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Methodology, Analysis and eXperiments for the “SafetyIn MYRRHA Assessment”

EC project officer: Mykola DZUBINSKY

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Introduction

The progress of the work of the different technical work packages of MAXSIMA at mid-term was discussed during the 5th semi-annual review meeting, held at ENEA in Bologna, Italy on 25-26 November 2015.

I. WP 2 Safety analysis in support of MYRRHA

The sixth Work Package 2 Technical Meeting was held at ENEA headquarters in Bologna on Tuesday, 24th November 2015. The minutes of the meeting (reported by D. Castelliti, SCK•CEN) can be found on the MAXSIMA website in the folder documents/WP2 meetings. This WP2 meeting was organized in parallel with the general MAXSIMA review meeting to allow extended and thoughtful discussions on WP2 topics such as reactor models, assumptions for safety analyses, comparison between different computational tools, etc....

Task 2.1 Neutronic and shielding analysis in support of safety studies

The Task 2.1 activities have been officially concluded. The Deliverable 2.1 has been submitted to the EC on 3rd November 2015 and uploaded on the MAXSIMA website.

Task 2.2 Transient analyses using system codes

Diego Castelliti presented the status of Task 2.2 activities. After the conclusion of the Phase 1, the new configuration for the MYRRHA reactor has been implemented in the STH models through the release of the second Technical Database.

The complete U + S methodology has been applied on the Unprotected Loss Of Flow (ULOF) and Control Rod Ejection (CRE) transients. The Control Rod Withdrawal (CRW) has been evaluated in best estimate configuration only.

The comparison of the definitive ULOF, UTOP-CRE and UTOP-CRW best estimate transient results obtained by the three Task participants actually performing STH calculations (SCK•CEN, ENEA and KIT-INR) has been shown, with the additional contribution of SIMMER-III results shown by KIT-IKET.

The conclusions coming from the application of the U + S methodology on ULOF transient can be summarized as follows:

- Uncertainty bands and sensitivity relative importance are clearly visible
- Pump inertia is the most influent parameter in the first transient evolution phase
- Later transient phase more influenced by physical properties
- Secondary Cooling System related parameters variation ranges are mainly influenced by SCS pressure variation

For what concerns the CRE transient, the main results from the U + S analysis pointed out the following conclusions:

- UTOP-CRE transient mostly influenced by fuel properties
- Fuel heat capacity is the most important parameter during the first reactivity peak
- Fuel conductivity and gap conductance properties are most relevant during steady-state stabilization phase
- Secondary Cooling System related parameters variation ranges are mainly influenced by SCS pressure variation

Task 2.3 Severe accident analyses

X. N. Chen (KIT-IKET) presented the results of a 3-D simulation of a Single FA blockage in the subcritical core. 2-D simulations of partial and total unprotected blockages in a single FA of the MYRRHA critical core have been also performed at KIT-IKET. The sensitivity study of partial and total blockages in the critical core with SIMMER-III showed that wrapper failure occurs only for a total blockage at the inlet of the active region. The results are in agreement with the internal study carried out by SCK•CEN.

As already discussed, the SIMMER-III code has been benchmarked against system codes on the UTOP-CRE and UTOP-CRW scenarios.

Francesco Belloni has presented the advancements in the Task 2.3 activities by SCK•CEN. For what concerns the protected core blockage scenario, the SIMMER-III core model has been updated with the new design data of the MYRRHA core (version 1.6).

Partial results of the protected blockage scenario were run on the preliminary model and important differences can be highlighted compared to the MYRRHA v. 1.4:

- The FA rings fail in a longer time and the interval between consecutive FA ring failures widens because of the much lower power density. As a consequence the pins in the second ring of FA are still intact once the wrapper of the first rings breaks up, and a cooling flow through the FA is restored, by natural circulation, removing also part of the decay heat generated in the following rings.
- Creep failure mechanism, besides cladding melting, can be activated because of the long transient duration (thousands of seconds), and it might lead to anticipated fuel dispersion.

The study of the Damage propagation by particle blockages following internal pin failure has shown how the increased size of the upper pin axial reflector can influence the release time of the particle blockages formed at the top of the pin bundle.

WP2 Action list

- SCK•CEN to issue the write-up of the Task 2.2 Phase 1 activities
- SCK•CEN to check with other participants the reason for slight difference in coolant expansion reactivity feedback
- Everyone to agree on the order to simulate the next transients and to agree on which ones to apply the full U + S methodology
- Everyone to converge on an agreed status for ULOHS transient
- Everyone to approve the final version of the 2nd Technical Database to be finalized in a Non- Contractual Report

II. WP 3 Core component safety

Task 3.1 Thermal hydraulic fuel assembly blockage experiments

J. Pacio (KIT) presented the status of the experimental work on a fuel assembly blockage in a 19-pin bundle. The main objective of this task is the experimental study of the sub-channel and cladding temperature behaviour in a partially blocked rod bundle, representative of the MYRRHA fuel assembly. Unfortunately, the completion of this task might be substantially delayed due to unexpected technical problems, and the related additional work required for fixing them. The 19 high-high-flux electrical heaters are damaged and must be replaced. When ramping up the applied power (390 kW, 4470 A) reaching 99% of the most demanding envisaged conditions (394 kW, 4500 A) a temperature peak exceeding the safety limits (800°C) was detected. The manufacturing of these key components is a challenging and time-consuming process, mainly due to specifications imposed by demanding conditions which they must sustain (both in terms of current and temperature). In particular, thermo-couples shall be installed at selected locations, cold extensions and rod tips must be mounted to each pin, and wire spacers must be attached. The completion of all these steps implies a significant delay of 12 to 18 months for reaching the status prior to this incident. After discussions in the GOV board, it has been agreed that:

- Partner KIT will send a document to the PCO describing the Status and outlook of task 3.1 at the latest on 1st December 2015
- The PCO will contact the EC project officer to discuss the situation and to assess the impact on the financial contribution of EC.

Task 3.2 Safety rod system tests in Heavy Liquid Metal

G. Kennedy presented the status of the experimental Control Rod (CR) test section that is to be installed in the COMPLOT LBE facility. Good progress has been made in the past six months and the shell and guide tube have been preassembled, with the exception of the bundle. The bundle assembly has been delayed by the long delivery time associated with the springs, which are due to arrive in mid-January 2016. Work on the assembly is however progressing where possible and the test section shell, which has been installed in COMPLOT and leak tested, is ready to be heat traced and connected to instrumentation. The task has already exceeded its intended timeframe of 30 months, but is expected to be completed within the timeframe of WP3 (Month 48).

<u>Task 3.3 Fuel Blockage Simulation</u>

H. Doolaard (NRG) presented the status of the numerical work. The pre-test analysis for THEADES (MS14) and the extended parameter study (MS15) are both finished. Recently, a sensitivity study on the blockage filler material was done. The results show that assuming pure lead oxide for the pre-test studies was conservative. All blockage materials show a similar temperature distribution at different flow rates and power input, and so a thermocouple in the centre of the blockage is deemed to be suitable. The simulation of the 127-pin MYRRHA FA blockage is still in progress.

<u>Task 3.4: Numerical analysis of the MYRRHA control rod system:</u>

M. Profir (CRS4) presented the status of the CR CFD numerical analyses. A side meeting between G. Kennedy and M. Profir (CRS4) was held to discuss detailed input and results. Further progress has been made:

- The pressure and level boundary conditions have been updated after comments from SCK•CEN. Previously the supposed free surfaces did not have zero static pressure, and were constrained and therefore exhibit some residual pressure that was not real. The LBE free surface level was originally fixed at 0.5 m, but after adjusting for zero static pressure, this level is now at 0.9 m above the LBE hot level during full flow (36 kg/s) and a pressure difference of 2.5 bar.
- The capabilities of the overset mesh method, in particular the zero-gap interface in the damper have been improved, resulting in a more accurate simulation. Furthermore, the 2-way coupling motion has proven to be successful. The next step is to identify the component forces, together with SCK•CEN, in order to resolve the resultant force and the associated bundle acceleration. The implementation of the free- surface modelling will be next.
- SCK•CEN and CRS4 will compare the steady-state and full-flow loads measured on the CORINTHE water experiment, and also compare the results from the analytical models developed at SCK•CEN.

III. WP 4 Steam Generator and cooling safety

The main objectives of this work package are related to the studies on safety aspects related to leakage or rupture of steam generator in the reactor vessel.

Task 4.1 SGTR analysis on large scale facility (M. Tarantino, A. Pesetti)

Alessio Pesetti (AP) presents the status of Task 4.1. After an introduction of CIRCE facility, AP highlights the objectives of the experimental activity. He shows the pre-tests calculations by SIMMER-III code, executed for designing the test section and the experiments. These analyses have supported the definition of the instrumentation plan in the test section, which is reported in the slides. The P&I is also described. Then, the pre-test analyses by SIMMER-IV are presented. They have the objectives to evaluate the initial and boundary conditions of the tests as well as the main parameter trends expected during the experiments.

Then, AP shows CAD drawings and photo of the component manufactured for the experimental campaign (i.e. the test section and the cover vessel). The presentation is concluded with the summary, including deliverables and milestones.

AP answers also to Paul Schuurmans (SCK•CEN), stating that almost all components for the experimental campaign are available. The test section should be installed by end of 2015. The execution of experimental campaign (four tests) is planned to be completed by April 2016.

Task 4.2 SGTR Bubbles Characteristics (Alessandro Del Nevo)

Alessandro Del Nevo (ADN) presented the status of Task 4.2. He introduced the objectives of the activity. Then, he started to describe the experimental facility and instrumentation according with the planned design. He gives a description of the final design of the experiment, highlighting the modifications needed at LIFUS5 in order to fulfill the objectives of the research. The P&I is described as well as the details of the instrumentation selected.

Next, ADN describes the pre-test performed by RELAP5 and SIMMER-III in order to evaluate the layout and the performances of the water injection system (RELAP5), to identify the specifications of the Coriolis flow meter (RELAP5), and to characterize the bubble formation and migration in the melt (SIMMER-III).

The presentation is concluded with the summary, including deliverables and milestones.

Diego Castelliti asks how the LBE tank and the CCFL are simulated with RELAP5. ADN answers that given the code limitation in terms of fluids, he preserved the pressure head at orifice inlet to evaluate which is the limiting pressure at which CCFL occurs. He also underlined that it is clear that the correct phenomenology cannot be simulated, as well as that he applied the CCFL model more suitable for this kind of geometry. He also expect large uncertainty in the parameter trends, but the main objectives (above) can be achieved, anyway.

Paul Schuurmans asked what was done during the last period and which is the experimental plan. ADN answered that during the last months large part of the time was devoted to prepare the technical specifications and to follow the procurement of the test section, of the instrumentation, of the valves, of the control and acquisition systems. The plan is that the facility will ready by June 2016, in order to complete the experimental campaign by the end of the project.

Task 4.3 Bubble transport validation (A. Konovalenko)

Janne Wallenius (JW) briefly outlines the status of Task 4.3 on behalf of Pavel Kudinov. The presentation starts with the summary of deliverables and milestones. Then, the objectives are outlined.

JW stated that currently the activities are focused on the design and validation of bubble velocity measurement system as well as on manufacturing and procurement of facility components. The procurement activity will be completed in January 2016. The first test is planned between March and May 2016. The experimental campaign will be completed by September 2016, whereas the reporting phase will finish before the end of project.

IV. WP 5 Fuel Safety

WP leader Csaba Roth (INR)presented a summary of the works planned to be carried out and their status in terms of submitted deliverables and accomplished milestones. The stage of works, especially the progress made in the last period, has been presented by speakers as follows:

Task 5.1 Transient testing of MYRRHA fuel

Csaba Roth presented the stage of preparation of transient experiments on MYRRHA type fuel segments to be done in the TRIGA-ACPR reactor in Romania. Irradiation capsule fabrication as well auxiliary equipments assembling and testing have been accomplished. The tests proved the equipment functionality and validated the working procedures. The 2nd edition of the Safety Documentation has been issued and accepted by the Romanian Regulatory Body (CNCAN).

Brian Boer (SCK•CEN) presented the stage of test fuel segments fabrication. Results of pellets fabrication pre tests are presented. Pre-tests provided data on fabrication parameters: powder properties, powder processing parameters, pressing parameters (forces, hold times), sintering parameters (temp, time, atmosphere), and grinding parameters. Based on this knowledge, production with HEU has started. Fuel specifications have been updated based on the findings of the pre-tests.
An informal parallel meeting was held to discuss technical details and the progress of the preparations for the pulse experiment with the participation of Csaba Roth, Mirea Mladin (INR) and Brian Boer (SCK•CEN). It was agreed that deliverable D5.8 concerning the fuel fabrication pre-tests will be issued by SCK•CEN in the coming weeks. Deliverable D5.9 concerning the fuel fabrication will be issued in March 2016.

The fabrication report is important for INR to obtain the license for conducting the irradiation experiment and should therefore not be delayed any further. A test matrix for the irradiation experiments, based on the fuel segments as-built characteristics is requested from SCK•CEN. This matrix has to contain the order (loading) of the irradiation of the test segments. It is proposed to hold a task meeting in 2016 after the first test at INR, Pitesti, dedicated to preliminary evaluation of test results.

Task 5.2 Fuel coolant compatibility up to 1700°C

For the LBE – Fuel Interaction a new approach has been used, as follows: due to the fact that leakage has been observed at 1073.15K (800 °C), and the Alumina crucible experiment raised problems when retrieving the fuel disk, another sample holder has been proposed for further experiments; due to the fact that the melting point of UO2 is approximately 3138 K (2864.85 °C) and MOX is approximately 3010 K (2736.85 °C), it was decided that the pellet itself will be used as a crucible. This was in order to ensure that no cross-contamination of the sample will occur, no leakage, no influence due to physico-chemical properties of the other crucibles will influence the experiment anymore. The proposed sample set-up has been performed by drilling several UO2 pellets (diameter of 0.5 mm with a depth between 3 to 11 mm). Additional to the initial 1073.15K (800 °C), two more temperature points were run: 1273.15K (1000 °C) and 1973.15 K (1700 °C) in the new set-up and identical experimental conditions. After the oven have cooled, the samples were retrieved and, each time and regardless if the temperature was 1273.15K or 1973.15 K, the LBE had completely disappeared from the pellet (crucible). While initially believing that an error could have lead to the disappearance of the LBE from the pellet during the dwell time experiment, several more runs proved that: neither the temperature, nor the geometry of the crucible or the oven itself (another oven was used to run similar experiments) was the cause of the LBE volatilization.

The initial conclusions showed that with the amount of LBE used in the experiments (<50mg) the system needs to be closed to avoid the total loss of LBE if the temperature is high enough (>1000 K). No significant LBE has been detected on the UO2 pellet, however it can be due to the evaporation. The integrity of the pellet was not affected by the temperature and the contact with LBE. Another set of experiments are planned with a heavy weight over the pellet in order to avoid evaporation of LBE. The proposed weight is a disk made of the same material as the pellet (UO2 or MOX) and an additional refractive material.

For the LBE – Cladding - Fuel Interaction, the same conditions were used (temperature and crucibles), however a different approach was used for sealing the crucible (UO2 pellet). The experimental setup consists of a UO2 pellet in which a hole has been drilled with a diameter of 5 mm and a depth of 3 to 11 mm to create a space for the LBE and cladding material. After adding these materials a lid made of UO2 has been placed on the pellet. All the set-up is placed in an guard – crucible of Alumina. Additional weight has been placed on top of the above presented set-up, in order to keep the set-up tight. Despite this effort, LBE has disappeared as well, only small traces of Pb being possible to be detected on the external crucible (Alumina). Even more, after the experiment, the cladding material has changed significantly its structure, Ti is congregating in small grains instead of being distributed evenly in the material as it has been before treatment. More experiments are underway.

Task 5.3 Conceptual design study for experiment in the IGR reactor

Information's about the progress have been sent by NNC. The conceptual design of test device for MYRRHA model fuel pins is developed. Results of calculation studies demonstrate the possibility of ensuring ofrequired test conditions for the pellet fragmentation experiment and fuel coolant chemical interaction (FCCI) experiment at the IGR.

V. WP 6 Enhanced Safety by Design for HLM reactors

Task 6.2 Development of innovative passive safety systems for HLM reactors

Within this task the desirable features identified at the end of the T6.1 were used to develop a conceptual design for an innovative DHR system to be used in any HLM-cooled pool-type reactor. At the heart of the concept is a primary coolant solidification prevention system, based on a non-condensable gas tank connected to the lower header of the system's condenser. The concept is applied to MYRRHA. The performance of the innovative DHR system has been tested, within Task 6.2, against a number of accident transients which are most severe from the point of view of primary coolant solidification.

The analysis show that the latter effect is avoided with some margin with a grace time before the onset of the phenomenon greater than one week (and in some cases one month). Simulations have been performed by RELAP5 (ANSALDO and ENEA) and TRACE (KIT) showing that both codes predict a similar behaviour and especially similar performances of the system. The system was shown able to fulfil the expectation. The Issue of the deliverable on task 6.2 is scheduled for month 40 (February 2016) as expected in the original DoW.

Task 6.3 MYRRHA Containment analysis

Models of the MYRRHA Primary Containment were completed by SCK•CEN (using the MELCOR code) and by KIT (using the CONTAIN code). Mass and Energy (M&E) releases from the secondary system were calculated by ANSALDO (using the RELAP code) with support from SCK•CEN for three transients: Main Steam Line Break (MSLB), Steam Generator Tube Rupture (SGTR) during normal operation and SGTR during maintenance (with open reactor cover). The calculated M&E releases were provided as input to the two containment analysis codes (MELCOR and CONTAIN) and a comparison was carried out for the main thermal-hydraulic parameters for all three scenarios. Simulation of containment behaviour shows results from the two simulation tools in very good agreement for the MSLB transient. Discrepancies in the SGTR transients are currently under investigation. The Task is expected to be completed by the rescheduled time (month 40, February 2016).

VI. WP 7 Education and training

The second MAXSIMA workshop on safety of heavy liquid metal (HLM) cooled reactors will take place in Sweden. Its purpose is to present achievements and progress obtained during the SEARCH and MAXSIMA projects and promoting information exchange with related international research and development activities. The workshop covers several aspects related to safety, design and operation of HLM cooled systems. Both experimental and modelling contributions are welcome. In particular, the workshop covers (but is not restricted to) the following topics:

- Core thermal-hydraulics and core components
- Steam generator and cooling safety
- Coolant chemistry control
- Fuel and fuel safety
- Safety analyses

Moreover, there will be a special session aimed at PhD students and young scientists dedicated to training in the use of a new HLM reactor simulator for mobile platforms developed in WP7 of the MAXSIMA project. Deadline for submission of abstract is January 2015. More information can be found via www.neutron.kth.se/icehotel-workshop

During the meeting it has been suggested to add a topic concerning the design of HLM cooled reactor projects and to organise the publication of the presented papers.