, repetition rate -, change of the source importance - various targets, change of target position -, reactivity changes),

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Online reactivity monitoring

Current to power experiments - Implementation

These experiments need to have a continous beam (or equivalent)

Since break frequency of TRIGA cores = 25 Hz at k_{eff}=0.999
= 750 Hz at k_{eff} =0.97
(on the basis of : β = 700 pcm, Λ = 50 ms)

=> accelerator repetition rate should be higher than 3 kHz at k_{effn}= 0.97

With a maximum repetition rate of 200 Hz, only very slightly sub-critical configurations can be investigated

A continuous monitoring of the neutron production is also required

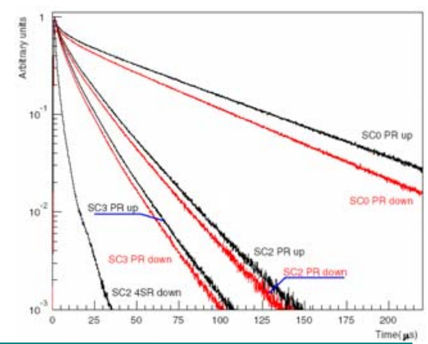
Management of normal events

Current to power experiments with beam trips

- because of the loss of reactivity due to burn-up, the proportionality coefficient will need to be regularly checked

- these checks could be performed by taking advantage of the neutron population decrease that follows a beam interruption

- these experiments need to have a continuous beam (or equivalent) with short and prompt beam interruptions repeated several times (duration of the source interruption in the range $4/\alpha$ - $10/\alpha$ => 25-60 ms at k_{eff}=0.999, 5-15 ms at k_{eff}=0.97)



- these beam trips need to be triggered

- 2 analysis methods are envisaged : the PNS fitting method and the prompt jump method

Experiments for the transient behaviour assessment of TRIGA cores

Thermal hydraulic characterization of the critical core in the power range 0-100 kW

- Measurements of :
  - Core inlet and outlet temperatures at various radial positions,
  - Fuel temperatures at various radial and axial positions,
  - Total core power

- 20 kW steps

- at least 5 fuel temperature measurements and 3 fuel instrumented element are necessary

- reactivity changes will be accurately quantified (need a calibration of control rods)

- peaking factors and reactivity coefficients will be deduced

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"Peripheral" experiments

As a consequence of the proposed program, preparatory/complementary experiments must be conducted.

The topics concerned are :

- study of gamma flash effects,
- source characterization,
- online source monitoring,
- reactivity measurement using the SJ method,
- characterization of the beam line,
- kinetic parameter measurement,
- calibration of rod worth,
- source importance,
- core characterization,
- overall experiments for start-up and core loading procedures

Complementary experiments

Study of gamma flash effects

- Currently under study (C. Jammes will report tomorrow about this topic)

Source characterization

- An accurate assessment of neutron production by calculation tools is expected by target designers (large discrepancies C/E in experiments performed last year at IAC)

- Measurements with various materials (W, W/Cu, Uranium, …) including production rate, energy spectrum and spatial distribution

- ECATS partners interested in calculating these experiments with their own tools

Complementary experiments

Online neutron source monitoring

- develop and experiment an instrumentation able to give an online and accurate assessment of the neutron production and the beam current (necessary for the current to power experiments)

Reactivity measurement using the SJ method

- this technique constitutes an alternative to PNS based techniques for reactivity calibration. Some experiments should be planned.

Characterization of the beam line

- assessing geometric stability and diagnostic consistency (necessary for the investigation of the precision of the current to power relation)

Complementary experiments

Kinetics parameters

- from reactivity calibration and interim cross check measurements, we will deduce either the reactivity in dollars ($\rho_\$$) or the prompt neutron decay constant $\alpha = (\beta-\rho)/\Lambda$

=> the assessment of the absolute reactivity (or k_{eff}) need to know β and Λ

- measurement of these parameters should be performed for all configurations (critical and subcritical)

- reduced uncertainties are expected

Complementary experiments

Rod worth measurements

- assessment using the RD+MSA/MSM method as well as PNS techniques

Source importance measurements

- effect of various target positions

Core characterization

- relative distribution of power (fission rates)

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Requests and recommendations

To use the same reactor and a limited number of core configurations for all the program (very limited manpower for preparation and analysis phases)

To have the target located at the centre of the core in order :

- to benefit of a high source importance,
- to ease the analysis and interpretation,
- to reduce biases and final uncertainties on results.

To arrange subcritical configurations by removing subassemblies from the internal ring (elements with fresh fuel in order to reduce the calculated bias within the interpretation phase)

Requests and recommendations

To have a (pseudo) continuous beam for current to power experiments (cf. previous slides)

To have regular beam trips (duration in the 5-50 ms) and a trigger signal to manage their sum

To have at least four detectors available for reactivity measurements

To measure fuel temperatures in 5 different points (3 instrumented fuel elements)

Contribution of IP EUROTRANS partners

- CEA detached C. Jammes for one year to contribute to the development of instrumentation, experimental techniques and analysis methodology

- CEA, CIEMAT, ENEA, FZK planned to directly participate to the experiments

- KTH planned to contribute also (not contractually involved in the experiments)

- CEA and CIEMAT will use their home made DAQ system

- ENEA made very interesting proposals that do need to be discussed

Time schedule

To be discussed and detailed but previously

- agreement on the experimental program

- commitments on a common work program

- details and commitments on our respective contributions

- several key points have to be clarified (previous slides)

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Main actors of the task

Sub-tasks	FZK	CEA	CIEMAT	ENEA	KTH
In-pile instrumentation, measurement devices, experimental techniques and data acquisition system for the RACE-LP experiments		**CEA (C. Jammes)**	**CIEMAT (D. Villamarin)**	**ENEA (R.Rosa)**	
Support to the transient behavior assessment of the TRIGA-reactors	**FZK (M. Schikorr, L. Mercatali**	**CEA (M.S. Chenaud)**		**ENEA (R. Rosa)**	**KTH**
Current to power experiments in RACE-LP	**(FZK)**	**CEA (C. Jammes)**	**CIEMAT (D. Villamarin)**	**ENEA**	**(KTH)**
RACE-Low Power Experiments interpretation	FZK	CEA	CIEMAT	ENEA	

Conclusions

Organization and objectives of DM2, WP2.1 and task 2.1.1 have been presented

The experimental program proposed aim to fulfill all these objectives

A number of key parameters have to be to precised (reactor(s) used, location of the target, accelerator performances, mid-term planning)

This program now needs to be discussed in details for the planning

This program can be arranged !

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Summary of « Reactivity measurements »

4 detectors for each measurements

Target at the centre of the core

			Core configuration				
	Items of experiments	Technical objective(s)	Critical	SC0 (keff around 0,995)	SC2 (keff around 0,97)	SC3 (keff around 0,95)	Comments
1	Rod drop experiment	Reference reactivity level for ASM/MSM methods	X				Reference reactivity level should be in the range [-0,4$; -0,7$] (Point kinetic valid)
2	ASM measurement	Reference method for reactivity measurements All results obtained with other techniques will be compared to these referencevalues		X	X	X	Count rates on detectors are used for assessment of MSM reactivities Experimental conditions similar to rod drop (same core, same burn-up, same detectors at the same locations, no modification of detector electronic acquisition parameters)
3	Calibration of the control rods in subcritical configuration	Determination of rod reactivity worth at various axial positions	X	X	X	X	Measurements are based on ASM/MSM method as well as PNS techniques Calibration of reactivity changes for the study of the current to power relation
4	PNS experiments with the accelerator provided by IAC	Reactivity calibration		X	X	X	RD+ASM measurements (item n°1 & 2) as reference measurements
5	PNS experiments with a DT source	Reactivity calibration		X	X	X	
6	Cf Source jerk	Reactivity calibration		X	X	X	
7	Current to power relation	Online monitoring of the reactiviy		X	X	X	Needs a continuous beam, Need an online monitoring of the source (neutron production, beam current) RD+ASM/MSM measurements for assessment of reference reactivity levels
8	Reactivity measurement using beam trips	Interim cross checks		X	X	X	Needs a continuous beam, regular beam trips and also a trigger signal for beam interruption RD+ASM/MSM measurements for assessment of reference reactivity levels

Summary of « Experiments for transient behavior study of TRIGA's »

	Items of experiments	Technical objective(s)	Critical	SC0 (keff around 0,995)	SC2 (keff around 0,97)	SC3 (keff around 0,95)	Comments
1	Thermal hydraulic characterization of the critical core in the power range 0-100 kW	Reference measurements in view of HP phase (validation of transient calculation tools on the critical core)	X				Monitor core inlet and oulet temperature at various radial positions, fuel temperatures at various radial and axial positions, and total core power
2	Determination of the reactivity coefficients in a critical reactor in the power range 0-100 kW		X				These data are extracted from the reactivity insertion transients (see below)
3	Reactivity insertion transients in 20 kW steps in the power range 0-100 kW in critical reactor		X				Monitor core coolant inlet and oulet temperature at various radial positions, fuel temperatures at various and axial positions, total core power, control rod movements (time stamping) and positions
4	Calibration of the control rods at delayed critical		X				Control of the reactivity inserted

1st fuel instrumented element close to the source : one measure at half fuelled zone height (max. fuel temperature)
2nd fuel instrumented element further from the source : one measure in the lower part of the fuelled zone and one measure in the mid part of the fuelled zone will give a mean fuel temperature and the axial peaking factor
3rd fuel instrumented element far from the source : one measure in the lower part of the fuelled zone and one measure in the upper part of the fuelled zone will give supplementary values for fuel average temperature calculation and the radial peaking factor

Summary of « complementary/preparatory experiments »

			Core configuration				
	Items of experiments	Technical objective(s)	Critical	SC0 (keff around 0,995)	SC2 (keff around 0,97)	SC3 (keff around 0,95)	Comments
1	Study of gamma flash effect	To assess how long the detectors are blinded by gamma ray and how it affects measurements performed using PNS based technique					C. Jammes 's first work He will investigate how to solve this problem if necessary
2	Source characterization	Production rate, energy spectrum and spatial distribution with tungsten/copper alloy, uranium; study of diagnostic techniques					Large discrepancy between calculations and measurements (D. Beller's presentation in FZK - October 2005 & J. Chen's presentation in Pocatello - June 2005)
3	Source monitoring	On line monitoring of neutron production rate and beam current					Necessary for current to power relation study (item n°12)
4	Characterization of the beam line	Assessing geometric stability and diagnostic consistency					Necessary for current to power relation study (item n°12)
5	Source importance with Linac	Effectiveness of source due to location		X	X	X	Different source locations (central, axial and possibly lateral)
6	Kinetics parameter measurement (β_{eff}, Λ)	Assessment of absolute reactivities from α or $\rho_{\$}$ experimental values	X	X	X	X	Existing data ? If yes, are these data sufficient ?
7	Power shape (axial and radial fission rate measurement)	Core characterization	X	X	X		Purpose : calculation tool validation
8	Start-up and loading procedure	Overall methodology for reactivity monitoring (task 2.1.4)			X	X	In the subcriticality range : 0.85 - 0.95