DOMAIN 2

Full Title: **Experiment on the Coupling of an Accelerator, a spallation Target and a Sub-critical blanket**

Acronym: **DM2_ECATS**

2 nd Draft of a programme proposal
(D. Struwe, FZK, Germany; June 29 th,2005)

List of Participating Institutions (incomplete!):

Table 1: List of Participating Institutions.

N°	Partner	Country
P1	FZK	Germany
P5	CEA	France
P6	CIEMAT	Spain
P8	CNRS	France
P12	ENEA	Italy
P13	ENEN (TUD-NL, CIRTEN, KTH, UPM, UPV, …)	Europe
P23	NRG	Netherlands
P28	SCK-CEN	Belgium

DM2 ECATS Co-ordinator: (interim FZK - J. Knebel/ D. Struwe)

Proposal summary

Experimental support for the development of the ADS concept and its associated performance

There is a wide international consensus on the fact that an experimental program is needed to improve the knowledge about the dynamic behaviour of an ADS and to validate calculation methods, in terms both of the physics parameters important for safety :

- source importance,
- reaction rate (power) distributions,
- reactivity (subcriticality) measurements.

and also in terms of operational parameters (at power) :

- startup and shutdown procedures,
- current/power/control rod relations (operating schemes, handling burnup swings),
- dynamic behavior at different subcritical levels (feedback effect).

Moreover, a full validation of the ADS concept, at the end will require a full-scale demonstration of the coupling of the different system components (proton accelerator, spallation target, subcritical core).

The expressed needs coming from IP-EUROTRANS DM1, towards IP-EUROTRANS DM2 are :

- Qualification of sub-criticality monitoring,
- Validation of the 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,
- Qualification of the proton beam reliability and the beam transport line, Pb-Bi or Pb-spallation target design in association with relevant proton beam and the effects of spallation residues including that of polonium,
- Safety and licensing issues of different component parts as well as that of the inte-grated system as a whole.
- Qualification of the impact of the high energy protons and the fast neutron flux on the damage of structures and shielding issues.

To satisfy this request, the EU strategy for the 6th Framework Program is to participate to three major experimental programmes, namely the Reactor-Accelerator Coupling Experiments (RACE) in the USA, SAD in RUSSIA and YALINA in BYELLORUSSIA. RACE is already underway and its funding has been continuously supported by the US/DOE, as a significant University contribution to the AFCI program. SAD after an initial funding by ISTC, will seek in 2005 a further financing from ISTC and DUBNA.

European scientists are already involved in the SAD abd the YALINA experiments, and the key US experimentalist is also fully involved in RACE.

On basis of proposals provided by P. Granget with contributions from D. Beller and G. Imel (see Appendix A), by V. Shvetsov with contributions from W. Gudowski and C. Broeders (see Appendix B), by P. Baeten and H. Ait Abderrahim (see Appendix C) and by E. Gonzales and D. Villarmin (see Appendix D) a first draft of a work programme proposal has been established which intended to take maximum advantage of the different capabilities in the above mentioned experimental facilities with the objective to meet the needs from the EUROTRANS DM1 as listed in Appendix E.. This first draft was intensively discussed at the 3rd ECATS meeting in Saclay on June, 23rd 2005 and some modifications to the 1st proposal were recommended and approved. As a result we have combined now the different tasks to be performed within the ECATS program into the following four Work Packages:

WP 2.1: Qualification of sub-criticality monitoring and of the core power/beam current relationship.

WP 2.2 Validation of the generic dynamic behaviour of an ADS in a wide range of sub-criticality levels and with consideration of thermal feedback effects.

WP 2.3 Impact of high energy protons and neutrons, respectively on the target and structures and on shielding issues

WP 2.4 Evaluation of licensing aspects deduced from RACE and SAD in view of the XT-ADS necessities

The content of the different work packages is as follows

WP2.1: Qualification of sub-criticality monitoring and of the core power/beam current relationship.

Co-ordinator:

(interim: SCK•CEN – Hamid Aït Abderrahim)

Partners:

t.b.d.

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 measurements performed in MUSE with those performed in a system with a continuous beam. In this respect, the YALINA facility was selected as one option to respond to the lack of data in this domain. Additional information on this issue can be deduced from the RACE-T and partly from the RACE-LP experimental campaigns and from the start-up measurements in the SAD facility. The final goal of work package WP2.1 is to provide a final and experimentally proven methodology for reactivity monitoring in an ADS.

Task 2.1.1 Zero power, RACE - T Experiments

Coordinator: ???

Participants: ????

Work package description and tasks identification :

The objective of this work package is to prepare the next RACE experimental plan. The characterisation of the critical phase will be performed by fission rate and fast rabbit traverses. The final configurations with generator at the centre will be measured at different sub-critical levels. The direct measurements and those given by the MSA/MSM method will be compared.

A campaign of measurement with the oscillation of a Cf source and the oscillation of specific samples like absorbers will help to settle the interpretation of the sub-critical measurements. The main issues of this phase is to consolidate the reactivity effects of interest, the thermalhydraulic conditions of TRIGA cores to 100 kW and to prepare the instrumentation (oscillations of Cf source and different samples, Piccolo Micromegas, …) for the next phases of ECATS in US.

The experimental conditions, characterized by deep levels of sub-criticality and by different strengths of external neutron sources, require new detectors, new devices for their positioning in the reactor core, and special dedicated acquisition systems. The instrumentation (including Piccolo Micromegas) and acquisition systems must be developed to determine the sub- criticality and the relation current/power for ADS in a large scale of sub-criticality (between K=0,95 and 1).

Task 2.1.2 Low power, RACE - LP Experiments

Coordinator: ???

Participants: ????

Task 2.1.2.1 Selection of core configurations for the low power experiments

The objective of this work package is to review and to qualify the capabilities of the different low power experiments with European calculation tools concentrating on the initially planned US experiments considering a ~10 kW core power for ~1 kW electron beam power. This work package addresses core, accelerator and target aspects and is to be seen as a kind of a reference for the performance of the high power experiments to be performed in the RACE program Phase 4.

Task 2.1.2.2 <u>In-pile instrumentation, measurement devices, experimental techniques and data acquisition system fort he RACE – LP experiments</u>

Coordination :

Participating Associations: …

The compact TRIGA cores and the RACE experimental conditions, characterized by deep levels of sub-criticality, require new detectors, new devices for their positioning in the reactor core, and special dedicated acquisition systems.

Fission reaction rates, source importance, and spectral index measurements will be performed.

The instrumentation must be developed to be able to follow the dynamics of RACE through the experiments: Reactivity measurements, Reactivity monitoring, Power/current/source importance relation (operational experiments).

Task 2.1.2.3 <u>Support to transient behaviour assessment of the TRIGA-reactors</u>

Coordination :

Participating Associations: …

This Work Package will support the steps requested for the assessment of RACE experiments.

The use of both standard and advanced methodologies will provide an additional proof that the updating requested by the subcritical configuration guarantees the safety and control functions in the RACE experiments.

The most suitable calculation tools for the transient analysis will be used to support assessment of the final design of the facility on the main safety issues if necessary.

The validation of the transient behaviour will be characterised on the critical core in the range of 30-100 kW.

These objectives will be reached through the following subtasks:

(a) Support to the Review of control and safety system
(b) Core and system transient analysis

Task 2.1.2.4 <u>RACE – LP commissioning tests, LP experiments and interpretation</u>

Coordination :

Participating Associations: …

The low power phase will provide the input for interpretation of the transition from RACE - T (near zero power) to RACE high power stage : validation of techniques and experimental plan after MUSE and RACE - T.

The objectives of this work package will be - besides the interpretation of the RACE- T and the RACE - LP experimental campaign - the analysis of the linking of the experiments with the MUSE-4 outcomes.

Task 2.1.3 Zero power, CW YALINA experiments

Coordinator: ???

Subtask 2.1.3.1: 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_{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.

Subtask 2.1.3.2: 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, ρ the reactivity (K_{eff}-1/K_{eff}) and φ^* 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 2.1.3.2 the feasibility of this technique for on-line reactivity monitoring will have to be demonstrated. Since due to the consumption of the ^{3}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.

Subtask 2.1.3 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.

Subtask 2.1.3.4 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 2.1.1.4.

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 2.1.4 Zero and low power, SAD experiments

Coordinator: tbd

Participents: tbd

Subtask 2.1.4.1 Start-up experiments in the SAD facility using the (D-T) source

The start-up phase will be highly influenced by the results obtained in BFS. It is foreseen that two configurations will be loaded during this phase of the experiments. First with $k_{eff} = 0.97$ and the final configuration with $k_{eff} = 0.95$. These two configurations will help validating the PNS reactivity measurement techniques for SAD. The objective for this phase is the calibration and implementation of different techniques (BFS and MUSE kinetic techniques), and to determine the reactivity of the system before initiating the accelerator phase.

These activities could be arranged in the following tasks:

1. Design of the two configurations
2. Set-up of the configurations
3. Calibration of the detectors and electronic chains present in SAD to work with low intensity source (pulse mode)
4. Transport and tuning to SAD of the data acquisition systems used during the MUSE and BFS experiments
5. Calibration and monitoring the (D-T) source
6. Validation of the thermal neutron shielding for diagnostic techniques
7. Estimation of SAD kinetic parameters with the simulation tools calibrated at BFS
8. Kinetic experiments in the subcritical configuration to determine the reactivity of the system
9. Analysis of the experimental results
10. To study of a core heating system to perform the kinetic experiments at the same temperature conditions that will be found with the proton accelerator

Subtask 2.1.4.2 Experiments in the SAD facility using the 660 MeV proton accelerator

The experimental campaign using the proton accelerator will be carried on a configuration with k_{eff} around 0.95. The key point of this phase will be the validation of an experimental technique based on a power to reactivity relationship and of the electronics and analysis of kinetic reactivity determination methods at significant power. The first technique cannot provide an absolute reactivity monitoring, hence, the second will be used as a reference calibration. Several objectives should be covered in this phase. First, it should provide a guide to license a nuclear reactor coupled with a proton accelerator; second, it will be the first time reactivity determination techniques are experimentally validated at power. Third, it should allow the experimental validation of high energy transport and associated shielding requirements for radiological protection during operation. Fourth, it will provide the necessary tools to investigate the radiological effect of a spallation source in the decommissioning of ADS. Last, it will provide an extensive experimental data set that will allow the validation of computational tools used for the design of a future ADS.

These activities should be arranged in the following manner:

1. Determination of the detectors and electronic chains required in SAD to work at full power
    i. Using fast extraction
    ii. Using slow extraction
2. Calibration of the detectors and electronic chains at full power
    iii. Using fast extraction
    iv. Using slow extraction
3. Development and validation of new data acquisition systems adapted to work with current mode detectors for kinetic measurements
    v. Using fast extraction
    vi. Using slow extraction
4. Definition of experiments
    vii. Using fast extraction (area method, slopes method)
    viii. Using slow extraction (source jerk, integrated slopes method, power to reactivity method)
    ix. Simulation support for the experiments
5. Monitoring of the accelerator and the importance of the source
    x. Online monitoring of the beam current
    xi. Monitor the number of neutrons per proton (part of source important)
    xii. Monitor the geometric distribution of primary neutron source (diagnostics for source importance)
6. Neutron fluence determination across large thickness shielding
    xiii. Definition and set-up of the detectors
    xiv. Measurement of the neutron fluence after lead, concrete and iron shielding
    xv. Comparison with the results obtained by simulation codes
7. Determination of the effects of using the thermal neutron shielding in the kinetic experiments

8, Kinetic experiments using fast extraction mode of the accelerator: area method and slopes method

9. Kinetic experiments using slow extraction mode of the accelerator: source jerk and integrated slopes method

10. Calibration of SAD power

11. Determination of the techniques that will be used to calibrate the power to reactivity technique

12. Experiments of power to reactivity online monitoring

13. Feedback experiments
    xvi. Temperature variation of the fuel
    xvii. Fast reactivity variation using insertion or extraction of absorbers
    xviii. Oscillation of reactivity with absorbers and/or fissile material

14. Static and kinetic measurements of the axial and radial(?) fission rate traverses to validate simulation codes

15. Interpretation of the experimental results

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.

Coordinator: tbd

Participants: tbd

As a result of the MUSE project, a proposal of a methodology for reactivity monitoring in ADS was presented. Within the tasks 2.1.1 and 2.1.2 the different parts of this methodology will be examined. Based on these results, results from WP2.2 on thr impact of 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.

WP 2.2: Validation of the generic dynamic behaviour of an ADS in a wide range of sub-criticality levels and with consideration of thermal feedback effects.

Co-ordinator:
(interim CEA – P. Granget)

Partners:
t.b.d.

The objectives of this work package can best be met by participation in the two experimental programmes RACE and SAD. The RACE experiments are subcritical experiments to be performed in TRIGA reactors at power, with the external neutron source provided by photo neutrons obtained by interaction with a metal (e.g. : WCu and Uranium depleted) target of bremsstrahlung photons, obtained with an electron accelerator.

These experiments, as specified below, can provide the crucial validation of the behaviour of a subcritical core at power, in a wide range of subcriticality levels. In particular, it is foreseen by the major partners of the international collaboration, to perform essential tasks in support of the RACE experiments.

The table hereafter summarises the complementarities of the different experiments, including MUSE (realised during the 5^{th} FP).

Validation of:	Full coupling of real ADS components	Physics and kinetics of an external-source driven subcritical core at ~0 power	Dynamics and experimental techniques of an ADS at power with feedbacks	High energy neutrons propagation	Power/beam current relation validation	Operations at power (start-up/shutdown /scram)
TRADE	YES	YES	YES	NO	YES	YES
RACE	NO	YES	YES	NO	YES	YES
SAD	YES	YES	NO (*)	YES	(NO)	NO
YALINA	NO	YES	NO	NO	YES	NO
MUSE	NO	YES	NO	NO	NO	NO

(*) YES, if power extended to ~100kW

The RACE experiments and their contribution to the specifications

RACE provides in a wide range of subcriticality some of the most significant validations expected since it is planned to use TRIGA reactors. In fact, a first series of experiments, essentially to validate experimental techniques in some preliminary subcritical configurations, is planned at UT NETL, and a second, more detailed, experimental campaign is planned at the TAMU TRIGA, which offers more experimental flexibility.

UT NETL is a TRIGA nearly identical to CASACCIA :

- same fuel
- hexagonal grid versus circular grid in Casaccia (0,96 in. spacing)

TAMU is a TRIGA also but with different fuel and grid :

- it’s called FLIP fuel (70% enriched uranium with Er burnable poison
- square grid (1,53 in. spacing)

Planned for 10 kW core power, with 20 -25 MeV electron LINAC (~2kW beam power), this power will be largely increased to 100 - 150 kW with a high power accelerator (~30 kW beam power), sufficient to implement the power feed-back effects in two different TRIGA types reactors UT NETL and TAMU.

Preliminary tests are foreseen during the RACE - T (for RACE in Trade) phase in the TRIGA type reactor of CASACCIA : measurement of the main reactivity effects important for the next RACE phases, tests of instrumentation :

- piccolo-micromegas, oscillator
- X-mode advanced acquisition system for ADS. This equipement is developped taking into account the MUSE experiment
- techniques : oscillation.

The neutron spectrum which can be obtained in the RACE experiments, will demonstrate a continuum structure relatively similar to the spallation continuum finishing to ~40MeV (instead of ~140MeV foreseen for TRADE).

The SAD experiments and their contribution to the specifications

Creation of large sub-critical accelerator driven systems ADS should precede experimental checks of the theoretical predictions and estimation of technological features of such systems. Tasks requiring the solution are:

- Substantiation of safety of operation of such systems;
- Calculation of the ADS power gain;
- Choice of fuel, target type and reflectors;
- Designs of an active core;
- Development of methods of reliable monitoring of keff;
- Measurement of the ADS power gain;
- Measurement of the contribution of high-energy (E >10 MeV) part of a neutron spectrum, especially important for creation of reliable radiation protection.

To resolve these tasks the ADS with thermal power of about 15 kW in principal is sufficient.

In JINR the experimental and theoretical works on usage of the proton accelerators in nuclear technology are conducted from middle of the 50-s' years. The yields of neutrons and their spectra in lead and uranium targets of various types, neutron cross sections for a number of isotopes, important for an estimation of efficiency of various modes of transmutation are measured, the mathematical models with appropriate constant databases and software for calculation of electronuclear systems properties are created. JINR has the license for operation the research nuclear reactors with active cores with metal plutonium and plutonium oxide. These reactors are maintained reliable and safely within more than 35 years. JINR has also the long-term experience of operation of proton accelerators. All mentioned above is a good basis for creation and subsequent use in Dubna of the experimental ADS with MOX fuel. The JINR international status allows joining the financial contributions of the JINR member countries. The creation in JINR of the subcritical assembly with MOX fuel based on standard fast neutron reactor BN-600 fuel elements, will give unique experimental basis for solving the complex tasks connected to a problem of safe maintenance of subcritical fast assemblies driven by proton accelerator and nuclear waste transmutation.

Given project will be the natural step on the way from experimental subcritical assemblies of zero power, driven by external neutron source (MASURCA, BFS, YALINA) to proton beam driven semi industrial installations (MYRRHA, TRADE) which are now designing at Europe.

During implementation of the present project the complex of the design and construction works will be fulfilled according to normative documentation of Russian Federation and in volume providing in future creation of experimental installation SAD at JINR, and also the time profile and financial expenditures on its creation will be defined. In particular works on the AC, proton beam line and fuel element (FE) technical projects will be fulfilled, the technology of manufacture of fuel pellets made of MOX fuel will be designed, the technology of manufacture and assembling of the FE will be prepared and tested, production will be prepared and test batch of the fuel pellets will be manufactured. Within general engineering project the part of the project, necessary for licensing will be released, including substantiation of the safety operation (SSO).

It will allow at presence of sufficient financing creating experimental installation (SAD) on the basis of the proton accelerator with energy 660 MeV with replaceable target and subcritical blanket with mixed-oxide (MOX) uranium-plutonium fuel.

In the present project the following tasks will be fulfilled:

- On the basis of computer codes developed in JINR and other centers, modeling of the process of interaction of protons with a heavy target and ADS parameters will be carried out to optimize the installation design.
- Optimization of the spallation target design, estimation of the effects of charged particle interactions with the fuel in vicinity of a spallation target will be realized.
- Experimental ADS installation based on subcritical assembly with keff ≈ 0.95 and JINR proton Phasotron with thermal power 15 - 20 kW will be designed (design and calculation documentation developed).
- The following computer codes will be used in SAD-project: MCNP/MCNPX, CEM and eventually some others, depending on collaboration within SAD project.

At the following stage – stage of creation and maintenance of the installation the following tasks will be solved.

- Documentation of equipment for the plants-manufacturers will be designed.
- The complex of civil work will be fulfilled.
- Equipment will be manufactured and mounted on site.
- The starting-up and adjustment works will be carried out and putting of the installation into operation will be realized.
- Main characteristics (neutron yield, spectral and angular distributions) of the heavy neutron producing targets made of Pb, Pb-Bi, W will be measured. It's characteristics dependencies on proton energy, dimensions and shape of the proton beam will be studied. Those data, if appropriate will be used for validation of the computer codes.
- The measuring techniques for neutronic and kinetic characteristics of subcritical assembly will be prepared and the first test measurements are conducted. The equipment and techniques for realization of experiments on measurement of minor actinides and fission products transmutation reaction rates in subcritical assembly will be prepared.

Task 2.2.1 Experimental demonstration within the RACE – HP Programme

The work to be done within this task will cover a reevaluation and extension phase of the design of the RACE facilities and experiments according to the needs of high power phase of the program. This will include the detailed design of the target, the qualification, the follow-up of its realization and its cooling system ; support to the core characterisation ; in-pile instrumentation and experiments ; interpretation of the in-pile experiments, dynamic code validation, transposition of the results to the XT-ADS and EFIT design.

Accordingly, the RACE program has been subdivided into four subtasks :

- **T 2.2.1.1 Reevaluation and extension of the design of the RACE facilities**
- **T 2.2.1.2 Support to Safety Analysis and transient behavior assessment**
- **T 2.2.1.3 In-pile instrumentation, commissioning tests, experimental techniques development and validation**

- **T 2.2.1.4 Experiments interpretation, code validation and transposition to future ADS development : SAD, XT-ADS, EFIT.**

In the following, a detailed description of the technical activities, tasks identification and list of deliverables and milestones are provided for each of the five Work Packages.

T 2.2.1.1: Reevaluation and extension of the Design of the RACE facilities and experiments

Coordination :

Participating Associations: …

Work package description and tasks identification :

The objective of this work package is to review and to extend the capabilities of the different experiments with European calculation tools. The initial planned US experiment was considering a ~10 kW core power for ~1 kW electron beam power. The extended experiments to be performed within this task will consider ~100 kW core power for ~30 kW electron beam power. This will be obtained by changing the target material (probably uranium depleted uranium instead of WCu) and up-grading the accelerator power. Therefore, this work package addresses core, accelerator and target aspects. At this stage, the dose impact due to the new gamma source (and neutron induced source) in the building will be evaluated.

The objectives of this work package will be achieved through the following tasks:

(a) Review and definition of the core configurations

(b) Review of the target design and target-core coupling issues

(b) Target cooling design and qualification

T 2.2.1.3: Support to transient behaviour assessment

Coordination :

Participating Associations: …

Work package description and tasks identification::

This Work Package will support the steps requested for the assessment of the RACE –HP experiments.

The use of both standard and advanced methodologies will provide an additional proof that the updating requested by the subcritical configuration guarantees the safety and control functions in the RACE - HP experiments.

The most suitable calculation tools for the transient analysis will be used to support assessment of the final design of the facility on the main safety issues if necessary.

These objectives will be reached through the following subtasks:

(a) Support to the Review of control and safety system

(b) Core and system transient analysis

T 2.2.1.4: In-pile instrumentation, commissioning tests, and experimentsof the RACE – HP phase

Coordination :

Participating Associations: ...

Work package description and tasks identification :

These objectives will be reached with the following subtasks:

(a) In-pile instrumentation, measurement devices, experimental techniques and acquisition system

(b) Low power phase experiments

(c) High power phase experiments

T 2.2.1.5: Experiments interpretation and transposition to future ADS development : SAD, XT-ADS, EFIT

Coordination :

Participating Associations: ...

Work package description and tasks identification :

The objectives of this work package will be - besides the interpretation of the entire RACE experimental campaign - the analysis of the linking of the RACET experiments with the MUSE-4 outcomes, and in turn the transposition of RACE (and MUSE-4) results to XT-ADS and EFIT design.

The transposition concerns the main issues of RACE program : 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, core power/beam current relationship, start-up and shut-down procedures, instrumentation and specific dedicated experimentation, safety and licensing issues.

The different organizations participating in this Work Package will use both deterministic and Monte Carlo codes for their analyses.

The objectives of the interpretation package will be achieved through the following subtasks:

(a) Interpretation of the RACE high power Phase
(d) Transposition of RACE outcomes to XT-ADS and EFIT design.

Task 2.2.2 Experimental demonstration within the SAD Programme

During SAD project realization the facility (especially central part – target unit and fuel assemblies – and reflector) will be certified with high precision. Each fuel element will have own certificate with fuel isotopic content (^{239}Pu content will be given with 10^{-4} accuracy, ^{238,240,241,242}Pu – with 10^{-5} accuracy), fuel weight/density with accuracy 10^{-4}). Construction materials also will be certified according to the GOST standards. It'll give the possibility for precise modeling of the sub-critical assembly and benchmarking/code validation activities.
SAD experiments may also be used to validate newly developing routines for neutron importance determination in the continuous energy Monte Carlo codes.

Contributions from the SAD programme will be organized in two tasks:

T 2.2.2.1 Validation of generic dynamic behavior of an ADS in a wide range of sub-critical levels, sub-criticality safety margins and thermal feedback effects:

Subtasks which will be covered in this part cover:

a) Detail investigations of possible experiments to "simulate" dynamics of SAD without altering the design principles
b) Implementation – if appropriate – of experimental techniques and participation in experiments

BFS experiments during SAD construction

The proposal is to use the BFS assembly during SAD project preparation in a SAD-like configuration with a PNG (5 10^6 n/pulse, 1 µs pulse width, 20 Hz repetition rate). At BFS, subcriticality ranges from critical configuration down to deep subcriticality. This series of experiments should study and characterize a clean configuration built with lead and fuel similar to SAD. The two main objectives of this study will be: first, to allow the calibration of the simulation tools that will be used to model SAD; second, to allow the development of an experimental technique that can be transferred directly to the SAD facility to be during the start-up period for subcriticality measurements by PNS methods, and which will accumulate the experience from MUSE, YALINA and JINR experiments with IBR-30 booster. Additionally, if the schedule of SAD fuel fabrication and SAD construction allows it, it will be interesting the use of the actual SAD fuel in the BFS facility to determine its β_{eff} and to simulate the start-up phase of SAD.

These activities could be arranged in the following tasks:

1. Design of the most suitable BFS configurations
2. Set-up of the selected configurations
3. Calibration of the detectors and electronic chains present in BFS

4. Transport and tuning to BFS of the data acquisition systems used during the MUSE experiments
5. Calibration and monitoring of the (D-T) source during the experiments
6. Determination of the kinetic parameters of the system in the critical configuration
7. Kinetic experiments in subcritical configurations with k_{eff} = 0.95 and 0.97
8. Analysis of the experimental results
9. Detailed description of the configuration to be used as international benchmark (simulation code calibration)

To study the possibility to load BFS with the SAD fuel in a critical configuration in order to determine the kinetic parameter β_{eff} of SAD fuel

c) Processing and interpretation of the data
d) Report and recommendations

T 2.2.2.2 Interpretation and validation of experimental data, Benchmarking and code validation activities etc

ECATS takes full responsibility for this package in close collaboration with the SAD team and covers the following subtasks:

(a) ECATS is responsible for all simulations, code improvements, uncertainty analysis etc
(b) SAD-team guarantees necessary precision of all materials, istopic and geometry data.

WP2.3: Impact of high energy protons and neutrons, respectively on the target and structures and on shielding issues

Coordinator:

(interim KTH – W. Gudowsky)

Participating organisations: tbd

In this work package all activities performed in the different experimental programs related to these issues are combined into one set of activity. The work package will consist mainly of the following tasks:

T 2.3.1 SAD target design evaluations

T 2.3.2 SAD target materials investigations

T 2.3.3 Validation of “radiological/radiation protection” calculations

T 2.3.4 Radiation shielding and radiation doses

T 2.3.5 Specific design aspects of the beam line for XT-ADS and EFIT, respectively

T 2.3.1 SAD target design evaluations

Two replaceable targets: W and Pb will be used in SAD-experiment. The design of targets is different due to the difference in physical properties and different neutronics. Detailed calculations of the targets neutronics are fulfilled at design stage of the ISTC project #2267. Members of the ECATS community will review the respective analyses and perform uncertainty analyses if found necessary.

T 2.3.2 SAD target materials investigations

Experiments with bare lead targets irradiated at JINR Phasotron aimed to measure spallation products yield with He loop technique were prepared in the beginning of 2005. Experiments will be continued at JINR Nuclotron accelerator. At the working design stage of the SAD facility the design of the lead and tungsten targets with He loops will be developed.

Extensive "post irradiation" tests are foreseen for the SAD spallation targets. Special attention will be paid to Po production and Po migration in the Pb spallation target. Samples of the Pb reflector will also be investigated in order to assess radiological and decommissioning problems related to use of Pb in ADS.

ECATS can take responsibility (with UMM involvement) for measurements on bare targets, such as: beam heating power, radiation fields around the target with the use of dosemeters and microdosimetric counters (for validation of calculations), time structures of the beam and the generated neutron field (original and with spectra modified by inserted moderators; also for testing the experimental equipment)

T 2.3.3 Validation of "radiological/radiation protection" calculations

Validation of "radiological/radiation protection" calculations are badly necessary!! We already observed large discrepancie between code predictions and our experimental results!

These activities will combine all the respective support work to the SAD project. It will be organised in one Task.

T 2.3.4 Radiation shielding and radiation doses

The presence of the 660 MeV proton accelerator in SAD introduces a new dimension to the radiation shielding concerns, compared to the operation of critical reactors, due to the long range of high-energy neutrons created in the spallation reactions. The SAD experiments provide a good opportunity to validate the pre-calculations of the radiation doses at various places outside the biological shielding.

ECATS – co-partner (UMM group contributes to experiments). Simulations and interpretation of results and preparation of the final report will be done by members of the ECATS community.

T 2.3.5 Specific design aspects of the beam line for XT-ADS and EFIT, respectively

To be specified (A: Müller, CNRS)

WP 2.4 Evaluation of licensing aspects deduced from RACE and SAD in view of the XT-ADS necessities

Coordinator:

(interim FZK – D. Struwe)

Participating organisations: tbd

Safety assessment report for the SAD assembly is already fulfilled within ISTC project #2267 (NIKIET project). Safety assessment of the integrated system is under preparation and will be ready in June 2005. Immediately after that the licensing procedure will be started. All preparatory tasks are completed at present time. List of required documents/actions is prepared with phone numbers/addresses of the corresponding authorities, commissions, and agencies. At present in Russia the new version of the "Safety Regulations for Nuclear Installations" – main normative document is under preparation. JINR, NIKIET and GSPI are involved in preparation of this new version, specifically in elaborating the rules for ADS systems (in old version such category didn't exist).

All documents related to Safety and licensing issue will be translated into English in order to supply our Western collaborators with relevant information and data. Clearly a lot of requirements and procedures are not transferableto other countries but we can prepare kind of GENERIC SAFETY AND LICENSING document for ADS , where some general, basic requirements (probably 80-90% of requirements for S&L are not country specific) will be addressed. Or we can try to match SAD S&L documents against e.g. NRC (we do not have European requirements yet, but they may come in few years..)

This work package contains three tasks:

T 2.4.1 Evaluation of the SAD safety analysis report and its impact on generic aspects for licensing of an ADS

The SAD-team is fully responsible for the preparation of the SAD related licensing documents. Transfer of all documents to members of the ECATS team will be initiated.. Assessment and analysis of these documents will be done by members of the ECATS community. Feedback to the SAD team will be provided if identified of importance..

T 2.4.2 Evaluation of ADS- related aspects of licensing activities requested to be performed within the different phases of the RACE program

The different RACE-teams are fully responsible for the preparation of the licensing documents. Transfer of the documents of importance for evaluation of ADS specific aspects to members of the ECATS team will be initiated.. Assessment and analysis of these documents will be done by members of the ECATS community. Feedback to the RACE teams will be provided if identified of importance..

T. 2.4.3 Extraction of knowledge from the licensing experiences gained in SAD and RACE and transposition to the necessities of the XT-ADS design

Extrapolation of common aspects of licensing of an ADS plant will be identified and summarized in a document in relation to the necessities of the design if XT-ADS