

## ***WP2.1: Determination of the optimal reactivity monitoring methodology for XT-ADS/EFIT based on zero-power, CW YALINA experiments***

### **Co-ordinator:**

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### **Partners:**

SCK•CEN, CNRS, KTH, CIEMAT, FZK, Institute for Power&Nuclear Research-"Sosny", Chalmers University

Based on the results of the various measurement performed with different measurement techniques during the MUSE FP5 Project, it became clear that no unique measurement technique could be proposed to perform an on-line and accurate reactivity monitoring. As the final goal is to provide an accurate and robust on-line measurement of the reactivity during power operation and during loading operations in an ADS, a combination of techniques has been proposed in the framework of MUSE to solve the task. The application of the different techniques is based on a step-wise and in-depth approach of reactivity determination. In this methodology, the ratio of the beam current and the neutron flux level in the core was proposed to serve as an on-line reactivity indicator. Since the proportionality constant of this reactivity indicator can vary over time, interim absolute calibration at beam trips by independent measurement techniques is foreseen. Furthermore, it was also judged necessary to calibrate these interim calibration techniques by more accurate techniques during the start-up phase of the ADS.

Due to the pulsed nature of the accelerator in MUSE, not all the required measurement techniques could be investigated. Therefore it is essential to complement the measurement performed in MUSE with those performed in a system with a continuous beam. In this respect, the YALINA facility was selected to respond to the lack of data in this domain. The final goal of work package WP2.1 is therefore to provide a final and experimentally proven methodology for reactivity monitoring in an ADS based on results from YALINA experiments and to define procedures for start-up, loading, operation and shut-down. The WP2.1 will achieve five main goals and is organised around five different tasks as listed below.

### **List of Tasks and Coordinating Responsibilities**

#### **Task 2.1.1:**

Definition and characterisation of the different YALINA configurations in view of the investigation of the methodology for reactivity monitoring.

Co-ordinating Organisation: KTH – W. Gudowski

Partners: KTH, Institute for Power&Nuclear Research-"Sosny", CIEMAT, FZK, CNRS, SCK•CEN

### **Task 2.1.2:**

Investigation of the current-to-flux reactivity on-line monitoring technique

Co-ordinating Organisation: CNRS – A. Billebaud

Partners: CNRS, SCK•CEN, KTH, Institute for Power&Nuclear Research-"Sosny"

### **Task 2.1.3:**

Investigation of the interim calibration techniques used at beam trips for cross-checking of the current-to-flux on-line reactivity monitoring technique.

Co-ordinating Organisation: SCK•CEN - P. Baeten

Partners: SCK•CEN, CIEMAT, Institute for Power&Nuclear Research-"Sosny", CNRS, KTH

### **Task 2.1.4:**

Investigation of full calibration techniques for kinetic parameters during loading/start-up procedures.

Co-ordinating Organisation: CIEMAT – E. Gonzalez

Partners: CIEMAT, KTH, Institute for Power&Nuclear Research-"Sosny", SCK•CEN, Chalmers University

### **Task 2.1.5:**

Definition of a methodology for reactivity monitoring in ADS and definition of procedures for start-up, loading, operation and shut-down.

Co-ordinating Organisation: SCK•CEN – P. Baeten

Partners: CNRS, CIEMAT, KTH

## **Detailed description of the Work-packages**

### **WP2.1: Determination of the optimal reactivity monitoring methodology for XT-ADS/EFIT based on zero-power, CW YALINA experiments**

#### **1. Objectives**

Conclusions drawn at the end of the MUSE project and first results of experiments performed in the YALINA facility define the currently achieved status of measurement techniques for determination of the reactivity level to be applied in an ADS system.

Based on the results of the different measurement performed in the different configurations with various methods during the MUSE FP5 Project, it became clear that no unique measurement technique can be proposed to measure the different kinetic parameters and especially the online reactivity monitoring.

As the final goal is to provide an accurate and robust on-line measurement of the reactivity during power operation and during loading operations no single experimental technique can accomplish these tasks. Since only few techniques can act as an on-line indicator for reactivity and these techniques require additional information to extract the reactivity, additional measurement techniques are needed. Therefore only a combination of techniques will be able to solve the task and a step-wise and in-depth approach of reactivity determination will be needed. As a result of the MUSE experiments the following methodology was proposed:

1. on-line reactivity measurement based on the current-to-flux relation
2. interim cross-checking at beam trips by independent techniques such as the prompt decay method or ADS prompt jump technique
3. calibration of above mentioned techniques at low power during start-up/loading procedures by dedicated techniques.

In the framework of MUSE, information was primarily obtained with regard to the third point. The first point could not be addressed in MUSE due to time structure of the driving source. It is hence the objective of WP2.1 to give a detailed answer to the lacking information in order to redefine based on measurement results a methodology for reactivity monitoring. Therefore, five different tasks have been identified. The first one WP2.1.1 dealing with the definition and characterisation of the YALINA configurations used in the other tasks. In WP2.1.2, the applicability of the current-to-flux relation as an on-line reactivity indicator will be investigated. WP2.1.3 will be devoted to the investigation of different measurement techniques which could serve as an interim cross-checking technique at beam trips. The applicability and usefulness of full calibration techniques for the determination of kinetic parameters will be reanalysed in WP2.1.4. WP2.1.5 will then define based on the results of different candidate techniques investigated in the other different tasks an appropriate methodology for reactivity monitoring and procedures for start-up, loading, operation and shut-down.

## **2. Description of Work**

### **2.1 Description of Tasks**

As outlined in previous paragraph, this work-package WP2.1 is subdivided in five tasks. Each of the tasks is further discussed in detail hereunder.

*Task 2.1.1: Definition and characterisation of the different YALINA configurations in view of the investigation of the methodology for reactivity monitoring*

First of all, the most suitable configurations in view of the objective 2.1.1 have to be defined. In order to define these configurations, special attention shall be given to ease

the interpretation and transferability to XT-ADS. This means that the time constant of the system should be optimised in such a way to best reflect the conditions of XT-ADS and EFIT. Also the spatial zoning should be designed to represent closest XT-ADS and EFIT conditions in terms of neutronic characteristics and to allow an easy transferability of the results to DM1. Special attention should also be given to the choice of possible detector locations and types.

In view of these objectives, further optimisation of the proposed YALINA-Booster configurations will be carried and might lead to significant adaptations of the present installation.

Once the configurations to be investigated have been identified and implemented, an experimental characterisation of the core can be carried out. Calibration of the sub-critical level by a reference technique (e.g. the PNS Area technique) will be envisaged together with a rigorous follow-up of the subsequent changes of the configuration to allow a continuous traceability of the actual sub critical level to the sub-critical level determined by the reference technique. To further characterise the core, spatial traverses and spectrum indices will be needed.

As support to the measurements performed in the framework of the core characterisation, calculations will be carried. These calculations will encompass  $k_{\text{eff}}$ -calculations, flux traverses, spectrum indices, kinetic parameters, MSM-factors and others.

It is however not the purpose to obtain a fully detailed characterisation of the core, since the objective of WP2.1 is related to measurement techniques for reactivity monitoring in sub critical conditions.

#### *Task 2.1.2: Investigation of the current-to-flux reactivity on-line monitoring technique*

Seen from IP-Eurotrans DM1 a robust on-line and continuous sub-criticality monitoring based on first principle measurement has to be established. This on-line monitoring technique has to yield valuable information about the rapid relative change of the reactivity. The simplest approach is based on a measurement of the current  $I_p$  and on the power level  $P$  or neutron flux (through a fission chamber). Given the fact that the source strength is proportional to the beam current and that the power level is proportional to the fission chamber response one can get access to the reactivity through the following formula:

$$-\rho = q\varphi^* \frac{S}{P}$$

where  $P$  stands for the thermal power,  $q$  is the energy released per neutron fission,  $S$  is the source,  $\rho$  the reactivity ( $K_{\text{eff}}-1/K_{\text{eff}}$ ) and  $\varphi^*$  the importance of the source.

Any change in the reactivity is accessible through the current  $I$  and the flux. The theory associated to that type of measurement is the Multiplied Source (MS) method. This method is a relative measurement and one needs an absolute measurement at first and then from time to time to verify that the other terms remain constant.

In between checks, one should then be able to guarantee that the proportionality constant remains constant over the considered period. This can be accomplished by monitoring signals which together determine the source characteristics such as the beam position, proton energy etc. By calculating the reactivity sensitivity coefficients for these source signals, the overall bias due to an unknown variation in the proportionality constant can be limited by bounding the acceptance range of the source signals. In this way, the current-to-power reactivity indicator can serve as a reliable and accurate on-line reactivity monitoring technique.

In task 2.1.2 the feasibility of this technique for on-line reactivity monitoring will have to be demonstrated. Since due to the consumption of the  $^3\text{H}$ -target in YALINA the beam current will not remain proportional over time to the neutron production-rate, the beam current cannot be used as such for monitoring the source strength in the YALINA experiments. Hence, another signal which is directly proportional to the neutron production-rate will have to be identified and the necessary data-acquisitioning system installed. Once established, the stability of this ratio can be monitored under steady-state conditions and associated uncertainties can be derived. The influence of detector positions and detector types on the uncertainty of the derived reactivity will have to be analysed. Furthermore, the ability of this reactivity indicator to distinguish sufficiently small reactivity states will have to be investigated based on the interpretation of small induced reactivity perturbations. Moreover, the ability to follow reactivity changes during transient conditions will have to be examined and compared with conventional (critical) signals used to monitor reactivity changes such as flux meters and period meters.

*Task 2.1.3: Investigation of the interim calibration techniques used at beam trips for cross-checking of the current-to-flux on-line reactivity monitoring technique.*

The verification of the proportionality constant of the current-to-power indicator will have to be accomplished by independent measurement techniques. To limit the perturbation to the power operation of the ADS, benefit would be taken from the unavoidable occurrence of beam trips. At every beam trip the response of the reactor could be recorded. Since the repetition-rate of these beam trips is unpredictable and probably not sufficient to obtain desired statistics on the measured parameters, an imposed repetition of induced beam trips could be foreseen.

The candidate measurement techniques to be used in these experimental conditions are either a Prompt Decay fitting technique or the ADS Prompt Jump technique.

The ADS Prompt Jump technique is based on the determination of the removal of the prompt neutron part as in the rod-drop technique. The main advantage of this technique is related to the fact that no fitting, based on an interpretation model, has to be performed. Although in MUSE some relevant information is present from the Source Modulation measurements, a sufficiently large measurement campaign in YALINA will have to be foreseen. Different sub critical levels, detector positions and detector types

will have to be analysed to obtain a thorough evaluation of the uncertainties associated with this technique.

In practice, this technique might result in determining the levels before and after the beam trip. By averaging the level after the beam trip over a certain time period (in the order of some hundreds of microseconds), the uncertainty will be strongly decreased, but a possible small bias may arise due to the decay of the delayed neutron population. Measurements performed in YALINA within this task 2.1.3 will have to evaluate how the investigated period can be optimized in terms of uncertainty and bias, but also with respect to operational conditions of the ADS.

In the Prompt Decay fitting technique, the investigated period after a beam trip can be much shorter, since only the die-away of the prompt neutron population is recorded. From the measurements in MUSE it was demonstrated that the decay of the prompt neutron population cannot adequately be represented by a mono exponential. Therefore more complex interpretation models are needed among which the kp-method seems to be the most robust and promising one. The kp-method however heavily depends on calculation input which could be considered as a drawback.

In MUSE, a lot of measurements have been carried with these techniques, but one still has to be cautious in extrapolating the MUSE results to a real ADS since the beam structure in both situations is different. For a real ADS the decay after the interruption of a continuous beam will be investigated instead of the response to an impulse as in MUSE. Since the prompt neutron decay in both situations is different, the extrapolation of the results in regard to the applicability has to be confirmed by the proposed experiments in YALINA.

Therefore, based on orientation measurements in YALINA with Prompt Decay fitting techniques task 2.1.3 will in regard to the investigation of fitting techniques first analyse to which extent the MUSE results can be extrapolated to and are valid for XT-ADS/EFIT systems. Since the MUSE core will most probably be more representative of a XT-ADS/EFIT system than a YALINA-Booster configuration with regard to prompt decay characteristics, the extrapolation of MUSE results might be preferred over a detailed investigation of this technique in YALINA. Based on the outcome of this analysis, Task 2.1.3 will with regard to fitting techniques either concentrate on the extrapolation of the MUSE results based on YALINA experience or discard the MUSE results and use detailed YALINA measurement campaigns.

Anyway, the results for the reactivity obtained in this task 2.1.3 have to be compared with those for the reactivity in task 2.1.2 to assure the consistency of the results. In this way, a further breakdown of bias and uncertainty associated with the beam-to-flux reactivity indicator can be accomplished.

Based on the measurement results and the accelerator capabilities and other operational constraints, task 2.1.3 will determine the choice for the most appropriate technique in view of XT-ADS/EFIT together with an optimised time structure associated

with this technique. Combined with the results from DM1 DESIGN, a proposal for the frequency of such a cross-checking event will be formulated.

*Task 2.1.4 Investigation of full calibration techniques for kinetic parameters during loading/start-up procedures.*

In order to calibrate the techniques mentioned in task 2.1.2 and 2.1.3, additional independent and robust measurement techniques have to be applied. The standard approach followed in critical reactors by using a rod-drop and in combination with the MSM-technique is not feasible in ADS, since the critical state of the system is not intended to be reached. For the purpose of calibration dedicated experimental conditions can be envisaged, such as zero-power conditions. These calibrations could be incorporated in the loading and start-up procedures of the ADS. In these circumstances, dedicated external sources could be used to drive the system.

One possibility could be to use a pulsed neutron source as in MUSE and apply the PNS Area method which has been shown to be a very simple and robust measurement technique. Since in MUSE this type of source has been used extensively for reactivity determination, the lack of information in this area is very limited and no particular effort has to be devoted to it in the framework of 2.1.4.

Based on the MUSE results the use of an external isotopic source in a standard source jerk measurement was seen to be less attractive for reasons of radiation protection, practical implementation and measurement accuracy. Also, measurement techniques in ADS representative sub critical conditions without the introduction of an external source and thus with only the intrinsic source present were found to be of little interest due to unfavorable statistics. Since these results will also be valid for XT-ADS/EFIT, no further measurements in this respect will be foreseen in YALINA.

In MUSE, the investigation of calibration techniques with a continuous beam as driving source were not possible and could hence be analysed in YALINA. Different noise technique with a continuous beam will be investigated in this respect and uncertainties depending on the amplitude of the beam signal will be derived.

In these calibration experiments in ADS representative sub-critical conditions, the measurement, calculation and interpretation of kinetic parameters such as mean neutron lifetime and effective delayed neutron fraction need to be further pursued. Task 2.1.4 will therefore also consist of a detailed investigation of different measurement techniques in view of the determination of kinetic parameters. In this respect, some of the techniques extensively used in MUSE might be reevaluated.

*Task 2.1.5: Definition of a methodology for reactivity monitoring in ADS and definition of procedures for start-up, loading, operation and shut-down.*

As a result of the MUSE project, a proposal of a methodology for reactivity monitoring in ADS was presented. Within the tasks 2.1.2, 2.1.3 and 2.1.4 the different parts of this methodology were examined. Based on these results, results from WP2.2 on feedback effects, accelerator performances and operational conditions defined in DM1 DESIGN, a more detailed and validated methodology will be worked out for XT-ADS/EFIT. Uncertainty and bias for the different individual techniques as well as for the global reactivity determination methodology will be derived.

Based on:

- the experience gained with the different measurement techniques in various operational conditions,
- input from WP2.2 on feedback effects and operational experience procedures
- operational constraints from DM1 DESIGN

procedures for start-up, loading, nominal operation and shut-down will be established.

Within this work-package also an evaluation of a measurement methodology for kinetic parameter determination in sub critical conditions propose will be carried.

## **2.2 List of Tasks and Coordinating Responsibilities**

The different WP2.1 tasks which have been identified in the previous paragraph:

### **Task 2.1.1:**

Definition and characterisation of the different YALINA configurations in view of the investigation of the methodology for reactivity monitoring.

Co-ordinating Organisation: KTH – W. Gudowski

Partners: KTH, Institute for Power&Nuclear Research-"Sosny", CIEMAT, FzK, CNRS, SCK•CEN

### **Task 2.1.2:**

Investigation of the current-to-flux reactivity on-line monitoring technique

Co-ordinating Organisation: CNRS – A. Billebaud

Partners: CNRS, SCK•CEN, KTH, Institute for Power&Nuclear Research-"Sosny"

### **Task 2.1.3:**

Investigation of the interim calibration techniques used at beam trips for cross-checking of the current-to-flux on-line reactivity monitoring technique.

Co-ordinating Organisation: SCK•CEN - P. Baeten

Partners: SCK•CEN, CIEMAT, Institute for Power&Nuclear Research-"Sosny", CNRS, KTH

### **Task 2.1.4:**

Investigation of full calibration techniques for kinetic parameters during loading/start-up procedures.

Co-ordinating Organisation: CIEMAT – E. Gonzalez

Partners: CIEMAT, KTH, Institute for Power&Nuclear Research-"Sosny", SCK•CEN, Chalmers

### **Task 2.1.5:**

Definition of a methodology for reactivity monitoring in ADS and definition of procedures for start-up, loading, operation and shut-down.

Co-ordinating Organisation: SCK•CEN – P. Baeten

Partners: CNRS, CIEMAT, KTH

## **3. Deliverables**

To each of the tasks described in the previous paragraph corresponds one deliverable.

**D2.1.1** due M09: Report on the definition and characterisation of the different investigated configurations in YALINA

**D2.1.2** due M24: Report on the results and interpretation of the measurements with the current-to-flux technique in YALINA

**D2.1.3** due M30: Report on the results and interpretation of the measurements with the interim calibration techniques in YALINA

**D2.1.4** due M30: Report on the results and interpretation of the measurements with the full calibration techniques in YALINA

**D2.1.5** due M36: Synthesis report on the methodology for reactivity monitoring in ADS and procedures for start-up, loading, operation and shut-down.

## **4. Milestones and expected results**

Schedule of tasks (M=Month after start of project)

M01 – M09: Definition and characterisation of the different investigated configurations in YALINA

M09 – M24: Results and interpretation of the measurements with the current-to-flux technique in YALINA

Input required from:

DM1 DESIGN: Accelerator performances due M12

M09 – M30: Results and interpretation of the measurements with the interim calibration techniques and full calibration techniques in YALINA

Input required from:

DM1 DESIGN: Accelerator performances due M12

M24 – M36: Definition of a methodology for reactivity monitoring in ADS and procedures for start-up, loading, operation and shut-down.

Input required from:

DM1 DESIGN:	Accelerator performances due M12
DM2.2 RACE:	Characterisation of the feedback effects due M24
DM5 NUDATA:	Nuclear data uncertainties due M12

Milestones (Mx.y \_M= Milestone x.y to be reached at Month M)

**M2.1\_M09:** Definition and characterisation of the different investigated configurations in YALINA

**M2.2\_M24:** Applicability of the current-to-flux technique for an ADS based on the detailed results and interpretation of the measurements with the current-to-flux technique in YALINA

**M2.3\_M30:** Applicability of the interim calibration techniques for an ADS based on the detailed results and interpretation of the measurements with the interim calibration techniques in YALINA

**M2.4\_M30:** Applicability of the full calibration techniques for an ADS based on the detailed results and interpretation of the measurements with the full calibration techniques in YALINA

**M2.5\_M36:** Synthesis for the methodology for reactivity monitoring in ADS and for procedures for start-up, loading, operation and shut-down.

The estimated duration of this work are 3 years.

## Chart of schedule tasks (DM2 WP2.1 – Specifications)

Months starting from beginning of IP	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
Task 2.1.1 YALINA characterisation			D1.1													
Task 2.1.2 Current-to-flux technique								D1.2								
Task 1.1.3 Interim calibration techniques										D1.3						
Task 1.1.4 Full calibration techniques										D1.4						
Task 1.1.5 Methodology for reactivity monitoring												D1.5				
Definition and characterisation of the different YALINA cores			M1.1													
Applicability of current-to-flux technique for ADS								M1.2								
Applicability of interim calibration techniques for ADS										M1.3						
Applicability of full calibration techniques for ADS										M1.4						
Definition of methodology for reactivity monitoring												M1.5				

**D1.x: Deliverable x**

**I1.x: Interim Report x**

**M1.x: Milestone x**

## Chart of schedule answer sheets required by DM2.1 – Specifications

Months starting from beginning of IP	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
DM1 DESIGN																
Accelerator performances				A1,x												
DM2.2 RACE																
Feedbacak effects								A2,2								
DM5 NUDATA																
Nuclear Data Uncertainties for XT-ADS				A5,1												

**M1.x:** Milestone x

**Ax.y:** Answer sheet y from domain x

# **ANNEX I**

## DM2 – DELIVERABLE LIST: Link between Outline Document and Proposal

The Deliverables reported in the outline document were summarised in the proposal in the following way:

### WP2.1: Determination of the optimal reactivity monitoring methodology for XT-ADS/EFIT based on zero-power, CW YALINA experiments

Deliverable in proposal	Title of Del in proposal	Corresp. Del in Outline doc.
D2.1	Report on the definition and characterisation of the different investigated configurations in YALINA	D2.1.1.
D2.2	Report on the results and interpretation of the measurements with the current-to-flux technique in YALINA	D2.1.2.
D2.3	Report on the results and interpretation of the measurements with the interim calibration techniques in YALINA	D2.1.3.
D2.4	Report on the results and interpretation of the measurements with the full calibration techniques in YALINA	D2.1.4.
D2.5	Synthesis report on the methodology for reactivity monitoring in ADS and on procedures for start-up, loading, operation and shut-down.	D2.1.5.