STARS

Safety Research in relation to Transient Analysis of the Reactors in Switzerland

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ABSTRACT

For 2010-2012, STARS has for its collaboration with ENSI initiated a new project phase characterised on the one hand by an increased support for deterministic plant safety analysis and on the other hand, by a consolidation of the R&D activities around four main research lines: reference model development and assessment for the Swiss reactors, advanced higher-order methods, coupled multi-physics methodologies and safety evaluations of GIII/III+ designs.

During 2010, progress was achieved in many technical activities considered as key R&D areas for the new project phase. Among others, the following can be mentioned: CFD Large-Eddy-Simulations for thermal fatigue related mechanisms were carried out on the Swiss national supercomputing centre; an assessment of advanced sub-channel codes for local safety parameter evaluations was performed through participation to an on-going international benchmark; updates of the KKL and KKG core models to the latest available cycles were conducted along with the development of the required associated CMSYS modules; a trend and correlation analysis methodology for enhanced validation of 2-D/3-D core analysis methods was established and applied for the KKB1 reactor; the development of a BWR stability methodology based on SIMULATE-3K was started and a preliminary validation carried out for the KKL cycle 19 stability tests; the establishment of a non-axis symmetric modelling capability in FALCON for the analysis of non-classical PCI mechanisms was initiated in the perspective of studying recent KKG fuel rod failures; an evaluation with the coupled FALCON/GRSW-A codes and using TRACE Boundary conditions of EPR fuel rod behaviour during LOCAs was performed, revealing a sufficient margin to cladding rupture although with a certain sensitivity on the cycle length.

These above types of R&D activities are aimed at continuously strengthening the project's capacity to provide scientific support and in that framework, the project team consolidated during 2010 its support to ENSI on TRACE modelling of the Swiss reactors and deterministic plant safety analyses. For the On-Calls, focus was given on KKG related analyses. And in that context, while the effect of the axial power shape on LBLOCA analyses could be addressed using the TRACE code along with CMSYS core models, the evaluation of the KKG Cycle 30 core start-up procedure was delayed due to the non-availability of the necessary information to correctly model and describe the Aeroball detector system. The only other significant deviation from the objectives concerns the NURISP project where, similarly as last year, no substantial progress could be achieved due to the non-availability of the NURISP codes until mid of the year.

Project goals

During 2010, the STARS project initiated for the collaboration with ENSI, a new project phase characterised on the one hand by an increased support for deterministic plant safety analysis and on the other hand, by a consolidation of the R&D activities around four main research lines: reference model development and assessment for the Swiss reactors, advanced higher-order methods, coupled multi-physics methodologies and safety evaluations of GIII/III+ designs. This document presents the status and progress related to the activities carried during 2010 in the framework of this new ENSI project phase. The project objectives for 2010 were as follows.

Performance of On-Calls according to 2009 STARS/ENSI bilateral plan
Safety analyses with TRACE of EPR, incl. SBLOCAs, LBLOCAS and MSLB, and application of CFD for boron dilution
Assessement of FLICA and CFD towards development of Sub-Channel Methodology
Application of Dynamical Coupled CFD/TRACE model for selected PWR Transient
Development and Optimisation of CRONOS/FLICA numerical coupling schemes within NURISP SP3
Further development of TRACE/S3K coupling scheme and associated modelling methodologies for the Swiss Plant/Core models
Core Model Updates for CMSYS KKG Cycles 22–30 and Assessment of CASMO-5 also for full 2-D core analyses
Development of BWR Stability Analysis Methodology using S3K and on the basis of KKL
Establishment and assessment of deterministic neutronic uncertainty propagation methods
Development of APOLLO-2 lattice computational routes for nodal and cell cross-section libraries within NURISP SP1
Development of non-axis symmetric modelling capability in FALCON
Assessment of MOX Models in FALCON and/or application to CABRI WL tests
Pre-analysis and post-analyses of next HALDEN LOCA test with high-burnup KKL fuel

Deterministic Plant Safety Analysis for the Swiss Reactors

The migration of the models for all Swiss nuclear power plants (NPPs) to the TRACE code and the corresponding validation efforts have during 2010 continued. In particular, the input decks for KKB, KKG and KKM were finalized ([1], [2], [3], [4]). The KKL deck was moreover consolidated and extended, including a coupling to a full 3-D core model, as part of studies on anticipated transients without scram (ATWS). Scoping calculations on ATWS were also carried out for KKM, starting however in this case with point-kinetics for the evaluation of the neutronics feedbacks. The KKG model was extended in order to answer an ENSI On-Call request concerning the assessment of the plant response to a Large-Break Loss-of-Coolant Accident (LBLOCA). Using the CMSYS KKG core models as basis, the TRACE maximum peak cladding temperature (PCT) was studied for several axial power profiles. As shown in Figure 1, the PCT is for all cases found to lie below the prescribed safety limits. Finally, all the TRACE decks of the Swiss plants were transferred to the ENSI/DESA group and coaching activities were organized in order to assist the DESA group in the use of TRACE and the performance of transient analyses for the Swiss NPPs. An intensive 5-days training course on TRACE for the new members of the ENSI/DESA group was also organized and carried out by the project.

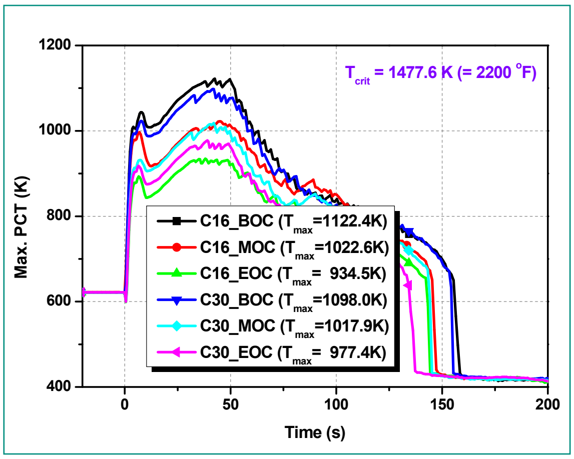

Figure 1: *TRACE LBLOCA Analyses for KKG.*

Trace Code Assessment for LWR Safety Analyses

The continuous assessment of TRACE for best-estimate LWR safety analyses constitutes a central pillar of the STARS project and has therefore continued to be a central work area during 2010. This relates to several fields of activities that were conducted, from detailed studies of important physical mechanisms [5] to code assessment within various international benchmark programs ([6], [7], [8], [9]).

And considering that the project aims at continuing its efforts towards developing expertise for GIII/III+ designs [10], the participation to international benchmark programs revealed to be particularly valuable also in that context. Indeed, a scaling Small-Break-LOCA (SBLOCA)

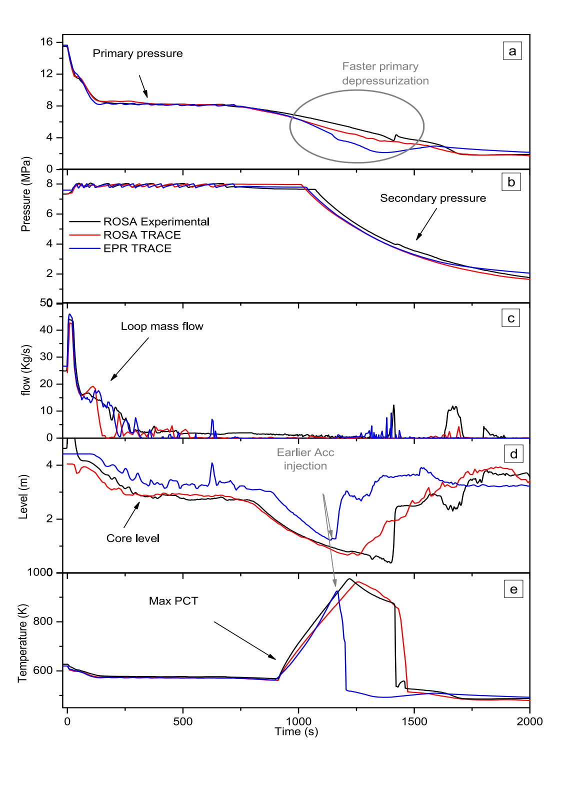

Figure 2: *ROSA Scaled SBLOCA Analyses of EPR.*

calculation from the ROSA/LSTF facility was performed with the EPR TRACE model [11]. This scaling calculation was primarily made in an attempt to evaluate the nodalization parameters and to identify eventual errors in the EPR nodalization. And when evaluating the results, it was found that all the main trend variables were in accordance with the experiment. But as shown in Figure 2, one main difference is the faster depressurization of the primary system after that reflux condensation has stopped. This could be explained by the geometry differences in the RPV. Indeed, the amount of volume above the coolant line is proportionally larger in the EPR. Therefore, when reflux condenser conditions are broken and the primary pressure starts to decrease, the empty space in the system is larger in the EPR, leading to a faster depressurization. This in turn means that the accumulator set points will be reached faster and the core reflooded earlier, which consequently implies that a lower PCT can be expected for the EPR reactor.

Regarding LBLOCA analyses for the EPR, a preliminary TRACE analysis was also carried out and the results were compared against the vendor S-RELAP5 based solution [11]. The main trends for this calculation were found to be in agreement with the vendor analyses noting however that for both the first and second peaks, lower PCTs were calculated with the PSI TRACE model.

Based on the scaled SBLOCA and LBLOCA analysis findings, it was concluded that no further changes to the TRACE EPR nodalisation are at this stage necessary.

Sub-Channel Methodology and Advanced CFD Simulations

Within the STARS project efforts are being dedicated to the introduction of sub-channel methodologies aimed at the determination of the safety margin in the hot channels of LWRs fuel assemblies. The subchannel code FLICA4, developed by CEA (France, and the computational fluid dynamics (CFD) code STAR-CD, developed by CD-ADAPCO, are employed. FLICA4 includes a full three-dimensional set of two-phase balance equations combined with a k-epsilon model to take into account turbulence, which is important for the computation of the cross-flows among assembly sub-channels. CFD codes instead are being established as the new frontier of state-of-the art methods for sub-channel analyses. In order to assess the range of validity and the accuracy of FLICA4 and STAR-CD for LWR applications, the STARS project is taking part to an international benchmark based on the NUPEC PWR subchannel and bundle tests (PSBT) organized by OECD/NEA and US NRC. The first exercise of the benchmark is concerned with steady-state single subchannel measurements, which can be used to assess and improve the current models of void generation and void distribution within a subchannel. The results obtained with the FLICA4 code [12] are reported in Figure 3. It is found that a reasonable agreement with the experimental data is obtained when the Chexal-Lellouche correlation is employed for the drift-flux model. A systematic underestimation of the void fraction is instead found for void fractions higher than 10 % when the Ishii correlation is employed.

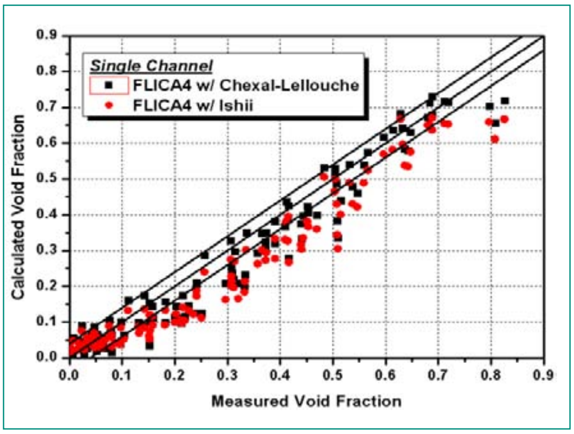

Figure 3: *Prediction of FLICA4 void-fractions in single subchannels using Chexal-Lellouche and Ishii.*

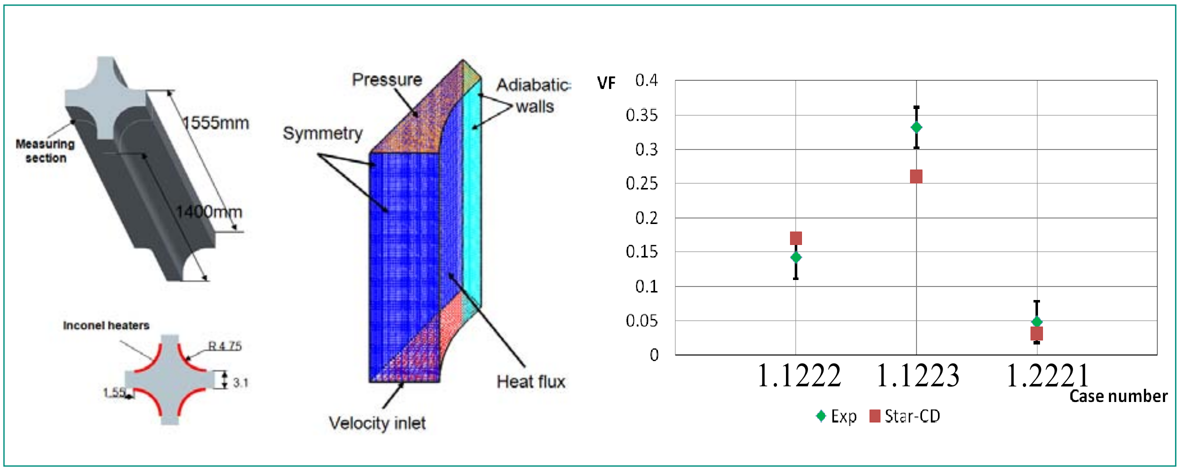

Figure 4: *CFD model of test section (left) and void-fraction predictions for selected cases (right).*

The employment of CFD codes for subchannel codes requires still major efforts in the development of appropriate two-phase models which includes boiling. And as shown in Figure 4, significant void under-predictions are obtained for void-fractions above 15% when the CFD code STAR-CD is employed. Therefore, a collaboration with the developers of the STAR-CD two-phase and boiling models has been initiated. Within this collaboration, the STARS project is testing and validating more advanced models currently not distributed in the official version of the code.

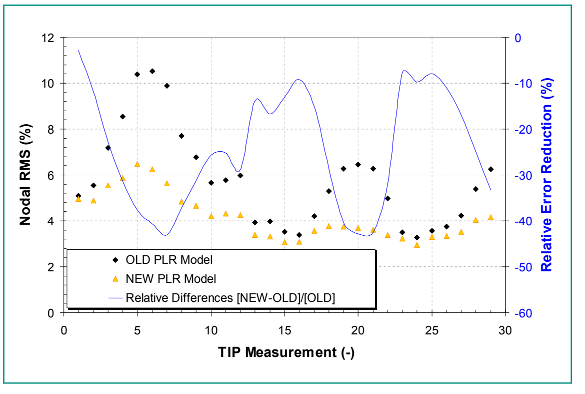

Figure 5: *Effects of Enhanced PLR Fuel Modelling on CMSYS KKL Model Accuracy.*

Core Modelling of the Swiss Reactors

Up to 2009, core models for KKM, KKB1 and KKB2 had been brought «in-line» with the objective of having reference validated models up to the latest completed cycle for which plant data is available. During 2010, significant efforts were invested to achieve the same status for the KKL and KKG models. For KKL, models for Cycles 22–24 were developed using CASMO-4E with the more recent JEF-2.2 library and no spacer void model [16]. To ensure a consistent set of code/methods, all models of KKL Cycles 1–21 were also updated. In that context, an enhanced 2-D lattice modelling approach for nuclear segments containing partial length rods (PLR) was introduced. With all these updates, the previous core modelling difficulties, reflected by a strong increase

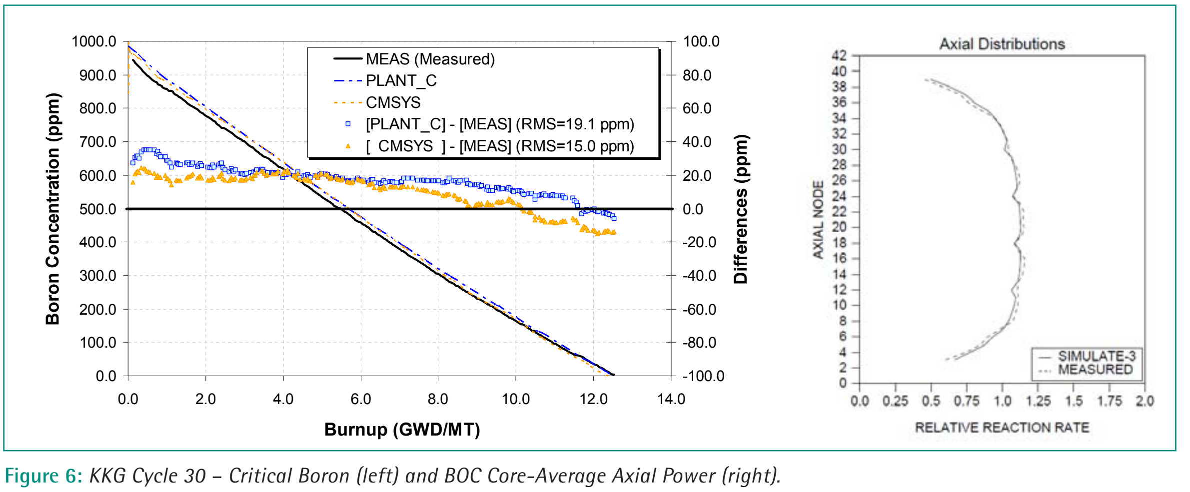

Figure 6: *KKG Cycle 30 – Critical Boron (left) and BOC Core-Average Axial Power (right).*

of the RMS error at Middle-of-Cycle (MOC) for recent PLR dominated cores, could as shown in Figure 5 be significantly reduced, leading thereby to a substantially higher accuracy for the CMSYS KKL models reaching now nodal RMS around or below 4 %.

Regarding KKG, models for cycles 22–30 where both MOX and ERU fuel gradually started to be utilised were developed. For each cycle, the validation of the models has been made against plant measurements of the soluble boron concentration and of 3-D Vanadium reaction rates measured with the Aeroball (AB) detector system. On the left-hand side of Figure 6, the Cycle 30 boron concentration calculated with the PSI CMSYS model is compared to the measured data as well as to the vendor calculation provided by the plant (PLANT_C). The CMSYS model shows a satisfactory performance with actually, a smaller boron RMS error over the cycle compared to the plant calculation. On the right-hand side of Figure 6, the calculated versus measured core-average axial reaction rate distributions at BOC 30 are shown. This illustrates that the 3-D power distributions are qualitatively well captured with the CMSYS models. However, further studies are currently being conducted to enhance the quantitative agreement. On the one hand, more detailed bottom reflector models might be necessary because of fuel assembly designs with different active lengths. On the other hand, a description of the AB system has not been available until very recently, preventing thereby to assess the reliability of the 3-D reaction rate predictions. Now with the available data, refinements of the AB detector modelling have been initiated and studies are being conducted to assess the capabilities of the codes to adequately handle this type of detector system.

Trend Analysis of PWR Core Model Accuracy

Although the development of higher-order neutron transport methods [17] remains an attractive objective, conventional few-group nodal diffusion codes will for the foreseeable future continue to be the principal methods for LWR core analyses. For such codes, RMS values of the differences between calculated vs. experimental reaction rates are typically used as principal «performance metrics» for the Verification and Validation (V&V) procedure. These metrics do however neither provide information regarding the eventual presence of much larger errors at the local level nor reveal eventual patterns in the local errors.

To address this, the development and integration within CMSYS of a trend analysis methodology was initiated during 2010. More precisely, a study was conducted to investigate the capability of the KKB1 models to reproduce in-core neutron flux measurements for a total of 21 cycles [18]. This study was made pos-

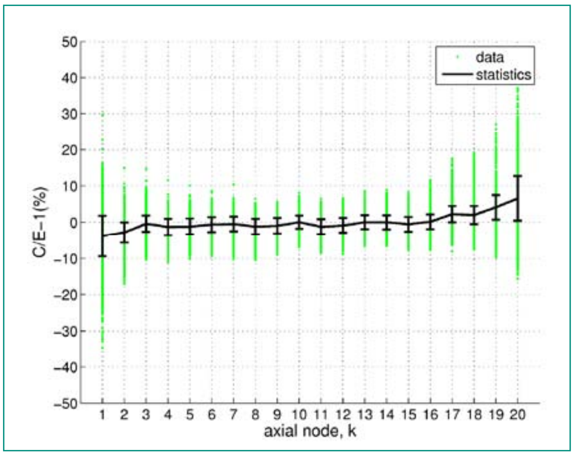

Figure 7: *Local Error Analysis as function of Axial Elevation (All KKB1 Cycles).*

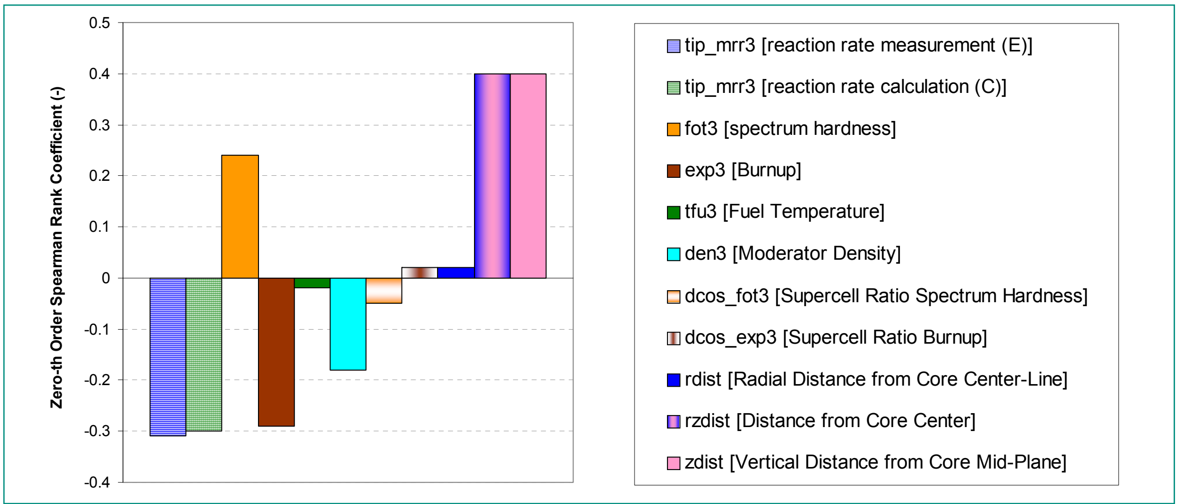

Figure 8: *Zero Order Spearman Rank Coefficients for Selected Parameters (All KKB1 Cycles).*

sible, first by the modification of the S3CORE code to output detailed local 3D measured fission rates and second, by the development of the CMSYSTIP toolbox a) to allow for investigations of trends with respect to different variables (e.g. fuel temperature), b) to determine the assemblies/nodes with highest contribution to the total RMS error, and c) to calculate correlation between errors and local/core parameters. Using this methodology, it was found, as shown in Figure 7, that the highest errors appear at the core axial peripheries where mean C/E-1 errors of 7% are observed for the top nodes and -4% for the bottom nodes, noting moreover that the maximum C/E-1 error can reach at times much higher values (± 40–50%) The trend analysis was thereafter complemented by introducing a correlation analysis to understand the reasons for the observed large local differences. To that aim, Spearman partial rank correlations of IC/E-1I were estimated for a set of local parameters as illustrated in Figure 8 based on all measurements for all cycles. Whereas one can for instance observe a reduction of the error with increased burnup (negative rank coefficient), a larger distance from the core centre will tend to increase the local error. Although not presented here, first-order correlations were also investigated and showed that the large relative errors at the axial periphery could not be explained by other variables (e.g. low moderator density). On that basis, the main areas suggested for enhancements of the CMSYS KKB1 models were identified as follows: top and bottom axial reflector models, MOX assembly models and control rods models.

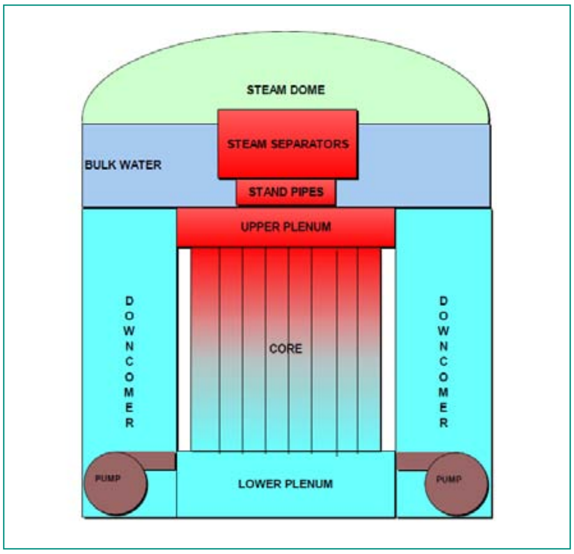

Figure 9: *Overview of S3K Vessel Model for BWR Stability Analysis.*

Development and Assessment of S3K for BWR Stability Methodology

The transition from the previous PSI BWR stability methodology using RAMONA-3 (R3) to a new approach based on the CMSYS core models along with the SIMULATE-3K (S3K) 3-D kinetics code (S3K) was launched during 2010. As starting point, a complete S3K vessel model as illustrated in Figure 9 was developed for KKL, comprising thus reactor core as well as a series of 1-D components for the vessel loop: upper plenum, steam separators, bulk water region, downcomer, recirculation loop, lower plenum, steam dome and jet pumps. For the core, all data is directly transferred from the corresponding CMSYS models.

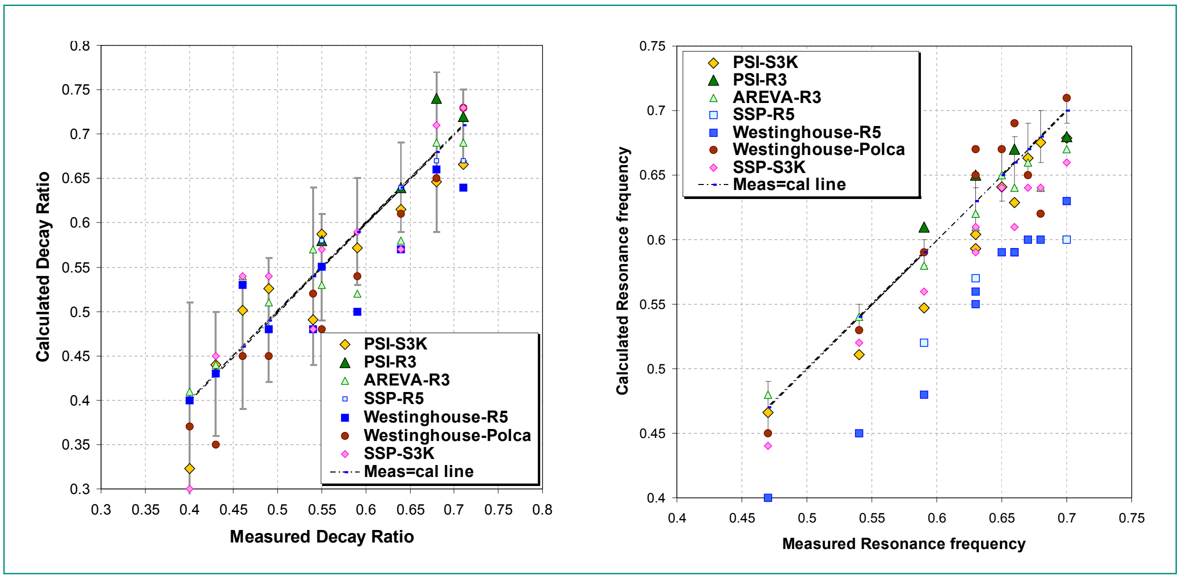

Figure 10: *KKL Cycle 19 Stability Test Analyses – Decay Ratio (left) and Resonance Frequency (right).*

For a first validation, the KKL Cycle 19 stability tests were analysed and the results were compared to both stability measurements as well as to a wide range of other analytical solutions previously submitted for a benchmark study organised by the plant [20]. These previous solutions include: PSI-R3 (previous PSI methodology using RAMONA-3), AREVA-R3 (AREVA using RAMONA-3), SSP-R5 (Studsvik Scandpower using RAMONA5), SSP-S3K (Studsvik Scandpower using S3K), Westinghouse-R5 (Westinghouse using RAMONA-5), and Westinghouse-Polca (Westinghouse using Polca-T). For the new PSI S3K solutions added here, it must be underlined that the analyses were made in a complete independent manner from the other benchmark participants, using as only basis, the in-house CMSYS KKL core models also developed/updated during 2010 (see previous section).

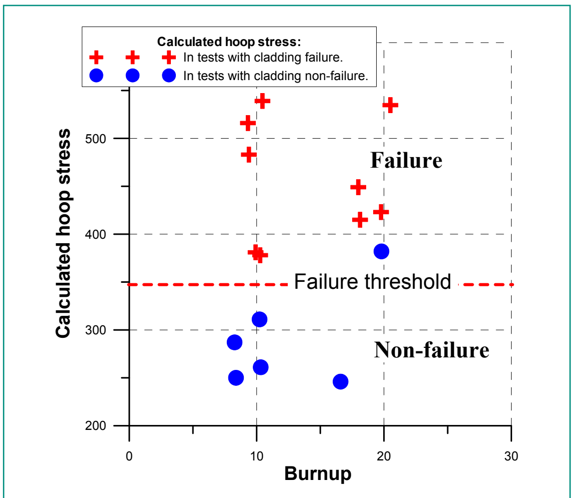

Figure 11: *Calculated peak hoop stress in cladding of the irradiated specimens during the power ramps.*

The results are shown in Figure 10 where the decay ratios are shown on the left-hand side while the resonance frequencies are shown on the right hand side. For the later, the new PSI S3K results show a similar trend as most other participants, namely a tendency to underestimate the core natural frequency. On the other hand, no particular trend is observed for the decay ratio for which the new PSI S3K model yields for all tests, results well within the uncertainty intervals and in fact, shows a similar if not better overall performance than the other models. Hence although this only constitutes a very first validation case, it certainly provides confidence in the consolidation and enlargement of the validation basis for the new PSI S3K based stability methodology.

Assessment of FALCON and further Development for PCI Mechanisms

During 2010, the development and validation of FALCON on the basis of experiments involving fuel samples from the Swiss reactors was continued both for RIA [21] and LOCA analyses [22]. For the later, an important activity was to perform post-analyses of previous HALDEN LOCA tests using KKL fuel samples [23] as well as to initiate a study to design the new experiments planned for 2011 with high-burnup KKL samples.

Also, work was initiated related to the FALCON capabilities to model Pellet Cladding Interaction (PCI) mechanisms. To start, the BWR cases of the INTERAMP experimental project were analyzed within the IAEA Programme on Improvement of Computer Codes used for Fuel Behaviour Simulation (CRP FUMEX-III). The results have put forward good predictive capabilities by

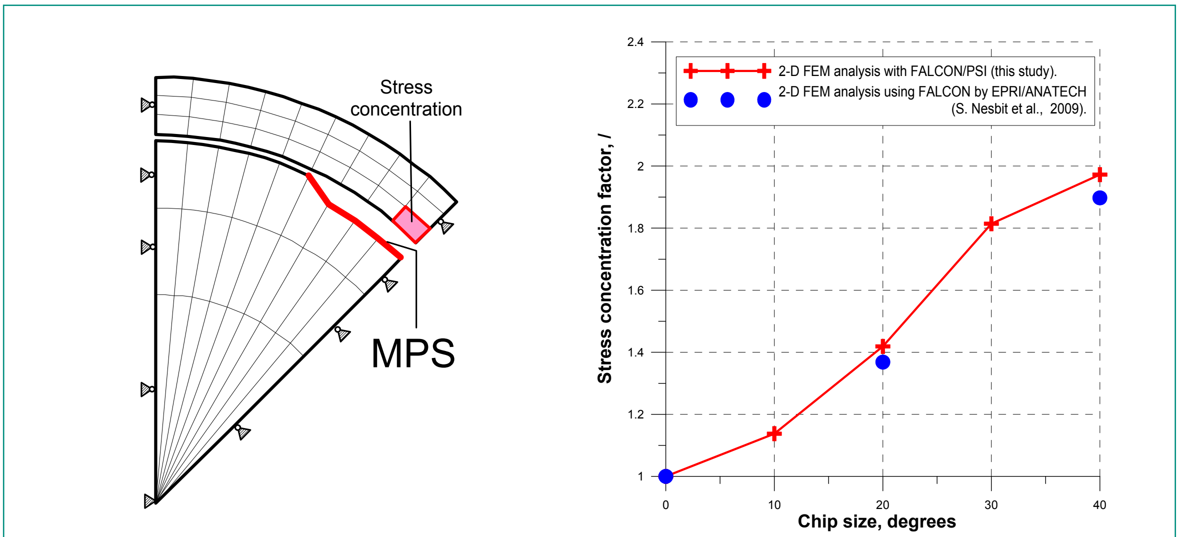

Figure 12: *FEM mesh utilized to simulate impact of MPS on cladding failure (left) and calculated stress concentration factors as function of the angular defect size (right).*

the coupled FALCON and GRSW-A models for the (PCI) failure-thresholds. As shown in Figure 11, the FALCON/ GRSW-A results were able to segregate tests with and without failure. These results were presented to the 2nd Research Coordination Meeting on IAEA CRP FUMEX III in Pisa, in June 2010.

And as follow-up to the ENSI On-call 2009 relating to the KKG fuel failures, work was carried out in order to establish a methodology allowing to account for the impact of missing pellet surface (MPS) defects on the PCI cladding failure (so called non-classical PCI mechanism). The principle is shown on the left-hand side of Figure 12 and consists in the generation of a FEM mesh using an r-ϴ-geometrical representation to simulate a single fuel slice with a MPS. With such model, the stress concentration factors can be calculated as function of defect size and other fuel parameters as illustrated on the right hand side of Figure 12. Currently, this modelling approach is being implemented along with the coupled FALCON/ GRSW-A code to analyse recent KKG fuel rod failures and to conduct optimisation studies regarding the thermo-mechanical response versus reactor start-up power ascension scenarios for fuel rods containing MPS defects.

LBLOCA Fuel Behaviour Analyses for EPR

As part of the on-going STARS activities on modelling and safety analyses for the European Pressurized Reactor (EPR), studies of the fuel rod behaviour during LBLOCAs were conducted [24]. Using the cumulative damage index method and the Chapman's correlation, the cladding rupture behaviour and safety margin were estimated for a high burnup EPR fuel rod (~ 65 MWd/ kgU). First, the fuel performance during base irradiation was analyzed for different operating power histories, including 12-month, 18-month, and 24-month cycles. The fuel characteristics reached at the end of the base irradiation were then used as initial conditions for the FALCON LBLOCA transient analyses using TRACE boundary conditions for the coolant temperature. On that basis, it was observed that the fuel performance during base irradiation and the response to a LBLOCA transient would be strongly affected by the operating histories. Especially during base irradiation, a significantly different amount of total fission gas release (FGR) would as shown in Figure 13 be obtained depending on the considered operating cycles, yielding thereby significant different internal rod pressures at the onset of the LBLOCA. For these FGR estimations, both the standard FALCON ESCORE model as well as FALCON coupled with the PSI GRSW-A model were employed. And in that context, it was found that the GRSW-A model would provide a better description of the substantial FGR increase expected at high burnups over 40 MWd/kgU.

Now for the transient LBLOCA analysis with FALCON/ GRSW-A, the cumulative damage index was estimated to be less than unity for all three types of operating-cycles, indicating that the safety margin against cladding rupture remains, according to these predictions, sufficient. This is illustrated in Figure 14 where the calculated hoop stress is compared to the predicted rupture stress for the 12 M cycle fuel rod case. However, it must be noted that the safety margin would to some extent be

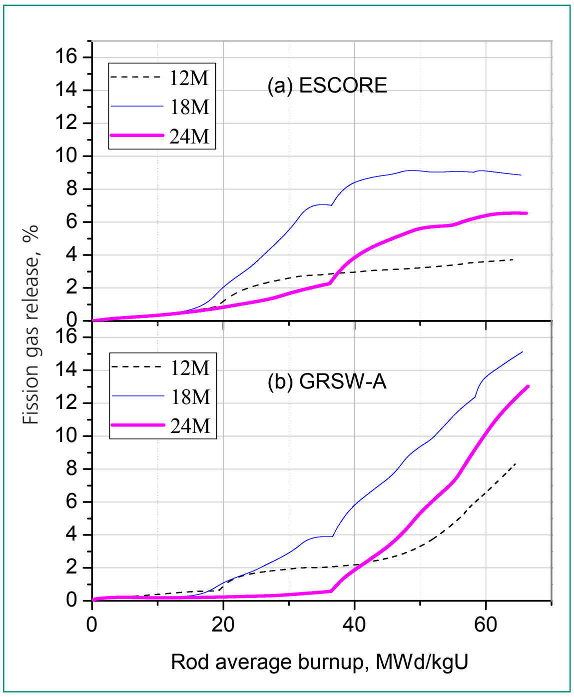

Figure 13: *Fission gas release in EPRTM fuel rods with different operating histories.*

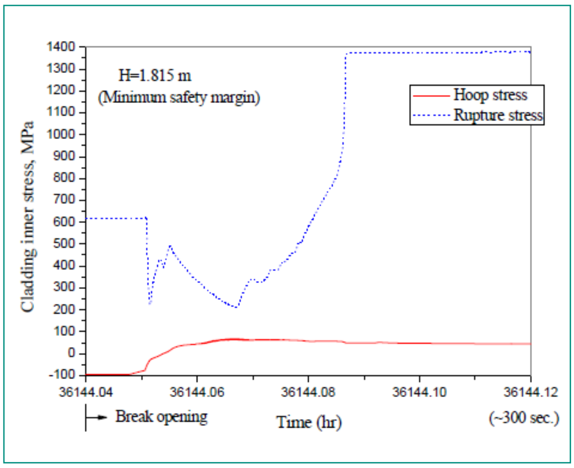

Figure 14: *Hoop Stress of 12M Cycle EPR Fuel Rod versus Rupture Stress during LBLOCA.*

influenced by the operating cycles and in that context, the minimum safety margin was obtained for the 18-M cycle due to the higher initial rod internal pressure.

Multi-Physics Methodologies

One central objective of STARS is to bring together the methods developed and assessed in a stand-alone manner in the three main technical areas in order to establish coupled multi-physics based analytical approaches. Currently, focus is given to couple 3-D kinetics/plant system thermal-hydraulic analyses within the European NURESIM/NURISP project [25] as well as for applications specific to the Swiss reactors [26] where a central activity is now to consolidate the methodology around the coupled TRACE/S3K code system [27]. During 2010, a main objective was to launch the TRACE/S3K assessment for BWR ATWS. To that aim, a 1-D kinetics based analysis previously carried out at PSI with the TRAC-BF1 code was repeated with TRACE/S3K [28]. As can be seen in the top part of Figure 15, the ATWS assumed here to occur after MSIV closure could be reproduced with, similarly as for TRAC-BF1, a power stabilisation below 1000 MW although with stronger oscillations specially after the periodic closure of the SRV valves. These differences are however not considered as surprising since for this beyond-design-basis accident, very atypical flow patterns evolve as water level and core void content are counteracting each other. As shown in the lower part of Figure 15 for illustrative purposes, strong redistribution of the active core flow might take place with natural circulation between cold and hot channels, putting thereby a much stronger demand on the code numerical capabilities and modelling reliability to capture such conditions.

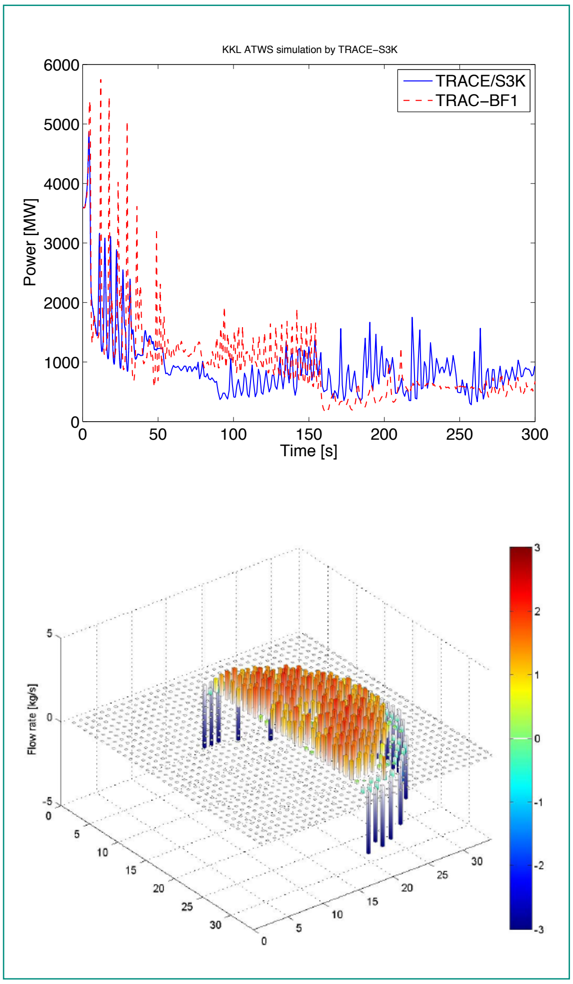

Figure 15: *ATWS Analyses with TRACE/S3K – Comparison of Reactor Power versus TRACE-BF1 (top) and Snapshot of 3-D Core Flow Distribution (bottom).*

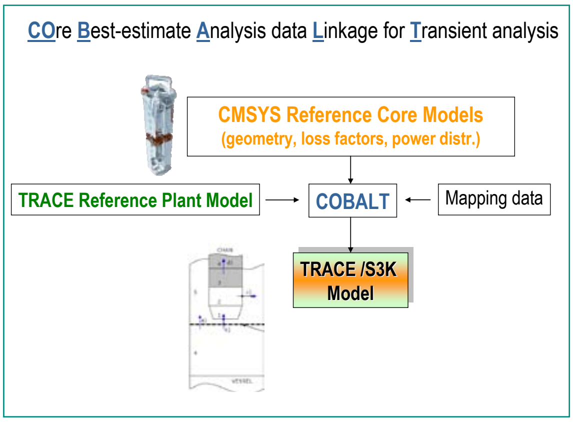

Figure 16: *Concepts of the COBALT Methodology.*

Therefore, in an attempt to ensure reducing as much as feasible modelling uncertainties in terms of core data, the development of a new methodology referred to as COBALT and shown in Figure 16 was in parallel to the ATWS analyses started. The objective of COBALT is to establish a direct link and thereby full consistency between the validated CMSYS reference core models and the employed TRACE/S3K transient model in terms of core and fuel assembly data. Although this method is only at a preliminary phase of development, it is foreseen to become a central component to ensure best-estimate coupled 3-D core/plant system analyses of the Swiss reactors as well as to allow for a systematic and consistent approach to conduct uncertainty/sensitivity analyses.

National Cooperation

To carry out its research and scientific support activities, the STARS project collaborates with ENSI as well as with swissnuclear and the Swiss individual nuclear power plants. Along this, the project also collaborates with other laboratories at PSI, among which the Laboratory for Thermal-Hydraulics (LTH), the Laboratory for Energy Systems Analysis (LEA) and the Laboratory for Nuclear Materials (LNM) can be mentioned. Finally, the project is also involved in an increased collaboration with the Swiss federal polytechnic institutes ETHZ/EPFL for the elaboration, supervision and realisation of relevant MSc and PhD theses.

International Cooperation

At the international level, the project collaborates with international organisations (OECD/NEA, IAEA) principally as part of working/expert groups as well as through international research programs and benchmarks. The project also collaborates with other research organisations, on the one hand through e.g. EU 7th FP NURISP project and on the other hand, through bilateral cooperation e.g. GRS, CEA, Purdue University. An active cooperation with the Finnish regulatory body STUK as well as with the AREVA plant vendor is also carried out for safety evaluations related to the GIII/GIII+ EPR and Kerena reactors respectively. Finally, close cooperation with code developers and/or providers is necessary and conducted principally with US NRC (TRACE), Studsvik Scandpower (CASMO-4/SIMULATE-3/SIMULATE-3K) and EPRI/ANATECH (FALCON).

Assessment 2010 and Perspectives for 2011

During 2010, progress was achieved in many technical activities considered as key areas for the new project phase of the collaboration with ENSI, among others: LES CFD simulations, sub-channel code assessment, KKL and KKG core models update, S3K stability analysis for KKL Cycle 19, FALCON non-axis symmetric modelling capability, EPR fuel rod behaviour during LOCA. The project team also strengthened the collaboration with ENSI on deterministic safety analyses and for the On-Calls, focus was given on KKG related analyses. While the assessment of the effect of the axial power shape on TRACE LBLOCA analyses could be performed, the evaluation of the Cycle 30 core start-up procedure was delayed due to the non-availability until very recently of the information necessary for the correct modelling of the Aeroball detector system. The only other significant deviation from the objectives concerns the NURISP project where, similarly as last year, no substantial progress could be achieved due to the non-availability of the NURISP codes until mid 2010. Concerning the perspectives for 2011, the technical objectives are as follows.

Publications

[1] *W. Barten,* TRACE KKG model and its validation against a pump trip event. PSI Technical Report TM-41-09-19, 2010.

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Establishment of strategy (vulnerability search) for applications of TRACE coupled with DET
Completion of CASMO-5 transition and assessment for all Swiss cores
Modelling and assessment of NURISP codes towards 3-D full core higher-order pin-by-pin analyses of Swiss reactors
Participation to OECD/NEA Oskarshamn stability benchmark with S3K and TRACE/S3K
Quantification of neutron cross-section uncertainties with XSUSA for selected BWR transient analysis
Analysis and design of HALDEN 2011 LOCA tests 1/2 for High Burnup KKL samples
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