TOWARDS A CONSOLIDATED APPROACH FOR THE VALIDATION OF PLANT SYSTEM CODES AND MODELS: CASE STUDY FOR A BWR FAST DEPRESSURISATION EVENT

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ABSTRACT

The STARS project at the Paul Scherrer Institut (PSI) has adopted the TRACE thermal-hydraulic (T-H) code for best-estimate plant system transient simulations of the Swiss Light Water Reactors (LWRs). For analyses involving interactions between system and core, a coupling of TRACE with the SIMULATE-3K (S3K) LWR core simulator has also been developed. In this configuration, the TRACE code and associated plant models play a central role to achieve a comprehensive safety analysis capability. Therefore, efforts have now been undertaken to consolidate the validation strategy by implementing a more rigorous and structured assessment approach for TRACE applications involving either only system T-H evaluations or requiring interfaces to e.g. detailed core or fuel behavior models.

The first part of this paper presents the preliminary concepts of this validation strategy. The principle is to systematically track the evolution of a given set of predicted physical Quantities of Interest (QoIs) over a multidimensional parametric space where each of the dimensions represent the evolution of specific analysis aspects, including e.g. code version, transient specific simulation methodology and model "nodalisation". If properly set up, such environment should provide code developers and code users with persistent (less affected by user effect) and quantified information (sensitivity of QoIs) on the applicability of a simulation scheme (codes, models, methodology) for steady state and transient analysis of full LWR systems. Through this, for each given transient/accident, critical paths of the validation process can be identified that could then translate into defining reference schemes to be applied for downstream predictive simulations.

To illustrate this approach, the second part of this paper presents a first application of this validation strategy to an inadvertent blowdown event that occurred in a Swiss BWR/6. The transient was initiated by the spurious actuation of the Automatic Depressurization System (ADS). Here, the validation approach progresses through a number of dimensions: First, the same BWR system model is assessed for different versions of the TRACE code, up to the most recent one. The second dimension is the "nodalisation" dimension, where changes to the input model are assessed. The third dimension is the "methodology" dimension. In this case imposed power and an updated TRACE core model are investigated. For each step in each validation dimension, a common set of QoIs are investigated. For the steady-state results, these include fuel temperatures distributions. For the transient part of the present study, the evaluated QoIs include the system pressure evolution and water carry-over into the steam line.

KEYWORDS
TRACE, SIMULATE-3K, thermal-hydraulics, boiling water reactor, validation

1. INTRODUCTION

State-of-the-art safety analysis requires a number of different computational codes, tools as well as models and input information for each code and tool involved. In addition, the way the codes and tools are combined and the models involved may change from application to application. Therefore, it is crucial to have a rigorous management of code validation, model development and validation, as well as methodology development and validation.

To efficiently manage the validation of the codes and models employed by the STARS project at the Paul Scherrer Institut (PSI), different platforms are currently being developed. The "Core Management SYStem" CMSYS [1] is the most mature of these platforms. Its purpose is to establish and maintain the capability to perform at any given time, validated 3-D core calculations of the Swiss LWRs up to the latest completed operating cycle. Similarly, two other platforms are currently being developed: The "Fuel Management SYStem" FMSYS and the "Plant Management SYStem" PMSYS. The goals of these platforms are to develop and maintain the fuel/plant models and methodologies for the Swiss reactors including their validation. Apart from serving as a central platform to maintain and update models of the Swiss plants, the structure and functionality of CMSYS/FMSYS/PMSYS also allows using it for the verification of new analysis methodologies.

The STARS project has adopted the TRACE thermal-hydraulic (T-H) code for best-estimate plant system transient and accident simulations of the Swiss LWRs. For analyses involving interactions between system and core, the coupling of TRACE with the SIMULATE-3K (S3K) LWR core simulator is used. Thus, the TRACE code and associated plant models play a central role to achieve a comprehensive safety analysis capability for anticipated operational occurrences up to beyond design basis accidents (excluding core melt). As part of the PMSYS platform, efforts have now been undertaken to consolidate the model development and validation strategy by implementing a more rigorous and structured assessment approach for TRACE applications involving either only system T-H evaluations or requiring interfaces to e.g. detailed core or fuel behavior models.

The following section details the first version of the validation approach for the plant system code TRACE and the associated models. Sect. 3 presents a case study of a BWR/6 fast depressurization event, i.e. the validation approach outlined in the first section will be applied to a transient that actually happened in a power plant and where measured plant data is available. Finally, Sect. 4 summarizes the findings and concludes the paper.

2. APPROACH FOR THE VALIDATION OF PLANT SYSTEM CODES AND MODELS

This section presents the preliminary concepts of the development and validation strategy for TRACE plant models. The principle is to systematically track the evolution of a given set of predicted physical Quantities of Interest (QoIs) over a multidimensional parametric space where each of the dimensions represent the time-evolution of specific analysis aspects including e.g. code version, model "nodalisation" (input deck) and transient specific simulation methodology. If properly set up, such environment should provide code developers and code users with persistent (less affected by user effect) and quantified information (sensitivity of QoIs) on the applicability of a simulation scheme (codes, models, methodology) for the analysis of full LWR systems. The methodology consists of the following steps:

1. Determine the QoIs as a function of the application.
2. Define the starting point and the aimed path in the multidimensional validation space (codes, models, methodology).
3. Evaluate (and validate if necessary) each standalone incremental step along the validation path.
4. Evaluate and validate (when possible) the combined model for steady state and transient.

2.1. The Quantities of Interest (QoIs)

The first step of the presented model validation methodology consists of defining so called “quantities of interest” (QoIs) which can be followed during the evolution of the model. Ideally, these QoIs will be compared to experimental data. In that case, the discrepancy of the QoI to the measured value can be analyzed and used as an indicator of the quality of the model. If there is no measured data available for the QoIs, their change during the evolution of the model has to be assessed. Here, expert judgment is needed to decide if the prediction quality of a QoI from one model to another has actually improved or not. QoIs without available measured data are preferably avoided since there is an obvious user effect, which one would like to minimize for the simulation scheme to be as predictive as possible.

Furthermore, the choice of the QoIs can depend on the purpose of the analysis and on the type of scenario, i.e. the transient to be simulated. For example, for an unprotected transient the core power evolution may be chosen as a QoI, whereas the core neutronics may play an inferior role if the transient is protected. This brings about the need to specify generic QoIs and QoIs that are more specific to the scenario and the purpose of the analysis. Typical generic QoIs would include the parameters as measured in the plant, as well as the trip actuation times (sequence of events).

2.2. The Multidimensional Validation Space

The second part of the methodology consists in defining a path in the multidimensional validation space. The dimensions of this space are independent of the application or model to be investigated. The methodology currently applied in the STARS program includes the following three dimensions as shown in Fig. 1.

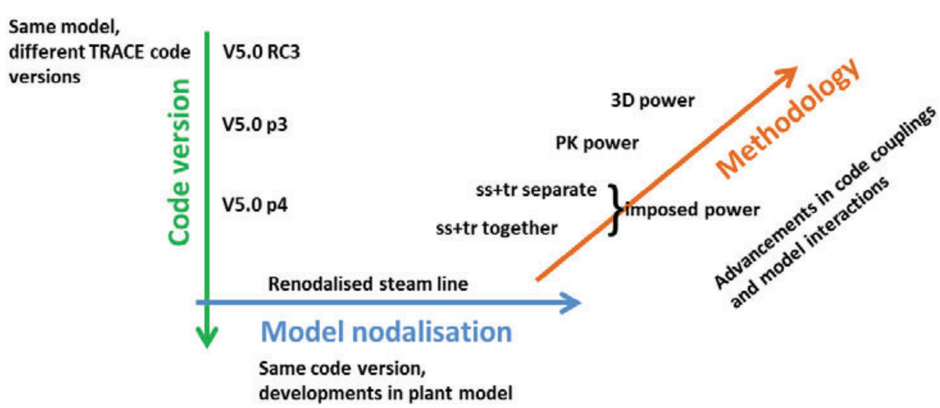

Figure 1. Three dimensional validation space for TRACE applications at STARS.

The first dimension is the ‘Code version’. When a new model is developed, the development starts with the latest validated version of the code. Sometimes the model development starts from an already existing legacy model and an upgrade of the model to the latest validated code version is needed. Ideally, the model should not change along this axis, only the code version does. However, the code input might need to be modified (upgraded) to comply with the new code version.

The second dimension is the ‘Model nodalisation’. This dimension contains all model changes that involve only the TRACE code, e.g. mesh refinements, selected component models and plant control systems. In this dimension, every development change, for example a more detailed heat exchanger model has to be validated in standalone before it can be connected to the full model. In addition, the validation through the selected QoIs has to be performed for steady state before the model can be validated for the transient. When no validation data are available (plant measurements or ITF experiments representative of the analyzed system) nodalisation best practices [4] should be applied.

The last dimension is the 'Methodology'. This dimension includes all developments that involve other codes than TRACE or other already established methodologies, e.g. methodologies developed in the framework of the CMSYS or FMSYS platforms. Typically, this dimension contains developments for code couplings like neutronic or fuel performance codes.

For each given transient/accident, a critical path of the validation process has to be identified that can then translate into defining reference schemes to be applied for downstream predictive simulations. The starting point of the path should be defined as:

- Dimension 'Code version': Latest version validated using Separate-Effect-Tests (SET) data.
- Dimension 'Nodalisation': Latest nodalisation validated using Integral-Test-Facility (ITF) data.
- Dimension 'Methodology': Methodology making use of latest validated other codes and models.

As for the progress along the validation path, a part or even all cross points in the dimensions could be validated. Moreover, each step along the first or second dimension should be preceded or accompanied by a corresponding increment of the V&V campaigns (SET for 'Code version', ITF for 'Model nodalisation'), but in reality this is not always feasible or useful (usefulness measured using the QoIs as metrics).

3. CASE STUDY FOR A BWR FAST DEPRESSURISATION EVENT

To illustrate the above presented approach, the second part of this paper presents a first application of the validation strategy to a real BWR/6 fast depressurization event, which was initiated by the spurious actuation of the Automatic Depressurization System (ADS). The validation approach progresses through all three dimensions. First, the same BWR TRACE system model is assessed for different versions of the TRACE code, up to the most recent one. For the 'Methodology' dimension an updated TRACE core model pre-processing method is investigated. Finally, for the 'Model nodalisation' dimension, a new steam line model is evaluated in standalone mode and later connected to the full system model. For each step in each validation dimension, a common set of QoIs is investigated. The following sections will briefly describe the transient and the initial TRACE model. After that, the QoIs will be defined and their results for the model evolution will be presented.

3.1. Transient Description

The analysis of the ADS transient using TRACE has already been presented in detail in [2]. It is not the intention to reanalyze the transient in the framework of this paper, but to use it to introduce BWR/6 model developments made at STARS as well as to illustrate the developed model validation approach.

As mentioned, the depressurization event was initiated by a spurious actuation of the ADS. In particular, 8 ADS relief valves of the steam lines were fully opened. In the early phase of the transient, the total steam flow, i.e. the combined flow to the safety relief valves (SRVs) and the turbine, increased. Consequently, the turbine control valve tried to counteract and keep the steam flow close to the nominal value. This stabilized the system pressure for a short time before it started to drop.

The fast depressurization caused the wide range and narrow range levels in the downcomer of the reactor pressure vessel (RPV) to rise due to steam flashing below the lower pressure measurement tap. Reduction in steam flow and rise of the water levels led to a decrease of feed-water flow. These combined effects then led to a fall of the water levels. The reactor was automatically tripped through the RPV water level signal. The reactor trip (SCRAM) resulted in the isolation of the steam lines, the feed-water system and the reactor containment building. The fall in power caused a drop in the steam production which lowered the pressure. This collapsed the core void and levels fell rapidly. Sometime later, the depleting RPV water level signal tripped the recirculation pumps. The depressurization of the RPV caused flashing and consequently a level swell in the down-comer. As a result of the swell in the upper part of the down-comer, water flew (as indicated in [3]) into the steam lines and from there to the SRVs.

As the reactor continued to depressurize, the High Pressure Core Spray (HPCS) and the Reactor Core Isolation Cooling (RCIC) were both actuated manually. Subsequently, the RPV pressure almost immediately reached the saturation pressure of the water in the feed-water line. Since the feed-water line pressure is the lowest upstream of the injection nozzles, flashing started there and caused a surge of coolant into the RPV. Later on, after the ADS relief valves were closed, the RCIC was used to control the water level in the RPV while the SRVs were used to control the primary pressure. Later, when the pressure and the temperature in the RPV were sufficiently low and stabilized, the recirculation pumps were started again and the Reactor Heat Removal system (RHR) was then set on the shutdown/startup cooling mode some hours after the beginning of the transient.

3.2. Model Description

This section briefly describes the used TRACE model. As explained in the methodology section above, the TRACE model development can start from an existing, verified model input. For the case study presented here, the BRW/6 TRACE model that was formerly used to analyze the ADS transient [2] was used as a starting point. The model description given here is for this 'initial' model. Subsequent model changes, either on the nodalisation or the methodology axis of the validation scheme will be introduced in the corresponding sections later in the paper. The nodalisation is already presented in detail in [2]. Only the main features of the model are recalled here.

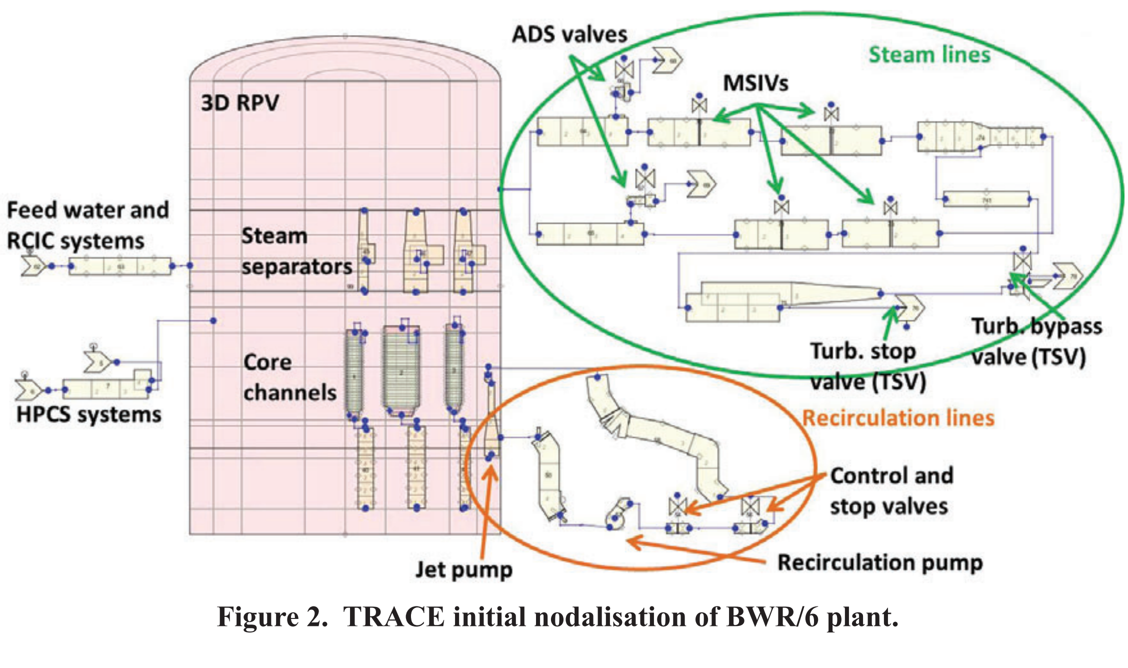

Figure 2. TRACE initial nodalisation of BWR/6 plant.

Fig. 2 shows the TRACE nodalisation of the BWR/6. The TRACE vessel nodalisation comprises 4 radial rings, 17 axial layers and one azimuthal sector. The three inner rings are located inside the vessel shroud, whereas the outermost ring represents the downcomer. The control rod guide-tubes are collapsed into three pipe components located in rings 1, 2 and 3 that connect the lower plenum to the core bypass region. The fuel assemblies are modeled by TRACE channel components (CHAN) placed in rings 1, 2 and 3, respectively. Similarly the plant steam separators are represented by three separator components (SEPD) which are as well located in rings 1, 2 and 3. The steam exiting the separators flows through a "perfect dryer" interface to the steam dome and out into the steam lines.

The two steam lines are divided asymmetrically into a 3:1 flow split, so that one TRACE line represents three physical lines, while the other represents one physical line. Each of the two modeled lines includes the SRVs as well as the main steam line isolation valves (MSIVs) inside and outside the containment. The two steam lines are then collapsed into a common line that leads to the turbine. Furthermore, the turbine bypass line branches from the common steam line and leads to the steam header.

Each of the two identical BWR/6 recirculation lines is modeled explicitly (only one recirculation line is shown in Fig. 2). The models for these lines are composed of a suction pump connected to the RPV represented by a PUMP component in TRACE followed by a flow control valve and a discharge or recirculation loop isolation valve. Finally, a pipe component represents the jet pump drive line that leads to the jet-pumps (JETP components in TRACE). One JETP component is associated to each of the modeled recirculation lines in TRACE, representing 10 of the 20 actual jet-pumps present in the reactor.

The six feed-water lines entering the RPV are modeled as one collapsed pipe component. All the BWR/6 emergency core cooling systems (ECCS) are included in the TRACE model. These consist of a) the high and low pressure core spray (HPCS and LPCS) systems, b) the standby liquid control system (SLCS) and c) the low pressure coolant injection (LPCI) system.

The following components are controlled by a control system or are boundary conditions where parameters are imposed:

- **Steam Lines:** The turbine and the turbine bypass (condenser) are represented by boundary conditions. The respective pressures for the turbine and the condenser are imposed during steady state and transient conditions. The MSIVs are closed by the plant SCRAM logic which is implemented in the model using TRACE control blocks. The ADS valves are opened at the start of the transient. The first closure, the reopening and reclosing of the valves is implemented in the model according to the transient times reported by the plant.
- **Feed-water system:** At the end of the simplified pipe representing the feed-water line is a boundary condition that is used to impose the feed-water flow rate and temperature. During steady state, these values are determined by the feed-water controller that keeps the core water level constant. The feed-water controller is implemented in the model using TRACE control blocks. During transient conditions, the feed-water flow rate and temperature are imposed according to plant measurements.
- **Recirculation system:** The recirculation pumps and flow control valves are controlled during steady state by the core flow controller which is implemented in the model using TRACE control blocks. During the transient, the recirculation pumps are tripped by the SCRAM logic.
- **Plant protection system:** The ECCS systems are triggered by their respective conditions (core level, RPV pressure, etc.) or imposed if the plant reported any operator action during the event.
- **Core power:** The core power and decay heat are imposed functions of time.

3.3. QoIs

As mentioned in the presentation above, the validation methodology consists of following selected QoIs during the evolution of the model. Furthermore, it has been explained that the selection of the QoIs depends on the transient to be calculated as well as on the purpose of the analysis. For the BWR/6 depressurization transient presented in this case study, the following specific QoIs have been selected from a safety point of view. A strong point of the methodology is the fact that this list can easily be extended if necessary.

- **Pressure induced stresses in the RPV**. During the initial phase of the event the RPV experienced a fast depressurization. The pressure gradient in the primary system leads to significant stresses on the RPV wall and the internal structures associated [3]. To quantify these stresses the chosen QoIs are the dome pressure time derivative, i.e. dp/dt and the pressure drops over the sensitive locations in the core as specified in [3]. It has been found that these pressure drops behave all very similar and therefore, only two are shown, i.e. the core lower support plate and the channel wall. The dome pressure and the pressure drop over the core plate are measured during the event. This allows comparing these QoIs to experimental values.
- **Water carry-over into the steam line**. The water level may rise to very high levels during the event. This increase of the measured water level is the consequence of the swelling of the fluid mixture due to steam flashing below the lower pressure measurement tap. One question is therefore to determine whether the swelling of the water level was sufficient to raise the mixture level close to the steam line intake and therefore to cause liquid carry-over to the components of the steam line, and in particular to the SRVs. To quantify this, the chosen QoI is the integrated liquid mass flow at the steam line inlet from the RPV.

The generic QoIs include pressures, temperatures and mass flows at different points in the system. The monitoring of these QoIs, allows for a better understanding of the model behavior during the steady state and transient. Thus, the RPV wide range (WR) and narrow range (NR) water levels are particularly relevant since they provide inputs to various safety systems, and can be related to water carry-over. The two water level measurements are reconstructed using the TRACE control system as follows:

$$lag\left(\frac{P_{tap_{bottom}} - P_{tap_{top}}}{\rho g}\right) + L_0 \tag{1}$$

where:

'lag' is a first order time lag
ρ is the reference water density
g is the gravitational constant
L_0 is a reference point
P_{tab} is the pressure at the tap position. It is corrected for the calculated geostatic pressure difference between the TRACE node center and the actual measurement tap elevation.

3.4. The Three Dimensional Validation Space

This section illustrates the model developments made for the BWR/6 TRACE model for the ADS depressurization transient and the corresponding model and code validations according to the validation methodology presented above. The section is divided into three parts according to the three validation dimensions, i.e. the code versions, the methodology dimension and finally the nodalisation dimension. All presented quantities as well as the transient time have been arbitrarily normalized to protect plant proprietary data.

3.4.1 First iteration: Code versions

The first step of the validation path is made along the dimension 'Code version'. The intention here is to bring an existing model to the current TRACE code version. In this example, the BWR/6 model described in Sect. 3.2 and used to analyze the ADS event [2] has been taken as the 'initial' input. The original ADS analysis has been done using TRACE V5.0RC3. The same model has been run with the current code version TRACE V5.0p4 (only minor changes have been made to make to model run with newer code versions).

Table I compares some of the generic QoIs to measured plant data at steady-state. As indicated above, the core power is imposed as boundary condition. The other quantities are adjusted by different control systems as explained in Sect. 3.2. The table shows that the new simulation case is able to capture the measured data within ±2%. No modification to the TRACE model has been made to improve the agreement for the core mass flow rate, as this would have infringed the validation approach.

Fig. 3 shows the evolution of the QoIs for the ADS transient for the different code versions. The top left figure shows the dome pressure time derivative for the first 10% of the transient only, since the highest pressure gradients happen during this period of time. One can see that among the QoIs, only the steam line water carry-over is significantly different between the code versions. The water carry-over is estimated differently at the beginning of the transient (< 0.1 normalized time), where version V5.0p4 predicts more water going to the steam line compared to V5.0RC3. The water carry-over is very sensitive to the system pressure which varies strongly at the beginning of the transient. The WR core level and the mass flow through the ADS valves are quite similar between the code versions.

Table I. Boundary and initial conditions for different TRACE code versions (C/E).

	V5.0 RC3	V5.0 p4
Core power	1.00	1.00
Core mass flow rate	0.96	1.00
Recirculation loop flow	1.00	1.00
Feed-water mass flow rate	0.98	0.98
Steam mass flow rate	0.98	0.98
RPV dome pressure	1.00	1.00
RPV level (WR)	1.01	1.01

3.4.2 Second iteration: Methodology

For the 'Methodology' dimension, the core component of the BWR/6 TRACE model has been replaced. While the 'initial' core component had a 3 channel representation with an arbitrary power distribution and fuel rod gap conductance, the new core component has been prepared with the COBALT pre-processing tool. COBALT is a development within the CMSYS platform that can collapse the assembly geometries representing the actual core loading into an arbitrary number of TRACE channels. Furthermore, the thermophysical properties of the fuel as well as the power distribution can be set by COBALT for any time of any core cycle actually operated in the plant. Here, COBALT has been used to generate a TRACE core model corresponding to the cycle and exposure of the actual ADS event. This simulation case is referred to as 'COBALT core' and has been run using TRACE V5.0p4.

Changing the core has no impact on the system steady state results, as shown in Table II. Fig. 4 shows on the top left figure the axial fuel temperature distribution at steady state for the 3 core channels. One can see that COBALT capture a more realistic power distribution compared to the arbitrary cosine shape from the previous model. The strongest impact of this change can be seen during the initial pressure gradient of the transient, probably due to the better representation of the energy stored in the fuel. To compare better to plant data, in addition to the dp/dt plot, the dome pressure has been included. One can see that the model 'COBALT core' captures the initial pressure gradient slightly better compared to plant data. The other QoIs are not shown since they behave very similar between the two models except the water carry-over into the steam line. The 'COBALT core' model predicts more water carried into the steam line at the beginning of the transient where the pressure gradient is highest. The water carry-over estimated by the 'COBALT core' model is probably more accurate since the early evolution of dp/dt is captured better.

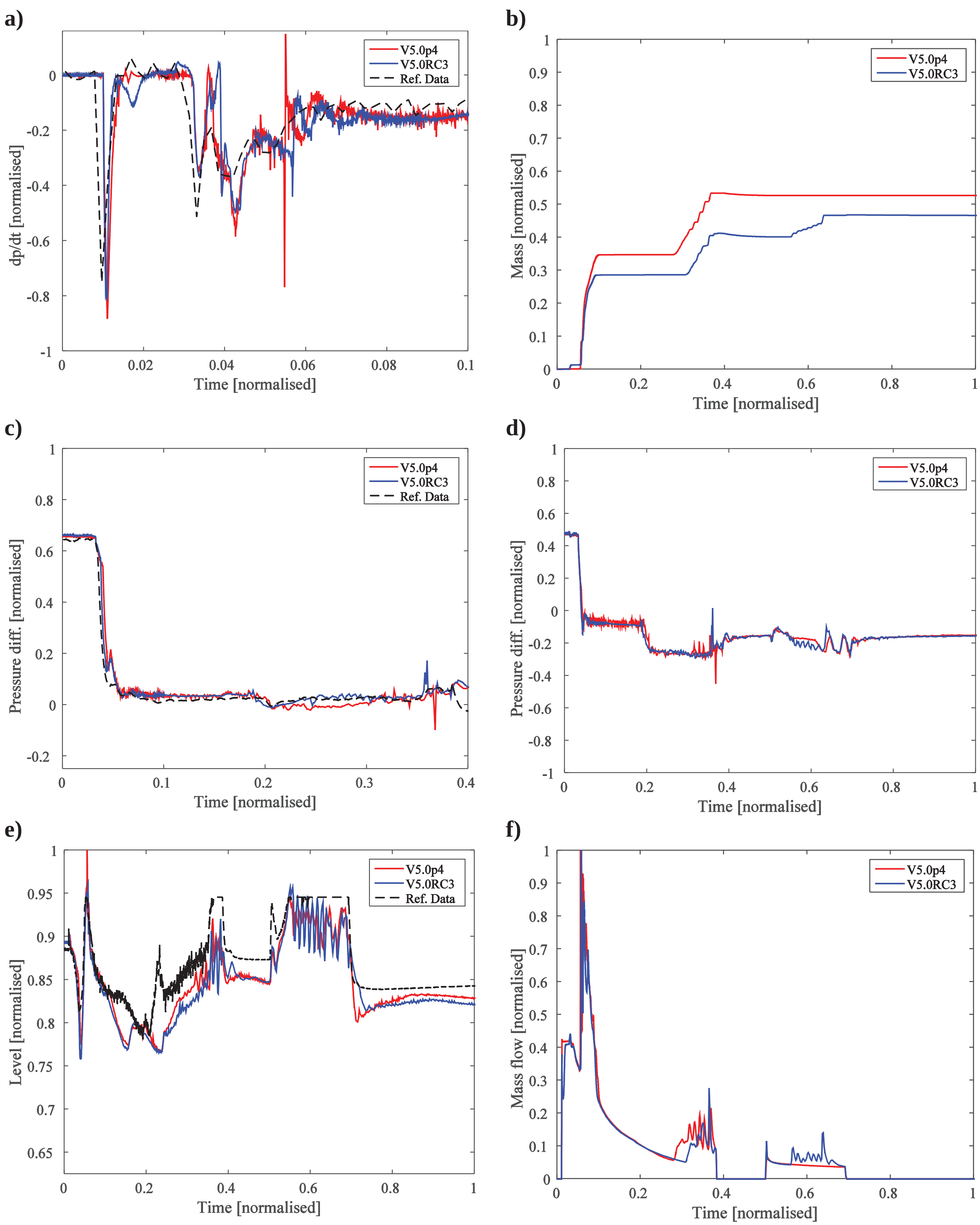

Figure 3. ADS QoIs for different code versions: a) Dome pressure time derivative dp/dt (detail beginning of transient), b) Steam line water carry-over, c) ΔP core lower support plate (detail beginning of transient), d) ΔP channel wall, e) Wide range core level and f) Mass flow through the ADS valves.

Table II. Boundary and initial conditions for dimension ‘Methodology’ (C/E).

	V5.0 p4	COBALT Core
Core power	1.00	1.00
Core mass flow rate	1.00	1.00
Recirculation loop flow	1.00	1.00
Feed-water mass flow rate	0.98	0.98
Steam mass flow rate	0.98	0.98
RPV dome pressure	1.00	1.00
RPV level (WR)	1.01	1.01

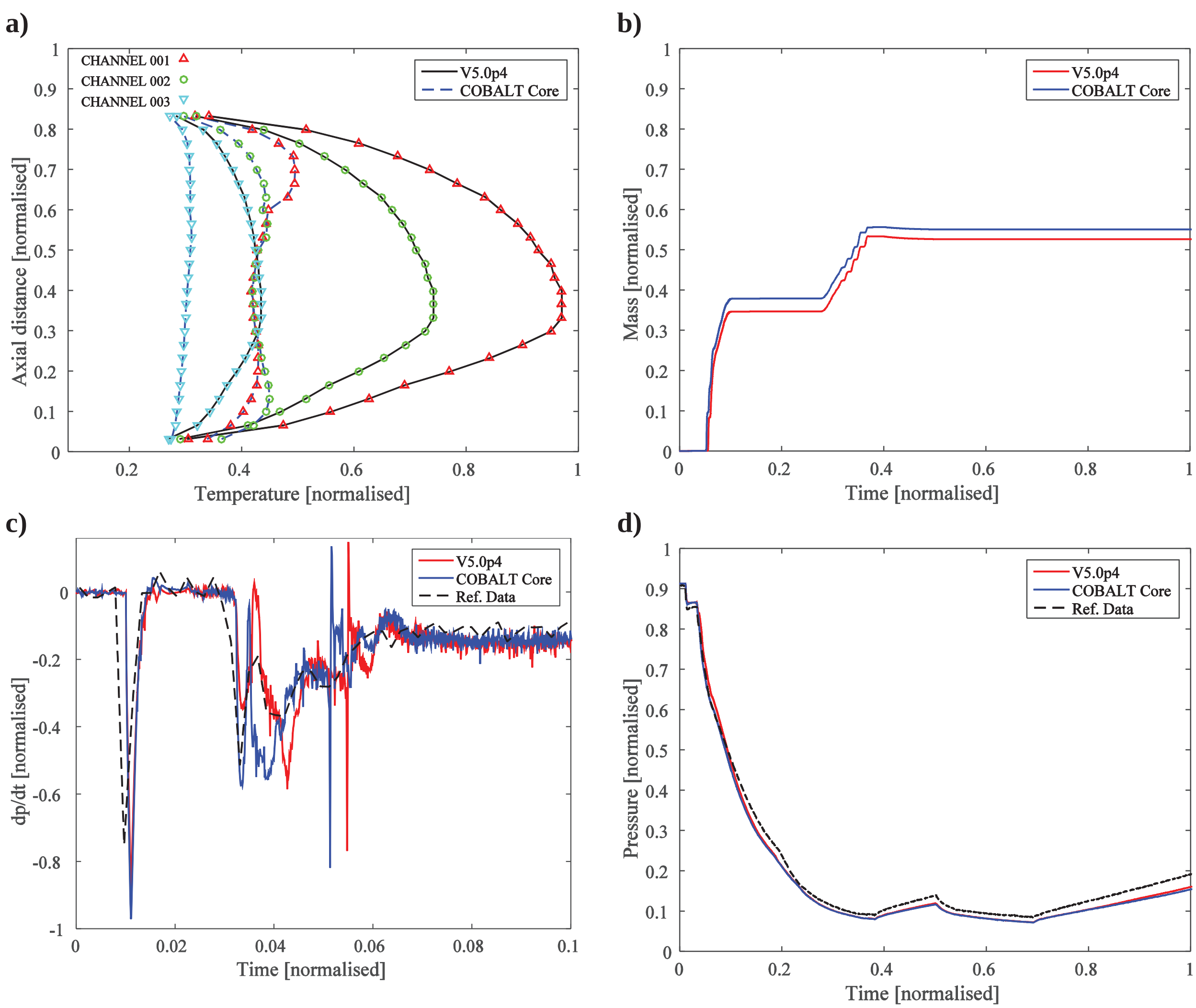

Figure 4. ADS QoIs for the TRACEv5.0p4 and the ‘COBALT Core’ models: a) Initial axial fuel temperature distribution, b) Steam line water carry-over, c) Dome pressure time derivative dp/dt (detail beginning of transient) and d) RPV dome pressure.

3.4.3 Third iteration: Model nodalisation

For the nodalisation dimension, the steam line model has been replaced with a newly developed, more detailed steam line model in TRACE. As required by the validation methodology, the newly developed steam line model has first been validated in standalone mode before it has been connected to the full system model.

Steam line standalone model

As shown in the nodalisation scheme in Fig 5, the revised model describes explicitly the 4 steam lines together with their individual bypasses. As can be noted, the bypasses end at the steam header which is also explicitly modelled, including two discharge lines that end at the condenser. In addition, a boundary condition is imposed to the steam header representing all connected auxiliary steam consumers (WAZU). Compared to the previous TRACE model, a finer axial discretisation has been employed and in line with the modelling guidelines from the U.S. NRC [4], all the TEE components have been replaced by 1-D components inter-connected through side junctions.

To check the steady state performance of the revised steam line model, the TRACE model has been run for different reference test points (one rated and 7 off-rated conditions) and the results have been compared to available plant data. The following boundary conditions have been used:

- **RPV pressure:** The pressure at the RPV boundary has been set to the measured value for each test.
- **Turbine inlet pressure:** The pressure at the turbine valve has been set to the measured values.
- **Turbine Control Valve:** The valve position for each test has been set in the turbine control valve model in TRACE.
- **WAZU:** The auxiliary and WAZU steam flow has been set to a constant negative mass flow as indicated for each test by the plant data.

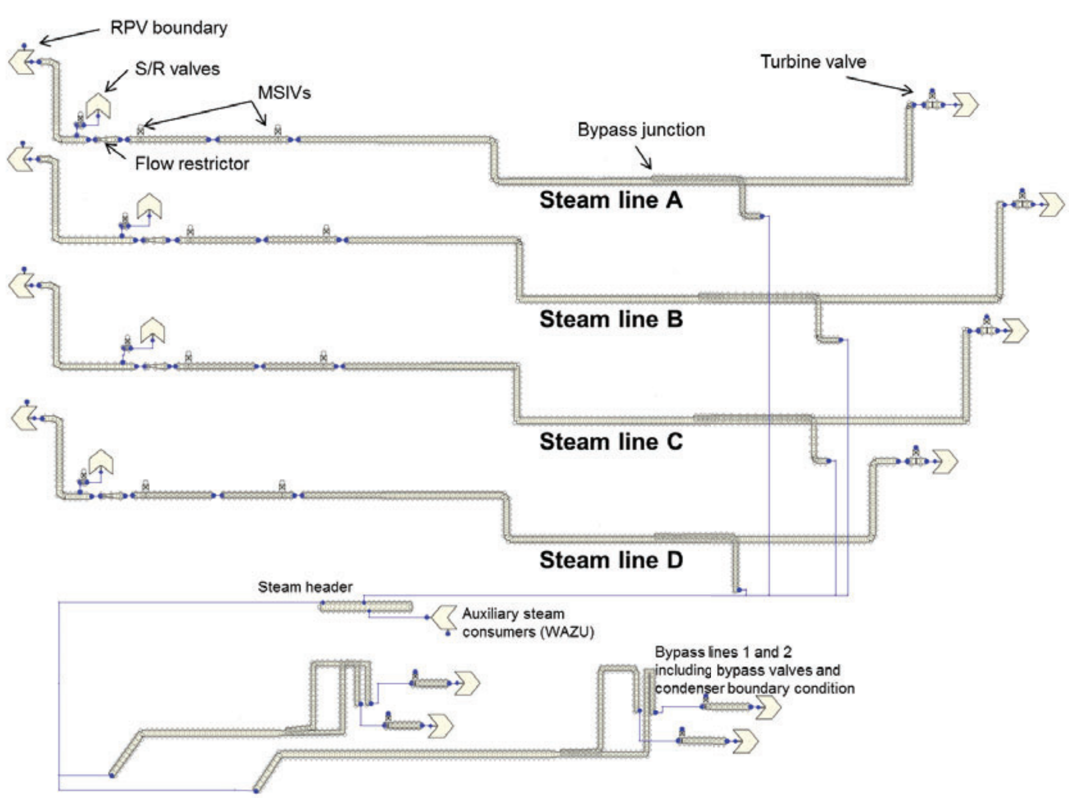

Figure 5. Steam lines with their bypasses. New TRACE nodalisation scheme.

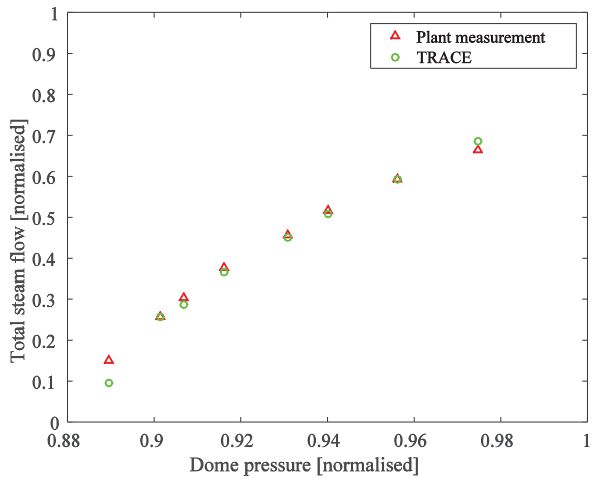

Figure 6. Steam line stand alone model: verification of total steam flow vs. plant data for different rated and off rated plant conditions (dome pressures).

The 8 assessment points have been calculated and the singular pressure drops (k-factors) for the MSIVs and the SRV valves segment have been adjusted to match experimental data. Fig. 6 shows the total steam flow as a function of the dome pressure for the 8 points. One can see that the TRACE calculations match the plant measurement quite well.

New steam line connected to the BWR/6 plant model

The new steam line model has then been connected to the BWR/6 TRACE plant model (now referred to as "New Steam Line"), i.e. this is now the initial model including the COBALT core and the new steam lines that is run using TRACE V5.0p4. Table III compares the most important steady state parameters to measured plant data. The table shows that only the RPV dome pressure changes compared to the "COBALT core" model. This change is only 1% compared to measured plant data and can be neglected.

Fig. 7 shows the evolution of the QoIs between the "COBALT Core" and "New Steam Line" TRACE models. Since the steam lines are isolated from the RPV shortly after the transient starts (MSIVs closure), the differences seen in the plots are mainly due to the different modeling of the SRVs. As one can see, this leads to a slightly different pressure evolution during the transient. This has limited impact on the core plate pressure difference but a significant impact on the water carry-over into the steam line. Furthermore, it can be seen that the wide range core level and the feed-water flow (feed-water surges due to flashing at times 0.2-0.6 and 0.6-0.8) are better captured in the "New Steam Line" model than the "COBALT Core" model compared to measured plant data. In particular, the better agreement (C/E) in the timing and amplitude of the onset of flash flow surge in the feed-water line (time 0.16) hints at an improved prediction of the pressure evolution overall and thus a more realistic water-carry over estimate.

Table III. Boundary and initial conditions for nodalisation dimension (C/E).

	COBALT Core	New steam line
Core power	1.00	1.00
Core mass flow rate	1.00	1.00
Recirculation loop flow	1.00	1.00
Feed-water mass flow rate	0.98	0.98
Steam mass flow rate	0.98	0.98
RPV dome pressure	1.00	0.99
RPV level (WR)	1.01	1.01

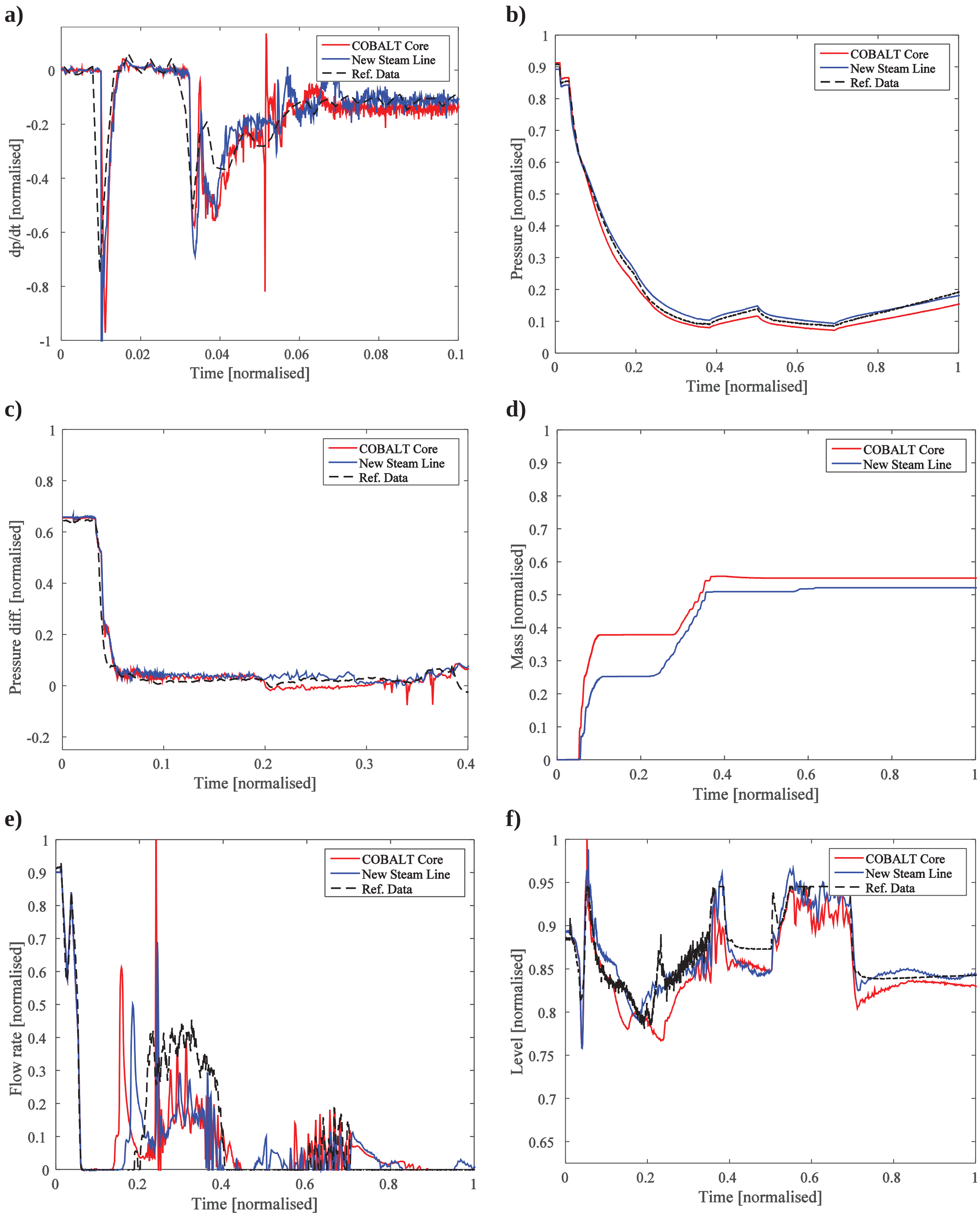

Figure 7. ADS QoIs for “COBALT Core” and “New Steam Line” models: a) Dome pressure time derivative dp/dt (detail beginning of transient), b) RPV dome pressure, c) ΔP core lower support plate (detail beginning of transient), d) Steam line water carry-over, e) Mass flow through the feed-water line and f) Wide range core level.

4. CONCLUSIONS

A preliminary concept of the STARS TRACE code and model validation strategy has been presented and exemplified with the analysis of a BWR/6 depressurization event. The methodology is based on systematically tracking the evolution of a given set of predicted physical QoIs over a multidimensional parametric space where each of the dimensions represents the evolution of specific analysis aspects. The parametric space contains three dimensions, namely code version, model nodalisation and simulation methodology. The QoIs have to be defined depending on the envisaged downstream TRACE analysis, i.e. on the transient and safety issue of interest.

The TRACE code and model validation strategy has been presented for a "spurious actuation of the ADS" event. First, relevant QoIs from a safety viewpoint were selected. These specific QoIs included pressure induced stresses in the RPV (dome pressure time derivative and pressure drops over sensitive locations in the core) and the water carry-over into the steam line (integrated liquid mass flow at the steam line inlets from the RPV). In order to be able to better analyse the quality of the model as it progresses through the multidimensional space, generic QoIs like pressures, temperatures and mass flows at different points in the system and the wide range water level were also considered. One improvement of the model along each of the validation dimensions has been presented.

First, the already validated 'initial' TRACE V5.0RC3 BWR/6 model that was used to analyze the ADS event has been upgraded to the current code version TRACE V5.0p4. It has been shown that all QoIs behave similar between the two code-versions except the water carry-over into the steam line, where the newer code version predicts more. The model has then been moved along the dimension 'Methodology' by improving the core model. It has been shown that the more realistic core modelling method (COBALT and run with TRACE V5.0p4) leads to a better initialization of the core fuel temperature. Finally, the nodalisation (third dimension) has been improved by refining the steam line model. The newly developed steam line model has first been verified as a standalone model and has then been connected to the latest iteration of the BWR/6 system model (using TRACE V5.0p4 and COBALT). It has been shown that the more detailed steam line model slightly improved the prediction of the pressure evolution and in turn, the feed-water flow rate and wide range water level predictions were improved.

As for the specific QoIs of the analysis, the exemplary case study showed that the improvements to the model predictions resulted in a small impact on the system pressure gradient, thus confirming a persistency of the downstream mechanical stress estimate, whereas the water carry-over could vary by up to 150% as function of the adopted simulation methodology.

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