

TRACE/SIMULATE-3K Analysis of the NEA/OECD Oskarshamn-2 Stability Benchmark

Abdelhamid Dokhane, Omar Zerkak, and Hakim Ferroukhi

Paul Scherrer Institute

CH-5232 Villigen, Switzerland

Abdelhamid.dokhane@psi.ch; omar.zerkak@psi.ch; hakim.ferroukhi@psi.ch

Ivan Gajev

Bulgarian Nuclear Regulatory Agency,

Sofia, Bulgaria

i.gajev@bnra.bg

Jerry Judd

Studsvik Scandpower, Inc.

Idaho Falls, ID 83402 USA

jerry.judd@studsvik.com

Tomasz Kozlowski

University of Illinois,

Urbana-Champaign, USA

txk@illinois.edu

ABSTRACT

A coupling between TRACE and SIMULATE-3K (TS3K) was developed in collaboration between PSI and Studsvik for analyses involving interactions between system and core, with the goal to enhance the capability to perform best-estimate simulations of Light Water Reactors (LWRs) transients, with strong coupling between core neutronics and plant thermal-hydraulic. In order to verify the coupling scheme and the coupled code capabilities to simulate complex transients, the OECD/NEA Oskarshamn-2 (O-2) Stability benchmark, launched recently, was modeled with the coupled code TS3K. The main goal of this paper is to present TS3K analyses of the Oskarshamn-2 stability event, noting that this constitutes the first reported assessment of this code system for a BWR stability problem.

A systematic analysis is carried out using different time-space discretization schemes in order to identify an optimized methodology to simulate correctly the O-2 stability event. In this context, the TS3K results are compared to the available benchmark data both for steady-state and transient conditions. The results show that using a refined model in space and time, the TS3K model can successfully capture the entire behavior of the transient qualitatively, i.e. onset of the instability with growing oscillation amplitudes, as well as quantitatively, i.e. Decay Ratio and resonance frequency. However, it is also shown that the qualitative as well as quantitative trends predicted by TS3K during the transient phase, especially when power oscillations start to take place, is highly sensitive to the pump boundary conditions and that the benchmark specification might in this context need to be further reviewed.

Key Words: Keywords: Stability of BWR, SIMULATE-3K, TRACE, coupling, Oskarshamn-2.

1. INTRODUCTION

The OECD/NEA recently launched an international benchmark on a combined feedwater transient and stability event that occurred at the Swedish nuclear power plant (NPP) Oskarshamn-2 [1]. The primary benchmark objective is to assess advances in coupled neutronics/thermal-hydraulic codes for simulations of challenging transients including the appearance of unstable power oscillations. The Paul Scherrer Institute (PSI) is participating in this benchmark in order to enlarge the validation basis of its advanced stability analysis methodology currently under development for Swiss BWRs. The first study of this transient, based on state-of-the-art SIMULATE-3K (S3K) three-dimensional reactor kinetics code, has been achieved recently and results demonstrated the capability of S3K to simulate complex behavior of such BWR stability event [2]. In addition, many other studies were dedicated to the analysis of the Oskarshamn-2 using TRACE/PARCS coupled code and results show the capability of this code to simulate the complex behavior of this stability event [3,4].

The TRACE/SIMULATE-3K thermal-hydraulics and three-dimensional reactor kinetics coupled code was developed recently, in collaboration between PSI and Studsvik, to consolidate the performance of two principal reactor analysis transient codes used at PSI by STARS (Safety research related to Transient Analysis of Reactors in Switzerland) project for supporting the existing Swiss NPPs. The first code is the two-group nodal kinetics code SIMULATE-3K [5] and the second one is the best-estimate thermal-hydraulic system code TRACE [6]. The motivation at the basis of the development of the TRACE/S3K coupled code is the continuing enhancement of the capability to perform best-estimate simulations of Light Water Reactors (LWRs) transients, where strong coupling between the core neutronics and plant thermal-hydraulics exists. The TRACE/S3K code has been verified using the available international LWR benchmark data, including the NEA/OECD Turbine Trip BWR and the Main Steam Line Break PWR benchmarks. The comparison with the experimental/benchmark data shows that TRACE/S3K code is able to reproduce correctly the coupled thermal-hydraulic/neutronics behavior of LWRs [7-9].

The main goal of this paper is the application of the coupled code TS3K to the OECD/NEA Oskarshamn-2 stability event, which will be the first reported application of such code for a BWR stability problem. This study allows the verification of the coupling scheme and the coupled code capabilities to simulate complex plant transients. In this context, a systematic analysis is carried out using different time-space discretization in order to optimize the model to simulate correctly the O-2 stability event. In addition, the TS3K results are compared to the available benchmark data both for steady-state and transient conditions.

2. OSKARSHAMN-2 2 FEBRUARY 1999 EVENT BENCHMARK

On February 25, 1999, during a maintenance work on the switchyard outside of the O-2 reactor, a load rejection signal was transmitted to the turbine and caused a turbine trip but not transferred to the reactor which kept on running at nominal power. Because of the turbine trip, the feedwater preheater system was no longer functional and the feedwater temperature started decreasing which resulted in the entrance of colder water in the reactor vessel and created a positive reactivity feedback, increasing the core power level. The automatic system reduced the main recirculation flow, thereby reducing the power. This sequence was repeated three times then the operator partially scrammed the reactor (see Fig. 1). However, the flow of the colder feedwater continued, causing the reactor power to oscillate with growing oscillation amplitudes and then scrammed due to high power at 132% (see Fig. 1). More details about the event can be found in [1].

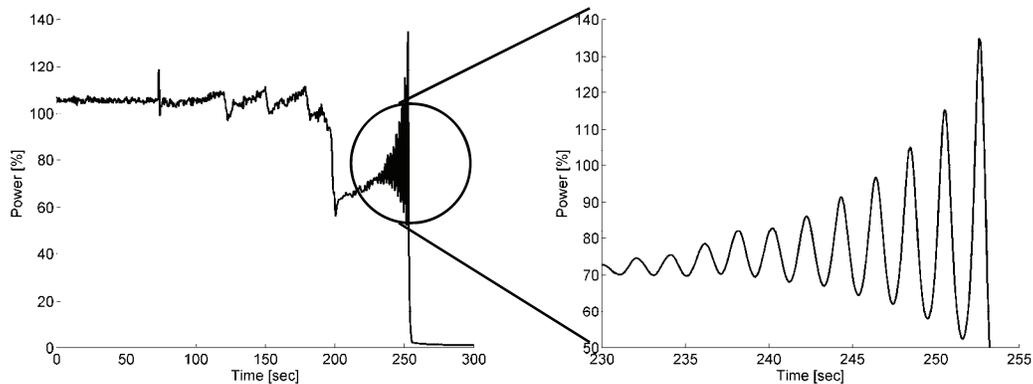


Figure 1. Power Oscillation of Oskarshamn-2 Event [1].

3. OVERVIEW OF TRACE/S3K COUPLED CODE SYSTEM

A detailed description of the TRACE/S3K code system is presented in a separate paper [7] in order to summarize recent activities ([8], [9], [10]) and the planned further developments. Here, only an overview of aspects relevant for the stability analyses is presented in this paper.

3.1. Neutron Kinetics Code SIMULATE-3K

SIMULATE-3K (S3K) is a best-estimate LWR core dynamics code that on a stand-alone basis is employed for full core coupled neutronics/thermal-hydraulics (T-H) transient analyses. For the neutronics, S3K is based on a 3-D two-group neutron diffusion solver, including a 6-group model for delayed neutron precursors. A transverse-integrated nodal method using either polynomial flux expansions or analytical functions for the thermal flux is applied for the spatial integration and the frequency transform method is used for the time integration during the transient. For the T-H, a five-equation drift flux model is employed to solve for 1-D non-equilibrium two-phase flow [5]. Through this coupled NK/T-H solver, S3K is designed for general LWR core transient analyses using full core models i.e. with each fuel bundle represented as a single neutronic assembly coupled with an independent single T-H flow channel. For BWRs, the S3K core model can be complemented by a vessel T-H model and can in this mode be used for stability analyses. Based on extensive validation of the latter approach, S3K has been adopted at PSI as the reference code for stability analyses of the Swiss BWRs.

3.2. System Code TRACE

TRACE is the latest in a series of advanced, best-estimate reactor system codes developed for analyzing steady-state and transient neutronics/thermal-hydraulic behavior of LWRs. The code is a result of a consolidation of the capabilities of previous USNRC supported codes, such as: TRAC-PF1, TRAC-BF1, RELAP-5 and RAMONA. TRACE includes multidimensional two-phase flow (6-eq model), non-equilibrium thermodynamics, generalized heat transfer, reflood, level tracking, and other special thermal-hydraulics models relevant to reactor safety. For neutronics, a point-kinetics model or the PARCS 3-D kinetics solver integrated in recent versions of the code can be used.

The fluid-dynamics equations use, by default, a Stability-Enhanced Two-Step (SETS) time-differencing procedure that allows the material Courant-limit (CFL) condition to be exceeded. A more straightforward semi-implicit (SI) time-differencing method is also available which behaves like an upwind finite difference method [11]. When the SI method is applied, numerical diffusion can be reduced either by

minimizing together the axial node and the time step or by allowing the material Courant number in every cell to stay as close as possible to unity through a non-uniform axial nodalization in order to artificially compensate the spatial and temporal error [3]. The system of nonlinear equations is solved by the Newton-Raphson iteration method, resulting in a linear equation system which is solved by direct matrix inversion.

3.3. Coupled TRACE/S3K Code System

The TS3K code system refers to a coupling between TRACE and S3K that was established at PSI in collaboration with Studsvik Scandpower in order to take advantage of the strengths provided by TRACE for plant system analyses and those provided by S3K for core modeling via its direct integration to a well validated core management system.

The coupling of the two codes is based on a serial approach where TRACE acts as a master code and S3K is integrated as subroutine to act as a slave code. For the spatial coupling, while an external coupling mode has been recently established [7], the standard approach, which is used in this work, is the internal coupling mode which refers to using TRACE as T-H solver for all model components including core while S3K is only employed as a kinetic solver to solve for the 3-D core power distribution.

With the internal coupling mode, the radial spatial mesh overlay is based on a flexible approach. This implies that either a “full core model” (FCM) can be employed where each S3K (neutronics) fuel assembly is represented by a single individual TRACE T-H core channel component or a “Lumped Core Model” (LCM) can be used where the number of TRACE core channel components is reduced by mapping each of these T-H channels one or several individual S3K fuel assemblies. Axially, a firm requirement is that the axial nodalization of TRACE and S3K must be the same. Since only uniform axial meshes can be used with S3K, this means that the TRACE T-H core channel nodalization must always be uniform in a coupled TS3K simulation. On this basis, the coupling is then effectively made at the nodal level and for the T-H to NK data transfer, two options are available: flat or nodal. In this work, the standard flat approach is applied which means that in case of a LCM, all S3K fuel assemblies lumped into a given T-H channel will received the same feedback quantities as computed by TRACE in that channel. However, in this context, it must also be noted that currently, TS3K allows only for one heat structure type per core channel component. This means that an intra-assembly sub-grouping of the heat structures in TRACE is not supported in the current version of the TS3K code system.

Regarding the temporal coupling, a fully explicit “marching” scheme, i.e. based on operator splitting (OS) method, is implemented with TRACE acting as leading code. This implies that TS3K also suffers from the conventional limitations of explicit schemes, namely that small time steps must be used to ensure numerical stability and convergence of the coupled solution. Moreover, although both codes have their own time-step control, the explicit coupling is implemented such that the leading code (TRACE) dictates the time step size and S3K is forced to follow. Thereby, when applying the TRACE SI method for transient analyses, the choice of the TRACE maximum time step-size (dtmax) as well as the S3K minimum time step size should always be selected with care, especially for problems where the neutron dynamics time scales are much smaller than the T-H ones [12].

4. METHODOLOGY FOR TS3K ANALYSES OF OSKARSHAMN-2 BENCHMARK

4.1. Code System and Computational Approach

For all TS3K analyses presented in the paper, the TRACE Patch 3 version (V5.0p3) combined with S3K V.2.04.00 has been used.

Regarding the computational approach, all TS3K analyses are performed using the internal “flat” coupling mode. Each TS3K calculation is performed with a three-step sequence consistent with the procedure applied in the previously reported TRACE/PARCS analyses of the benchmark [3,4,11]. That is, first a TRACE standalone steady-state mode is run, then a TRACE/S3K coupled steady-state mode run is performed, where the TRACE stand-alone restart file is used. Finally, a TRACE/S3K coupled transient mode is carried out.

For the steady-state initialization, the TRACE SETS algorithm is applied while for the coupled transient analyses, the SI method is employed.

4.2. Base Model

4.2.1. SIMULATE-3K model

The S3K model is based on the benchmark specifications where the core model, recently developed and reported in [2], is based on a full core representation of all 444 fuel assemblies and discretized into 25 uniform axial nodes with one radial node per assembly. In addition, reflectors are modeled with one additional axial node for bottom/top reflectors and with one layer of additional channels at the periphery.

For the few group homogenized neutronic data of the fuel/reflector nodes, these were prepared by an upstream CMSLINK model using as basis, the CASMO results provided as part of the benchmark specifications. Regarding the nodal histories required to initialize the core at the correct burnup, i.e. start of the transient event, these were also obtained as part of the benchmark specifications. They are provided directly to the SIMULATE-3 model used in turn to produce the restart data for the S3K model.

4.2.2. TRACE model

The employed TRACE model is based on the corresponding LCM model used in the previously reported TRACE/PARCS (TPARCS) analyses of the benchmark and including thus the same time-dependent feedwater flow, temperature, and recirculation pump speed boundary conditions.

To summarize, this model contains 222 core channels, each one representing two fuel assemblies with account of half-core rotational symmetry, and ten other hydraulic components, e.g. reactor vessel, steam separators, feedwater pipe, recirculation loop and steam lines, as shown in Fig. 2 and Table I.

However, since S3K imposes a uniform axial nodalization, the original TRACE model, used in the TPARCS analyses¹, is modified here in such a way that the core channels are divided now uniformly into 25 active axial nodes, along with two inactive cells at the inlet and one at the outlet. Also, it should be noted that the Oskarshamn-2 Cycle 24 core, i.e. at the time of the 1999 event, consisted of four main fuel types [1], including Full-Length-Rod (FLR) assembly designs (Type 1-2-3) and one (Type 4) with Partial-Length Rods (PLR). Since TS3K currently only allows for one heat structure type per channel, a second change to the original TRACE model is that all Type 4 PLR assemblies are replaced here by Type 3 FLR assemblies. This could constitute a serious limitation for stability analyses since PLRs have an impact on the one-phase/two-phase pressure drop relative distributions. However, the O-2 core at the time of the event only contained 26 Type 4 PLR assemblies (i.e. around 5% core fraction). From this point of view, the impact from neglecting PLRs should remain moderate. This was analyzed by a TRACE/PARCS sensitivity study showing discrepancies between models with and without PLR of less than 65 pcm in terms of k_{eff} , 1.4% axially and 0.5% radially in terms of nodal power.

¹ With non-uniform axial nodalization.

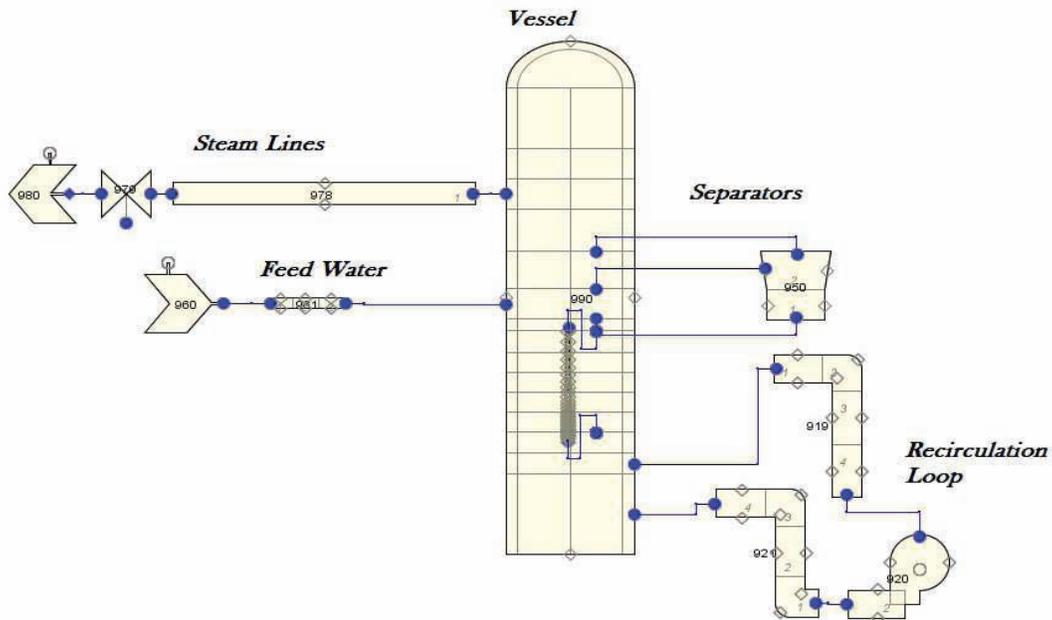


Figure 2. Oskarshamn-2 Base Model Nodalization Scheme [3]

4.3. Refined Model

As mentioned earlier, TS3K does not allow for non-uniform axial nodalization while this precisely can be employed in order to minimize numerical diffusions of the TRACE SI method during a transient simulation. Thereby, the only remaining option to minimize numerical diffusion in the TS3K coupled analysis is to jointly refine the axial nodalization (i.e. increase the number of axial nodes) and reduced the time step size. Hence to study the space-time convergence of the TS3K solution, a refined model is introduced using 100 axial equi-distance nodes instead of 25 and selecting a smaller maximum time step size (dtmax). On this basis, the differences between the “Base” and Refined models are summarized in Table I.

Table I. Space and Time Model Parameters

Nodalization Parameter	Base Model	Refined Model
Recirculation loop	8 cells	same as Base
Feedwater pipe	3 cells	same as Base
Steam Line pipe	1 cell	same as Base
Steam separators	2 cells	same as Base
Vessel	15 levels x 2 radial	same as Base
Bundles	28 cells (25 active)	112 cells (100 active)
Maximum Time Step (dtmax)	0.1	0.01
Dynamic Time Step Range	0.02s-0.01s	0.006s-0.001s

5. ANALYSES AND RESULTS

5.1. Steady-State Analysis

5.1.1. Comparison of initial conditions

The TRACE/S3K calculated steady-state initial conditions are compared in Table II to the reference solution, provided as part of the benchmark specifications, as well as to the TRACE/PARCS and S3K stand-alone results [13,2].

Table II. Comparison of TS3K Calculated Steady-state Initial Conditions against Benchmark Reference Solution, TRACE/PARCS and SIMULATE-3K stand-alone.

	Reference[1]	TRACE/PARCS[12]	PSI-S3K[2]	PSI-TS3K
Reactor Power (MW)	1802	1802	1798.6	1802
Steam Dome Pressure (MPa)	7.0	7.0	7.0	7.0
Core Inlet Pressure (MPa)	7.166	7.1626	7.1197	7.1638
Core Outlet Pressure (MPa)	7.067	7.0611	7.0164	7.0609
Core Pressure Drop (kPa)	98.8	101.6	103.3	102.9
Channel Pressure Drop (kPa)	46.0	54.7	58.1	
Orifice & Lwr plate dP (kPa)	52.8	46.8	45.2	
Core Average Void	0.42	0.37	0.39	0.38
Average Fuel Temp (K)	816.7	823.4	867.5	811.5
Feedwater Temperature (K)		457.6	457.7	457.7
Core Inlet Temperature (K)	548.1	543.9	544.6	545.6
Pump Speed (rad/s)		101.8	91.1	101.8
Total Core Flow Rate (kg/s)	5515.9	5515.9	5513.2	5504.2
Active Core Flow Rate (kg/s)	4793.5	4803.2	4795.4	4861.2
Downcomer Water Level (m)		8.40	8.10	8.4
K-eff	1.0026	0.9973	1.0051	1.0088

As can be seen in Table II, over all, a good agreement is obtained between the TS3K results and those of the Reference and S3K, while larger discrepancies are seen compared to TPARCS. This is most likely related to differences in cross section model and/or due to differences in the nodal methods which could each or jointly result in a stronger leakage in TPARCS. Note that k_{eff} computed by TS3K is the highest value among those all presented solutions with the discrepancy of around 620 pcm, 1150 pcm, and 370 pcm, with respect to the Reference, TPARCS, and S3K, respectively. The same applies for the active core flow. In addition, the TS3K average fuel temperature is closer than TPARCS and S3K to the Reference values.

5.1.2. Axial distributions

The normalized axial (planar-average) power and fuel temperature distribution calculated by TS3K are presented in Fig. 3, along with a comparison to the reference solution. As can be seen, the axial power discrepancies are typically below 2% at almost all the nodes.

Concerning the axial fuel temperature profile, the agreement is very good with a discrepancy less than 2.5% at all axial nodes. The TS3K results are larger than the reference at bottom part of the core while smaller at top part. Note some distinct peaks are observed in the relative difference between TS3K and Reference solution for both power and average fuel temperature. This is most likely due to the fact that spacer grid effects are not taken into account in the TS3K model while this might have been the case with the reference solution.

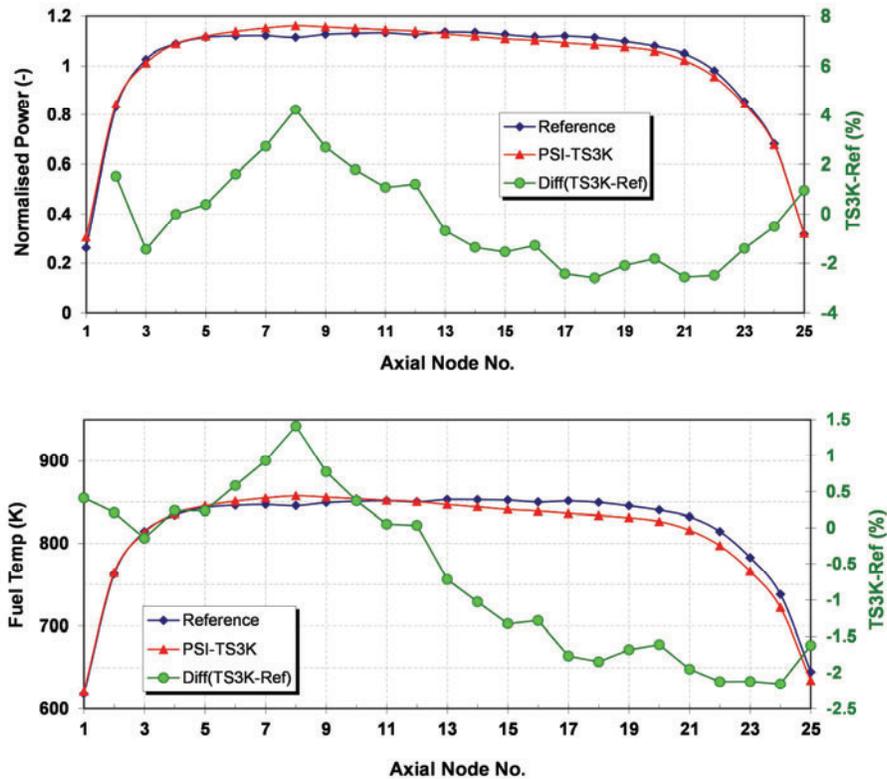


Figure 3. Steady-state Core Average Axial Power (Top) and Fuel Temperature Distribution (Bottom) – TS3K vs. Reference Solution and Relative Differences [TS3K-REF]/REF.

5.1.3. Radial distributions

The normalized radial (axially-averaged) power and active core flow distributions calculated by TS3K are compared to the reference solution in Figure 4. As can be observed, the discrepancy in radial power with respect to the reference results is typically $\pm 3\%$. However, the discrepancy can reach 6% at the core periphery, where the power is very small.

Concerning the active flow results, the agreement is rather good even for the peripheral highly throttled assemblies with an overall discrepancy less than 3%, except at some specific assemblies, where the reason for this discrepancy is not clear.

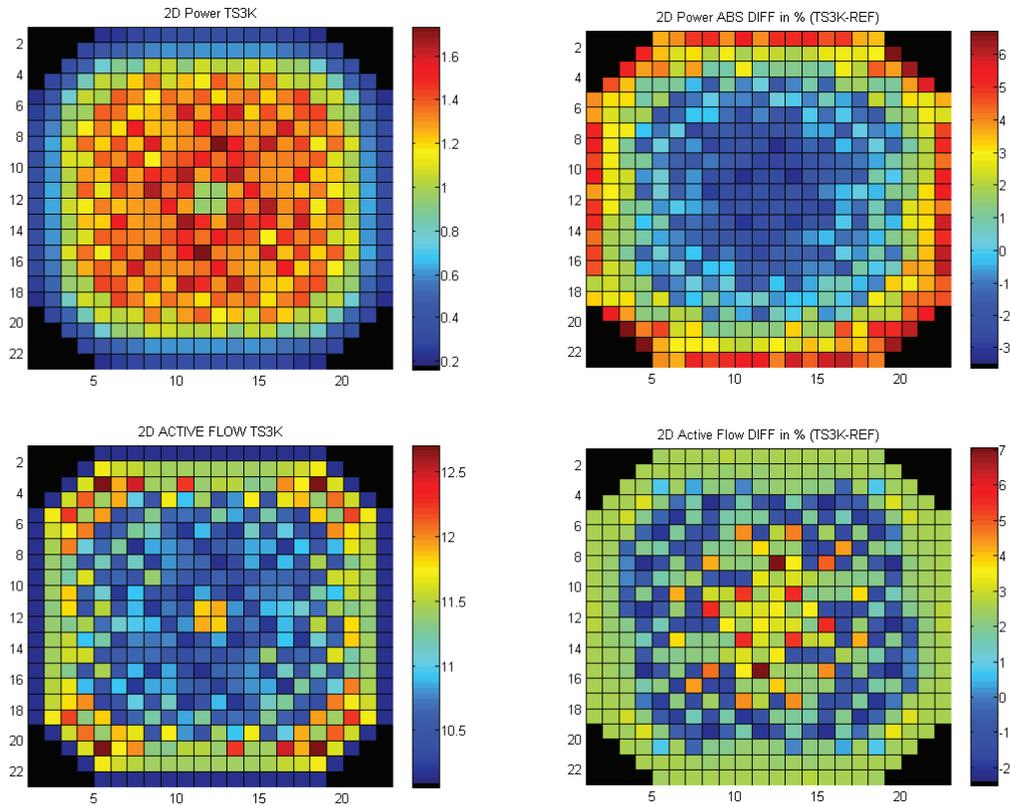


Figure 4. TS3K Steady-state 2D Distributions: Radial Power and Relative Difference against Reference (Top); Radial Active Flow and Relative Difference against Reference (Bottom)

5.2. Transient Analysis

The TS3K results of the transient simulation are presented in this section along with a systematic comparison to the measurement. Note that, in order to assess the predicted behavior without control rod insertion, the TS3K solutions shown in this analysis are performed without activation of a SCRAM model.

5.2.1. Base model results

As a first step, the Base Model, i.e. with 25 axial nodes for the active core region, specified in Table I, is used in this analysis and the results of the transient are presented in Fig. 5. The analysis was carried out with two different values of “dtmax” in TRACE input, i.e. 0.1s and 0.01s. As can be seen, using dtmax=0.1s, the time step optimized by TRACE, using semi-implicit method, is varying during the transient between ~0.012s and 0.02s. When dtmax=0.01s, i.e. lower than the optimal time step, the code is forced to use the suggested maximum time-step value (see Fig. 5(Bottom)). As can be seen, using both dtmax values, the model predicts a very stable behavior of the core. This is expected since the Base Model has a coarse space and time discretization resulting in high numerical diffusion which has a damping effect on any physical oscillation.

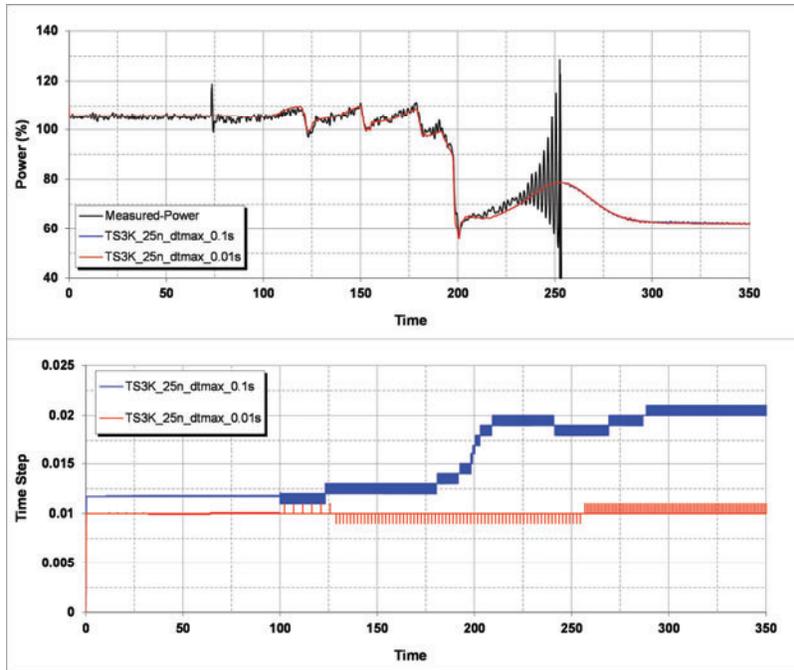


Figure 5. Transient Analysis of O-2 Event using TS3K Base Model – Power vs. Time (Top) and Time Step vs. Time (Bottom).

5.2.2. Refined model results

In this section, the refined model is used, i.e. the active core region is divided to 100 axial nodes (see Table I), and the results are summarized in Figure 6. The analysis was carried out with $dt_{max} = 0.01s$. As can be seen, using $dt_{max}=0.01s$, the time step optimized by TRACE, using the semi-implicit method, has significantly decreased and varies during the transient between $\sim 0.0025s$ and $0.005s$.

Concerning the event prediction, as can be seen, the transient behavior has been captured by the current TS3K model, i.e. the onset of the instability with growing oscillation amplitudes. This clearly illustrates the fact that using the Refined Model, the numerical diffusion has been significantly decreased compared to that of Base Model. In order to ensure that the model has reached a satisfactory space-time convergence, sensitivity analysis on time step size is carried out in the next Section.

Quantitatively, although a certain delay in the behavior of the core power oscillation is noticed, compared to the measurements, the comparison of the predicted stability parameters, i.e. the decay ratio (DR) and the resonance frequency (RF), to those of the measurement shows a very good agreement, as illustrated in Fig. 6 (Top). Note that the DR and RF were estimated, in the time interval 235s-250s, using a variant of the PSI methodology based on an Auto Regressive Moving Average (ARMA) modeling approach [14].

In addition, Figure 6 indicates that if the SCRAM had not been triggered, the growing power oscillations would eventually reach maximum amplitude around 225% and then decay into a stable limit cycle (oscillations between 30% and 150%). Note that the current solution is qualitatively different from that obtained using S3K standalone [2], where the growing oscillations were found to reach a maximum of 170% then decay to a stable state. One reason, besides that TS3K and S3K solution schemes are different, is that different pump speed BCs have been used in TS3K and S3K models at the instant where the oscillations are triggered, which was found to be a very critical parameter, with high sensitivity of the

core dynamics to any small change in the BCs which would result in different solution [2]. Hence, sensitivity analysis on the pump speed BC is carried out in the next section.

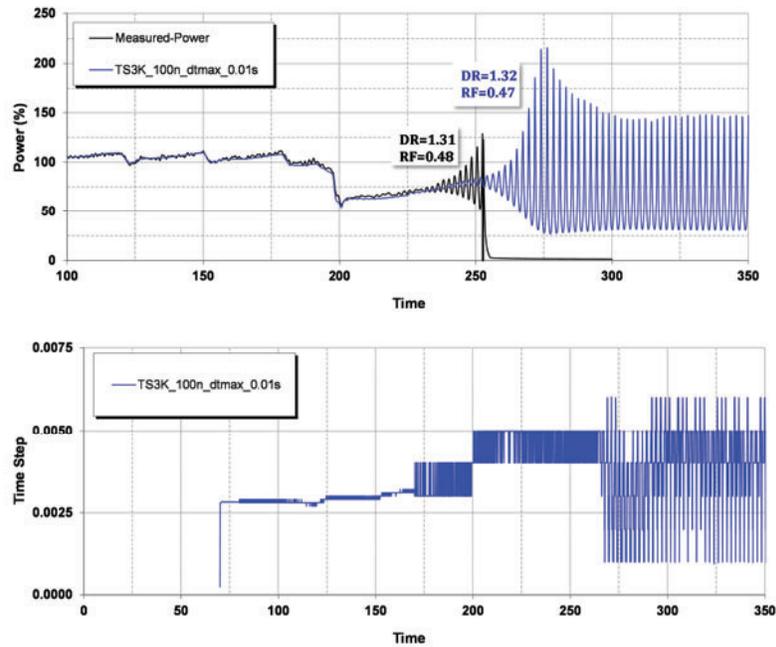


Figure 6. Transient Analysis of O-2 Event using TS3K Refined Model – Power vs. Time (Top) and Time Step vs. Time (Bottom).

5.2.3. Sensitivity and model optimization

In this Section, the Refined Model with $dt_{max}=0.01s$ is the basis model from which the sensitivity analysis is carried out.

Sensitivity to Pump Speed Boundary Conditions

In this Section, the pump speed BC that has been used in [2], S3K stand-alone, is used here in the TS3K model (referred to as TS3K_S3K_BC). Results are compared, in Figure 7, with those using the original BCs, given in the specification and presented in the previous section (referred to as TS3K_Orig_BC). As can be seen, using the new pump speed boundary condition, i.e. the one used in [2], in the TS3K model, the measured total mass flow is better captured compared when using the original BC (see Fig. 7 (Top)). Similarly, the measured core power oscillations are also better captured by the TS3K_S3K_BC model compared to the TS3K_Orig_BC model (see Fig. 7 (Bottom)). Qualitatively, the growing oscillation amplitudes predicted by TS3K_S3K_BC model reach a maximum of $\sim 600\%$ then decay to a stable limit cycle with a very small amplitude. Quantitatively, the RF evaluated by TS3K_S3K_BC is slightly underestimated, while the DR results is in good agreement with the measurements (see Fig. 7 (Bottom)). This analysis clearly illustrates the high sensitivity of the results to very small changes in the pump speed values at the instant where the instability is triggered.

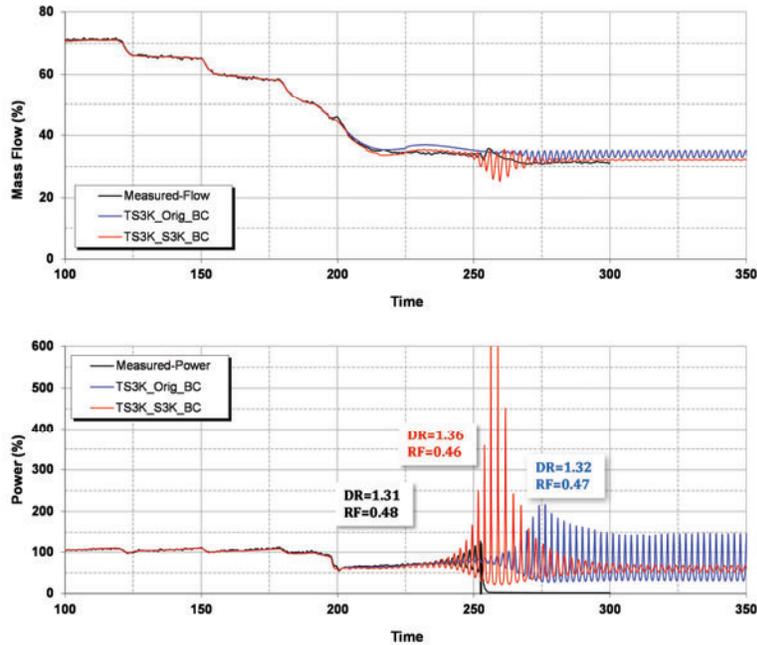


Figure 7. Pump Speed BC Sensitivity: Effect on Mass Flow (Top); Effect on Core Power (Bottom).

Sensitivity to Time Step Size

In order to ensure that the numerical discretization errors in the Refined Model were no longer significantly influencing the results, the time step size has been further decreased to 0.002s for the TS3K_S3K_BC model. Note that, when dtmax=0.002s, the code is forced to use the suggested maximum time-step value (see Fig. 8 (Bottom)).

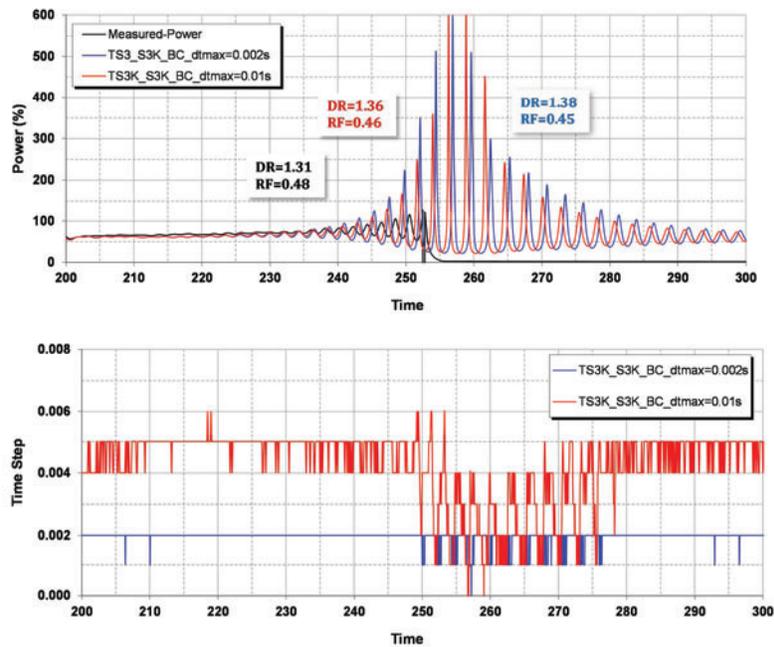


Figure 8. Time Step Size Sensitivity: Effect on Core Power (Top); Effect on Time Step (Bottom).

As can be observed from Fig. 8 (Top), the behavior of the core power is almost the same, i.e. a difference around 2% for DR and RF results. This gives confidence that a satisfactory space-time convergence has been reached with the Refined Model. However, it should be noted that, the Refined Model can be further refined in space and time but due to high computation cost the present Refined Model can be considered as satisfactory at this stage. Table IV compares the calculation time for the Base and Refined Models. As can be seen, the running time for the Refined Model is approximately 30 times longer compared to the Base Model.

Table IV. Runtime Comparison for Basic and Refined Models

	Calculation Time (h)	Simulation Time (s)
Basic Model (dtmax = 0.1s)	5.54	450
Refined Model (dtmax=0.01s)	103.47	300

6. CONCLUSIONS

The OECD/NEA recently launched an international benchmark on a combined feedwater transient and stability event that occurred at the Swedish nuclear power plant Oskarshamn-2. The primary benchmark objective is to assess advances in coupled neutronics/thermal-hydraulic codes for simulations of challenging transients including the appearance of unstable power oscillations. The Paul Scherrer Institute is participating in this benchmark in order to enlarge the validation basis of its advanced stability analysis methodology currently under development for Swiss BWRs. The first study of this transient, based on state-of-the-art SIMULATE-3K three-dimensional reactor kinetics code, has been achieved recently and results demonstrated the capability of S3K to simulate complex behavior of such BWR stability event.

A coupling between TRACE and S3K was developed in collaboration between PSI and Studsvik for analyses involving interactions between system and core, with the goal to enhance the capability to perform best-estimate simulations of Light Water Reactors transients, where strong coupling between core neutronics and plant thermal-hydraulic. In order to verify the coupling scheme and the coupled code capabilities to simulate complex transients, the OECD/NEA Oskarshamn-2 Stability benchmark was modeled with the coupled code TS3K. The main goal was to present TS3K analyses of the Oskarshamn-2 stability event, noting that this constitutes the first reported assessment of this code system for a BWR stability problem.

A systematic analysis has been carried out using different time-space discretization schemes in order to identify an optimized methodology to simulate correctly the O-2 stability event. In this context, the TS3K results were compared to the available benchmark data both for steady-state and transient conditions. The results illustrated that using a refined model in space and time, the TS3K model could capture the entire behavior of the transient qualitatively, i.e. onset of the instability with growing oscillation amplitudes, as well as quantitatively, i.e. Decay Ratio and resonance frequency. However, it is also shown that the qualitative as well as quantitative trends predicted by TS3K during the transient phase when power oscillations start to take place is highly sensitive to the pump boundary conditions and that the benchmark specification might in this context need to be further reviewed.

Although the Refined model can be considered as satisfactory at this stage, since it is the first assessment of the TS3K model for a stability problem, further refinement of the model is needed for a more rigorous

space-time convergence analysis. However this is outside of the scope of the present work. In addition, the incorporation of the non-uniform axial nodalization in TS3K model is planned for a future work.

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