МЕЖДУНАРОДНА ЯДРЕНА КОНФЕРЕНЦИЯ “БЪЛГАРСКАТА АТОМНА ЕНЕРГЕТИКА – НАЦИОНАЛНА, РЕГИОНАЛНА И СВЕТОВНА ЕНЕРГИЙНА СИГУРНОСТ

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Extension of the TRACE Model for NPP Gösgen for MSLB and MB LOCA

Evgeni Borisov and Kaliopa Mancheva, **GCR Ltd., 10 Vihren Street, Sofia 1618, Bulgaria**, kaliopa.mancheva@gcr.bg
Davide Papini, Rainer Kaulbarsch and Jens-Uwe Klügel, Safety Department, **Nuclear Power Plant Gösgen-Däniken AG, Kraftwerkstrasse, 4658 Däniken, Switzerland**, dpapini@kkg.ch

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Evgeni Borisov and Kaliopa Mancheva
GCR Ltd.
10 Vihren Street, Sofia 1618, Bulgaria
kaliopa.mancheva@gcr.bg
Davide Papini, Rainer Kaulbarsch and Jens-Uwe Klügel
Safety Department, Nuclear Power Plant Gösgen-Däniken AG
Kraftwerkstrasse, 4658 Däniken, Switzerland
dpapini@kkg.ch

ABSTRACT

Traditionally, the deterministic safety analyses are performed at the NPP Gösgen by the vendor AREVA (now Framatome), which developed an own version of the RELAP5/Mod 3.3 code (S-RELAP5). In the framework of building in-house expertise, the NPP Gösgen – together with the GCR Ltd. team – have been developing an additional thermal-hydraulic model of the plant using the US NRC code TRACE. This paper is focused on the main changes in the latest TRACE model, which extended the model usage over MSLB and MB LOCA analyses. These changes are related to the update of the reactivity feedback model using void curves, which is important for LOCA analyses, and the containment model. Entirely new containment model was developed based on the MELSIM data and has been validated in a stand-alone mode against MELSIM results. Based on the obtained results, it is concluded that the current TRACE model is appropriate for simulation of LOCA scenarios with break size up to 380 cm^2 and for double ended MSLB scenarios with and without containment.

Keywords:
TRACE, MSLB, LOCA, containment, reactivity feedback

1. INTRODUCTION

The NPP Gösgen (Switzerland) is a 3-Loop PWR (KWU, pre-Konvoi) based on German design. The commercial operation of the plant started in 1979. The NPP is currently active with introducing innovations, backfit measures and the continuous demonstration of the safety standards in the light of a long-term operation. In the framework of the deterministic safety analyses, proving the fulfilment of the success criteria in case of postulated Design Basis Accidents (DBAs), it is required to use a thermal-hydraulic code featuring physical models proven and accepted internationally and by the national regulator as well as the fulfilment of a validation covering the applicability range of the safety model.

Traditionally, the deterministic safety analyses are performed at the NPP Gösgen by the vendor AREVA (now Framatome), which developed an own version of the RELAP5/Mod 3.3 code (S-RELAP5). The S-RELAP5 code from AREVA includes additional types of hydraulic components and additional physical models compared to the regular version [1]. The development of the TRACE model (TRACE_KKG) started in 2015 by means of several projects with the company Risk Engineering Ltd. The GCR Ltd. team (formerly part of Risk Engineering Ltd) is currently involved and active in the update of the model and the extended V&V activities [2]. The current nodalization of Primary and Secondary side is shown on Fig.1. One of the last activities covers the extension of TRACE model applicability to MSLB and LOCA up to 380 cm2 scenarios. Under this part of the model upgrade, the following two major issues have been resolved: development of new, more realistic model of the reactivity coefficient feedback and new containment model for backpressure calculation in case of leakages to the containment.

This paper is structured as follows. In Section 2 an overview on the reactivity feedback coefficient models is given. The activities related to the development of the containment model and obtained results are reported in Section 3. The conclusions considering current applicability of the model and future developments is presented in Section 4. In the last section 5 are presented the graphics.

2. REACTIVITY FEEDBACK COEFFICIENTS MODELS AND APPLICATION

There are two major approaches for reactivity feedback modelling in TRACE code. The first one, also the traditional one, is by using the internal TRACE model, which is part of the power component model. If this approach is used, the reactivity feedback coefficients input fields become active when the option “Include Reactivity Feedback” is set to “TRUE”. Then the necessary fields for specifying these coefficients are given in the “Reactivity Coefficients” input menu. The other approach is with external to the power component model, which is called programmed reactivity. The currently used approach for the definition of reactivity feedback functions is the second one. This approach is simplified, but more flexible than the traditional one. It is based on control blocks which allow the point kinetics reactivity feedback coefficients to be defined interactively (in the traditional approach it is not possible to change the reactivity functions in interactive manner).

Using the second approach, two models for reactivity feedback coefficients are developed: with and without accounting for the moderator void. First model uses constant factors of reactivity effect for moderator temperature, fuel temperature and boron concentration in the core. This model is meant to be used for transients without LOCA and/or for small LOCA transients, where void effect is not dominant. For the medium and large LOCA cases, KKG specific functions for moderator temperature, fuel temperature and boron concentration are used [2]. These functions account for the moderator density (respectively void). Two cycles of reactor operation are considered, beginning and end of cycle (BOC and EOC respectively).

For the validation purposes MSLB type of transient has been chosen due to possible re-criticality effects. The MSLB analysis is important for the assessment of the TRACE_KKG plant model capabilities for transients with fast primary side overcooling. This assessment is aimed at comparison against S-RELAP5 calculations for the same initiating event (by using reactivity feedback calculation with and without void curves). One of the major parameters of interest is the reactor power response following the possibility of re-criticality occurrence. The important aim of the analysis is to assess the reactor point kinetics model response in result of MSLB by applying the kinetics model based on void reactivity curves. The application of the two approaches for reactivity feedback calculation within the MSLB analysis gives more insights about which reactivity feedback model can be applied when more conservative results are pursued. Thus, the two scenarios that has been conducted are double ended break of main steam line 1 before MSIV ***without*** (Sc.1) and ***with*** (Sc.2) reactivity void curves activation. The boundary conditions for both scenarios are:

- Double ended main steam line break with 2 x DN = 0.7 m (2 x 0.385 m2) before MSIV1 (loop 1);
- LOOP is not assumed;
- Steam dump to condenser valves (FDU) are failed;
- Both Auxiliary Feed Water (RR) pumps are failed;
- Automatic actuation of Special Borating Injection pumps (TA81, 82) when ECCS signal is actuated;
- Operator actions for accident management have not been considered;
- Emergency FW (RS) system actuation is based on the level in any SG below 5.0 m;
- Special emergency FW system (RX) injection to SG3 is started if the level in SG3 is decreased below 5.0 m.

The results for both scenarios are compared with S-RELAP5 results and are shown on Fig. 3 (A and B). Assessment of the results for both MSLB scenarios shows quite good agreement for the main primary and secondary parameters. The TRACE_KKG model is capable to correctly represent the plant response when rapid overcooling of the primary side through secondary side occurs. When void reactivity feedback option is not used (Sc. 1) then re-criticality of the reactor core occurs. In contrast, the application of this option (Sc. 2) does not predict re-criticality, which can be explained by the more realistic modelling of the reactor point kinetics (see Fig. 3A (a) and (b)). The total reactivity for the considered Sc. 1 and Sc. 2 is such that long terms subcriticality is ensured (see Fig. 3B (c) and (d)), mainly by the automatic injection of TA81, 82 pumps, the operation of which is started when the pressurizer measured level decreases to 2.2 m. Thus, it can be concluded that even using more conservative approach, i.e. without accounting for void reactivity feedback, the final conclusions for the transient behaviour do not significantly differ.

3. NEW CONTAINMENT MODEL

The available containment model showed strong temperature stratification along the height of the containment room and open spaces. It was concluded that this stratification is not physical considering the circulation caused by the mixing effect due toof LOCA flows into containment. Therefore, an entirely new simplified nodalization is developed in order to overcome the unphysical temperature stratification. The nodalizaton of the new containment model is shown on Fig. 2.

For the containment validation the MB LOCA (with break size of 380 cm^2) and MSLB before MSIV are conducted. The main boundary conditions for LOCA analysis are:

- LOCA to containment with DN220 mm (380 cm^2) from cold leg 2 on the discharge side of MCP2 (loop 2);
- Loss of normal power supply with loss of EY11 (failed) and EY41 (in maintenance) emergency diesel generators in the moment of IE occurrence;
- Turbine trip actuation, 3 sec after SCRAM;
- Manual start of the secondary side cooldown with 100 K/h by all atmospheric relieve valves (ARV), 30 min after SCRAM actuation;
- All hydro-accumulators are available;
- Special Borating Injection pumps (TA81, 82) start automatically to inject into all loops (automatic start based on ECCS signal actuation);
- Both Auxiliary Feed Water (RR) pumps are failed.

Correspondingly, the main boundary conditions for MSLB scenario are:

- Single ended main steam line break with 1 x DN = 0.7 m (1 x 0.385 m^2) before MSIV1 (loop 1);
- LOOP is not assumed;
- FDU is failed;
- Both AFW (RR) pumps are failed;
- Automatic actuation of Special Borating Injection pumps (TA81, 82) when ECCS signal is actuated;
- Operator actions for accident management are not considered;
- EFWS (RS) actuation is based on level in the individual SG below 5.0 m;
- SEFWS (RX) injection to SG3 is started if level in SG3 is decreased below 5.0 m.

The results of the two transients are compared against KKG MELSIM (Specific interactive tool for MELCOR model) as the containment parameters were of main interest. Additionally, for containment adjustment (validation), a simplified input deck has been developed, where only the containment hydraulic and control components are extracted from the main input deck. The goal of this input deck (stand-alone model) is to verify that the containment adequately calculates pressure and temperature behaviour given the MELSIM boundary conditions. The results from this validation are shown on Fig. 4B (c) and (d).

The main goal of the conducted scenarios is to assess the containment response under primary and secondary side breaks. Therefore, the representative scenarios are MB LOCA and MSLB before MSIV. For the considered MB LOCA and MSLB scenarios the energy released to the containment is maximized.

The overall results for the compared parameters (pressure and temperature) are in good agreement (see Fig. 4A, (a) and (b)). The condensation on the containment structures is reproduced in TRACE with a satisfactory accuracy. Main differences are observed in the short-term period considering the peak pressure and the temperatures of the atmosphere, and the heat structures dynamic response. The predicted maximum pressure in TRACE is slightly higher (see Fig. 4A (a), where pressure is 3.3 bar in TRACE against 3.1 bar in MELSIM). This result is satisfactory and is explained by the differences in the break flow characteristics, since the results for the stand-alone model show that TRACE slightly underpredicts the maximum pressure given the same break flow characteristics (Fig. 4B (c) and (d)). Considering the MSLB scenario (see Fig. 4A (b)), the observed stronger differences between TRACE and MELSIM codes are due to differences in the ejected flow differences.

4. CONCLUSIONS

This paper presents main aspects of the latest update of TRACE_KKG model for the full power conditions. The introduced changes in the model extend the application of the model considering the LOCA scenarios up to 380 cm2 and MSLB with and without containment back pressure. Moreover, the containment behavior has been successfully validated against MELSIM results. The other important resolved issue refers to the reactivity feedback coefficients when void reactivity plays a significant role. The updated TRACE model gives more realistic results with respect to re-criticality occurrence. Note that, this new more sophisticated model of the reactivity feedback coefficients cannot replace the 3D kinetics model, which is required for accident scenarios with asymmetric behavior in core.

5. NODALIZATION AND GRAPHICS

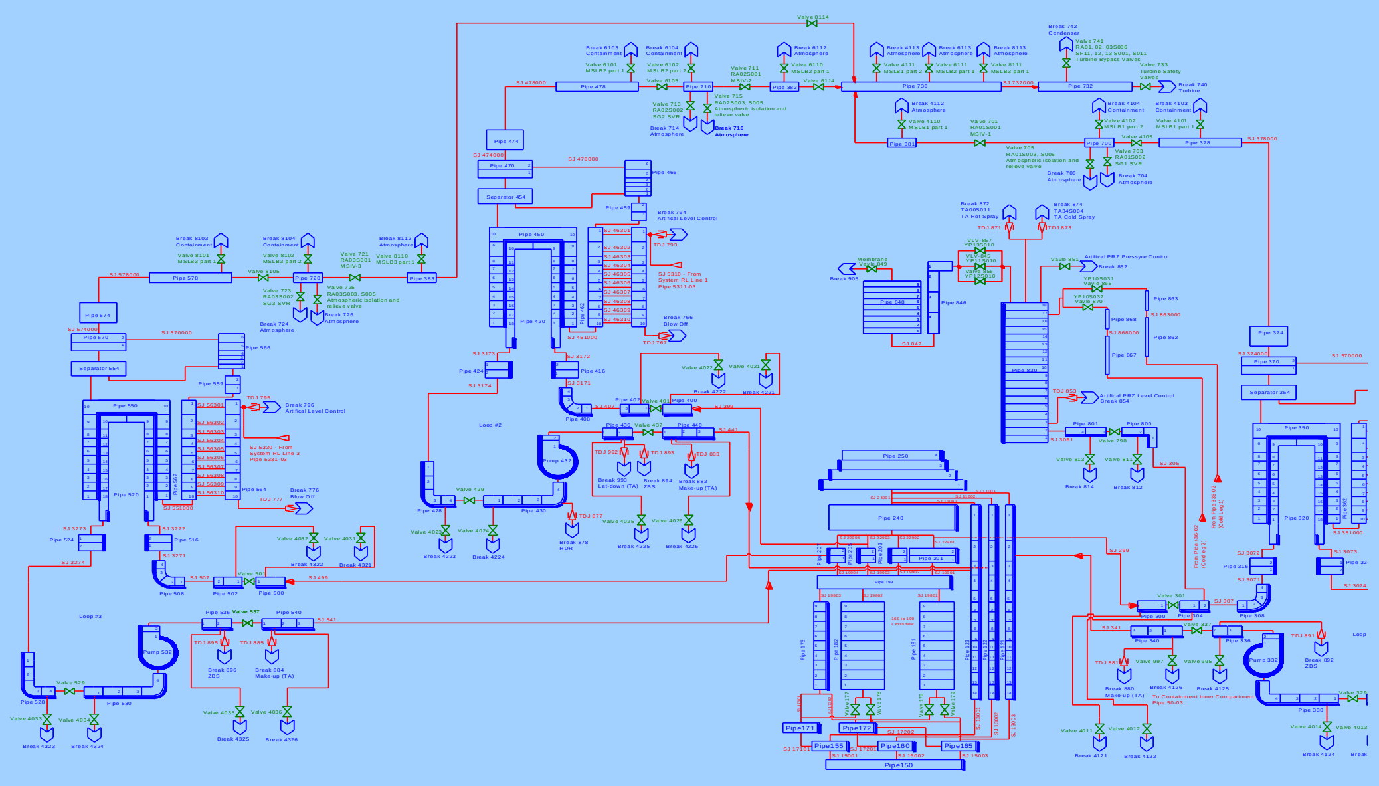


Figure 1. Primary and Secondary side nodalization

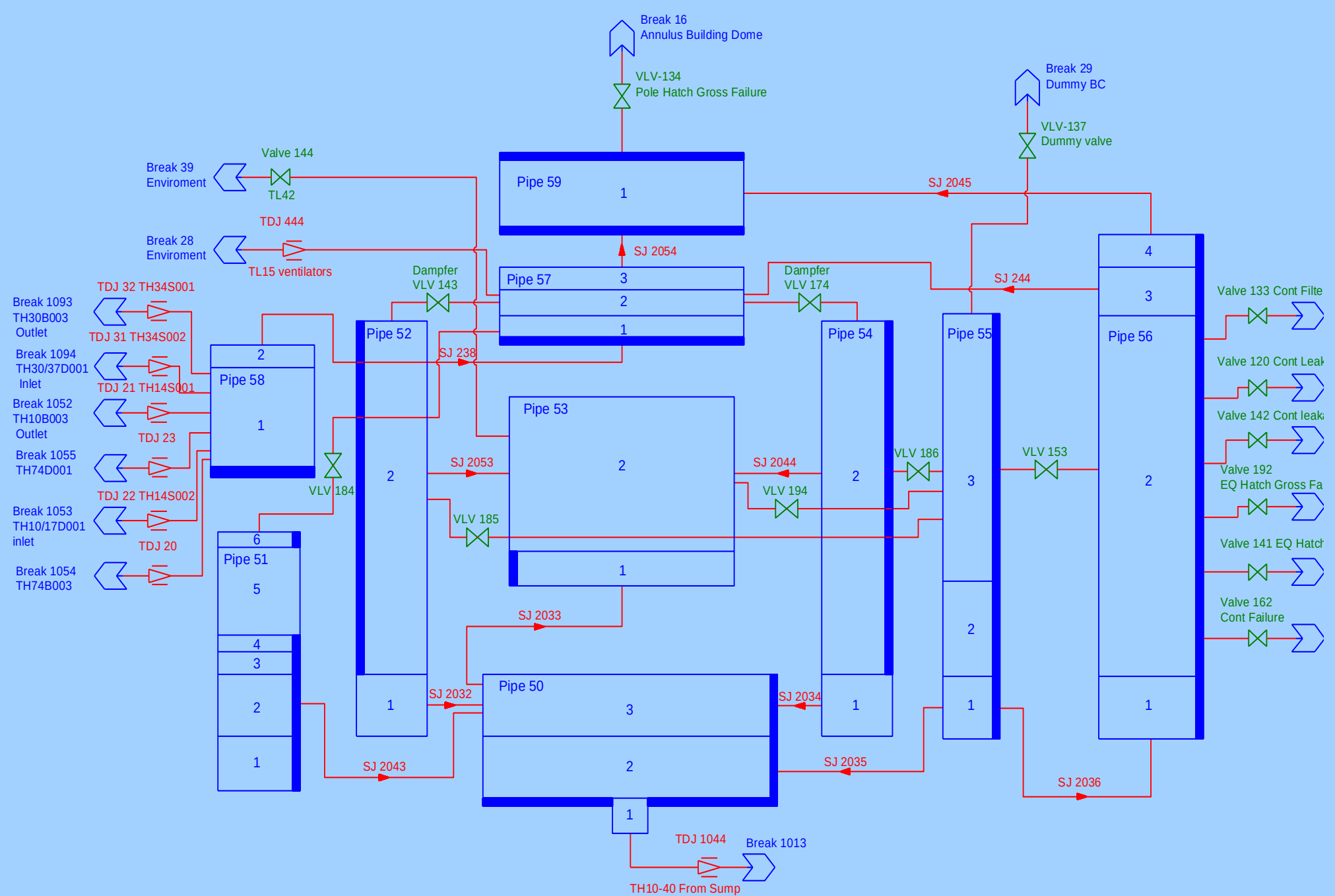
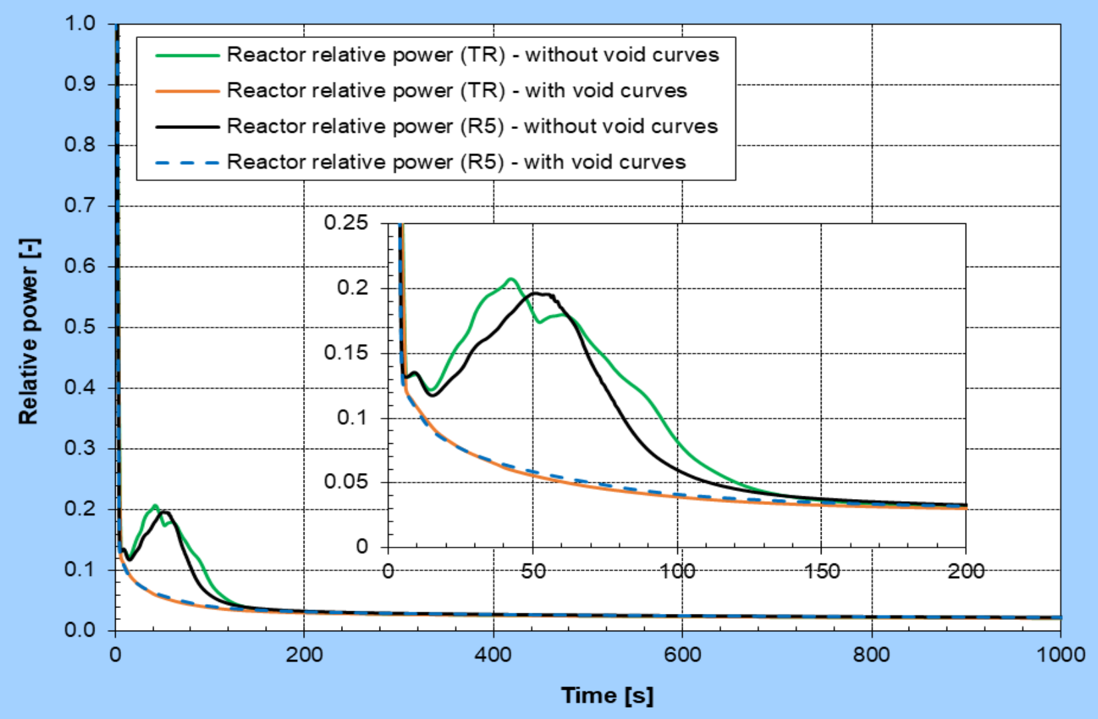
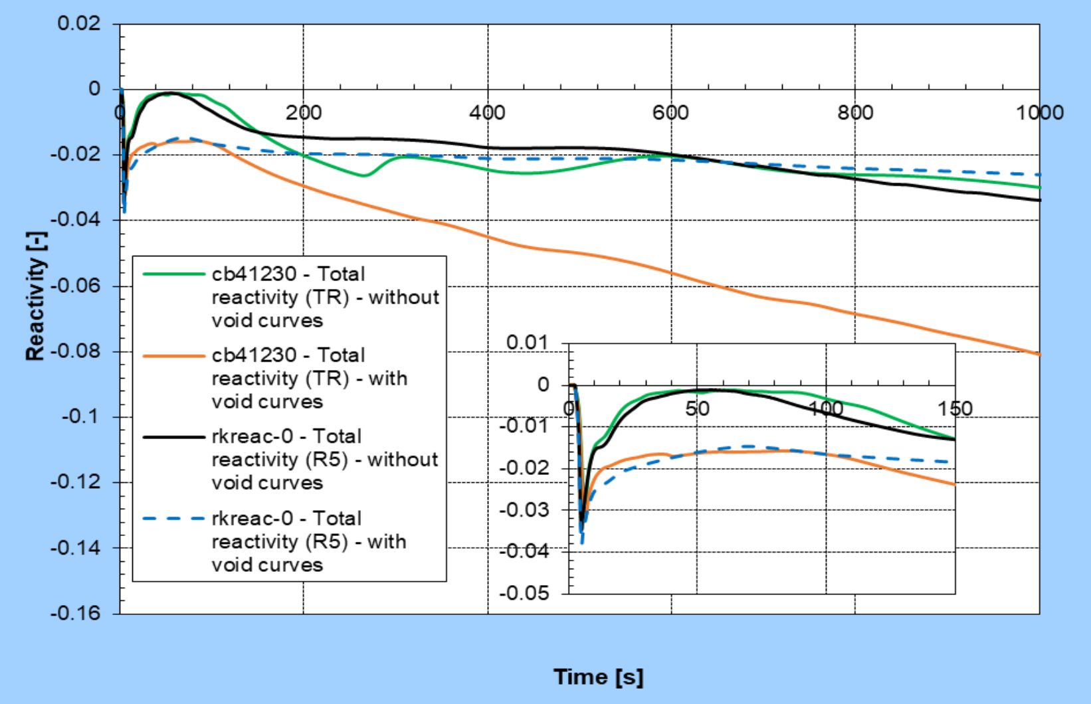


Figure 2. New containment nodalization

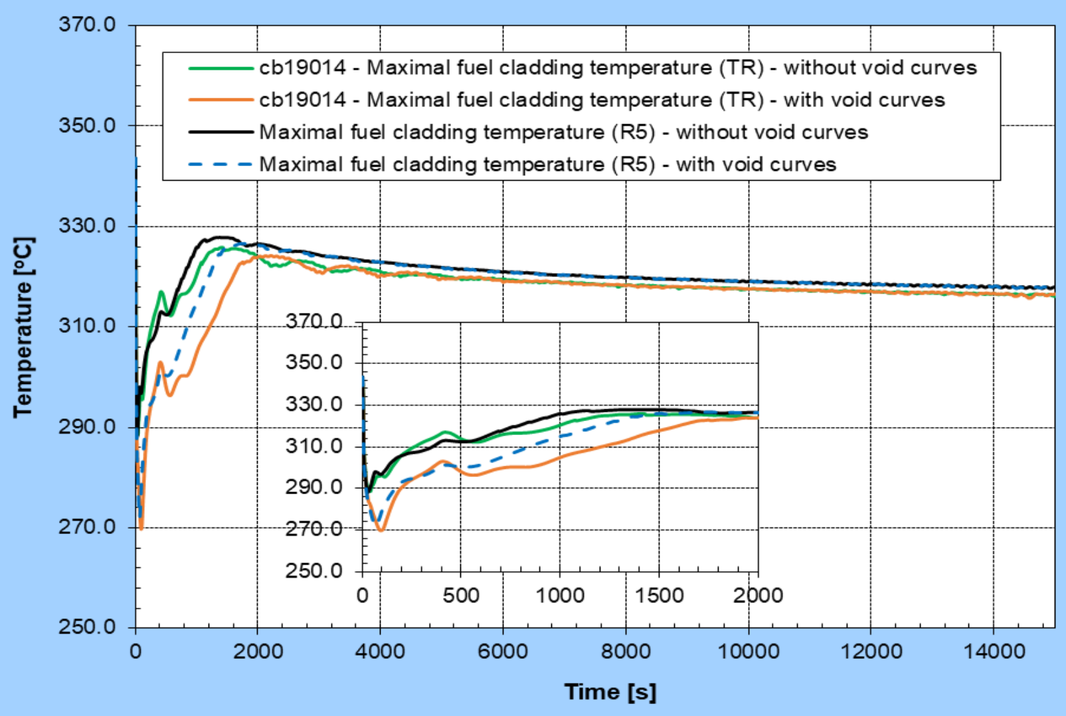


(a) Reactor thermal power

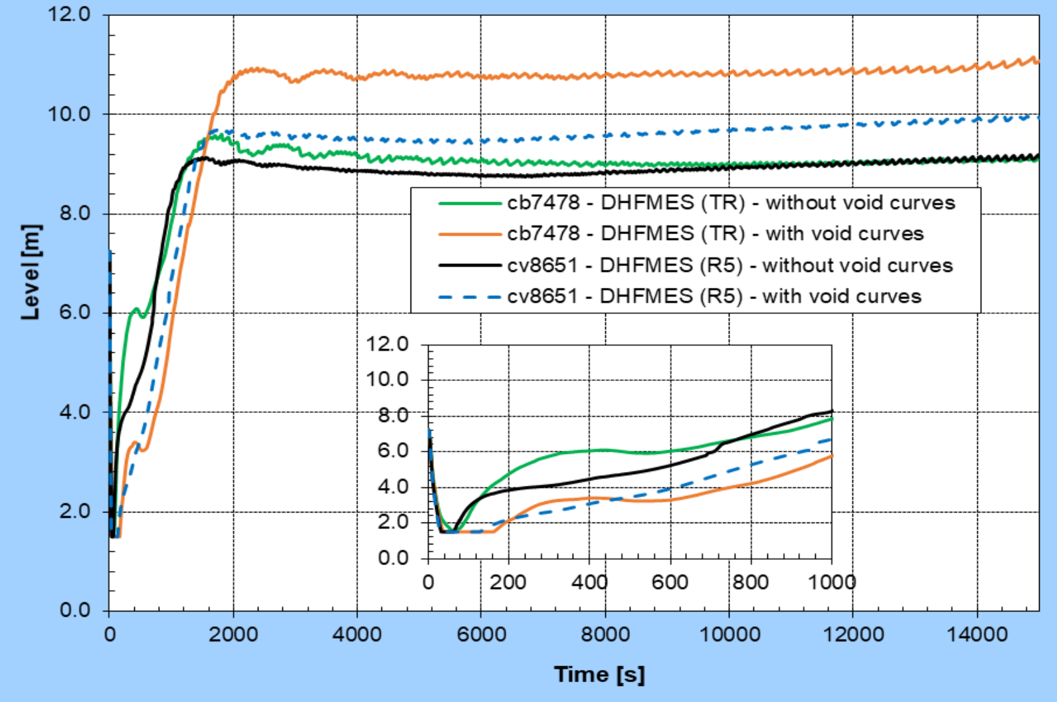


(b) Total reactivity

Figure 3A. Main results for the MSLB scenarios with and without void curves

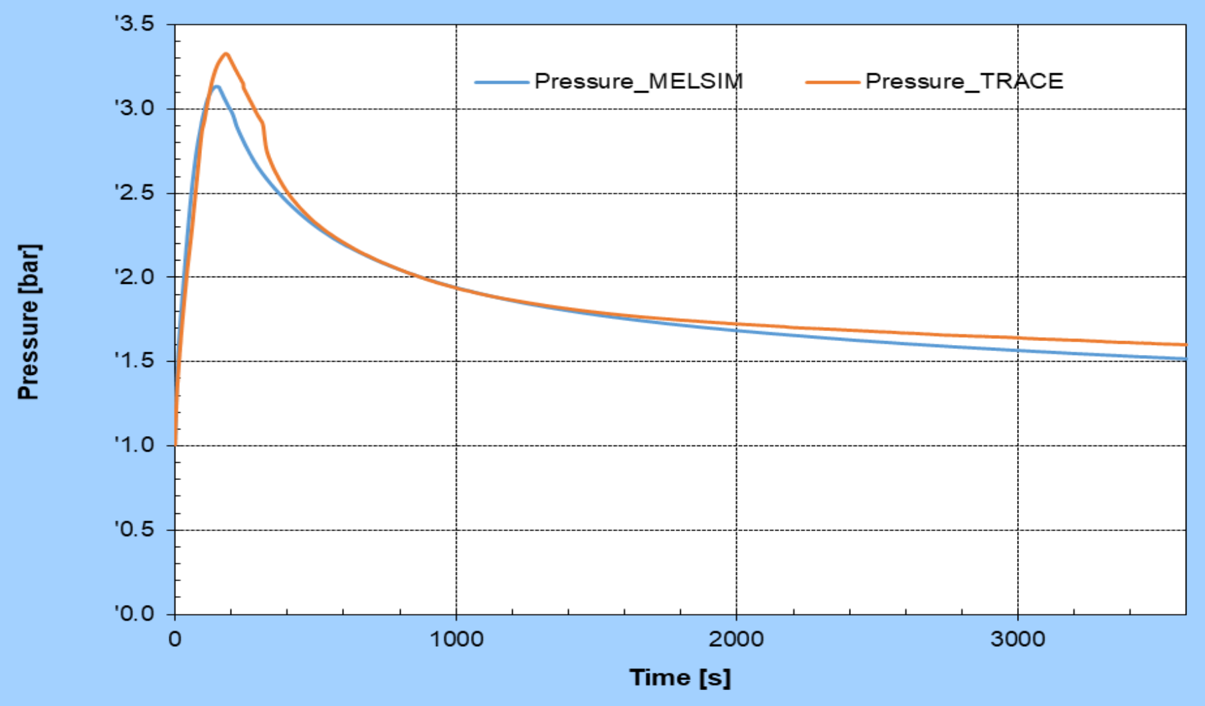


(c) Cladding temperature

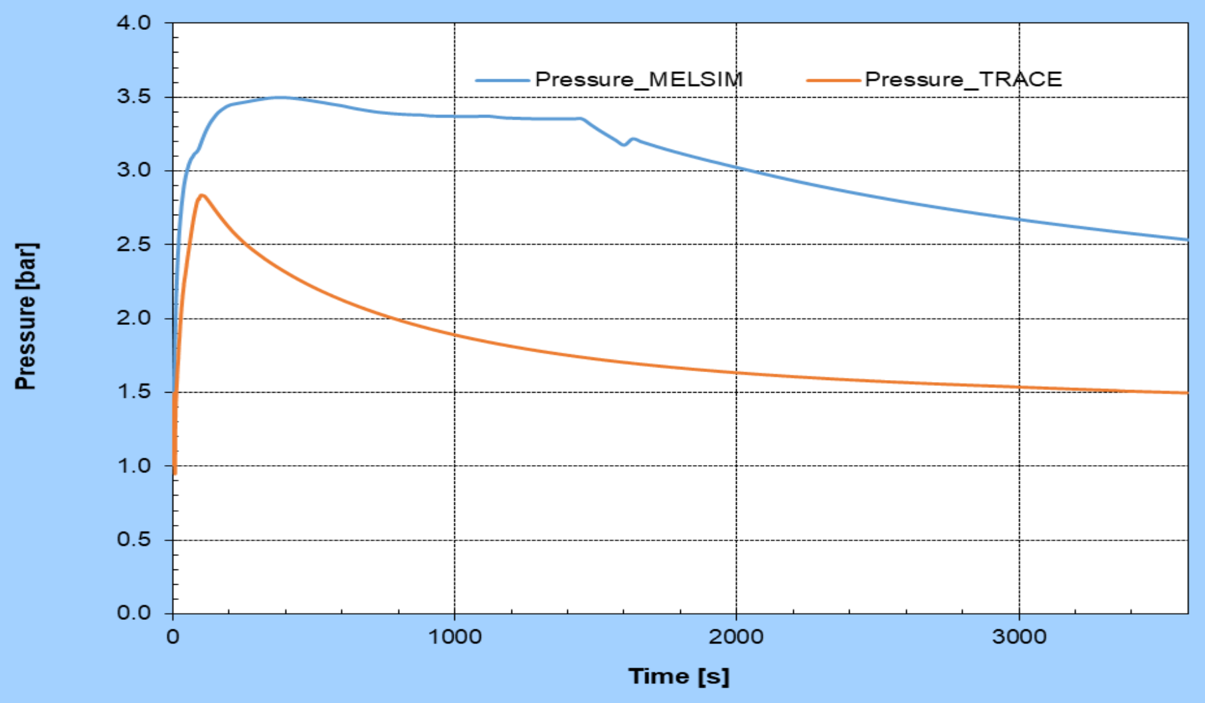


(d) PRZ level

Figure 3B. Main results for the MSLB scenarios with and without void curves

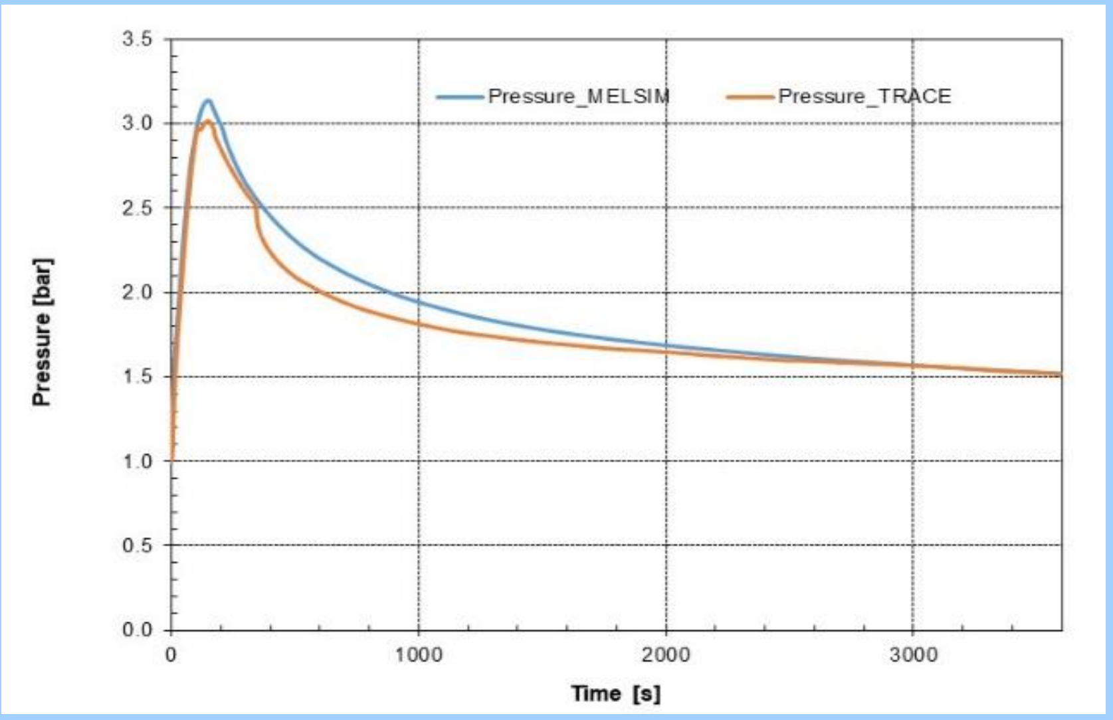


(a) Pressure in containment dome for MB LOCA

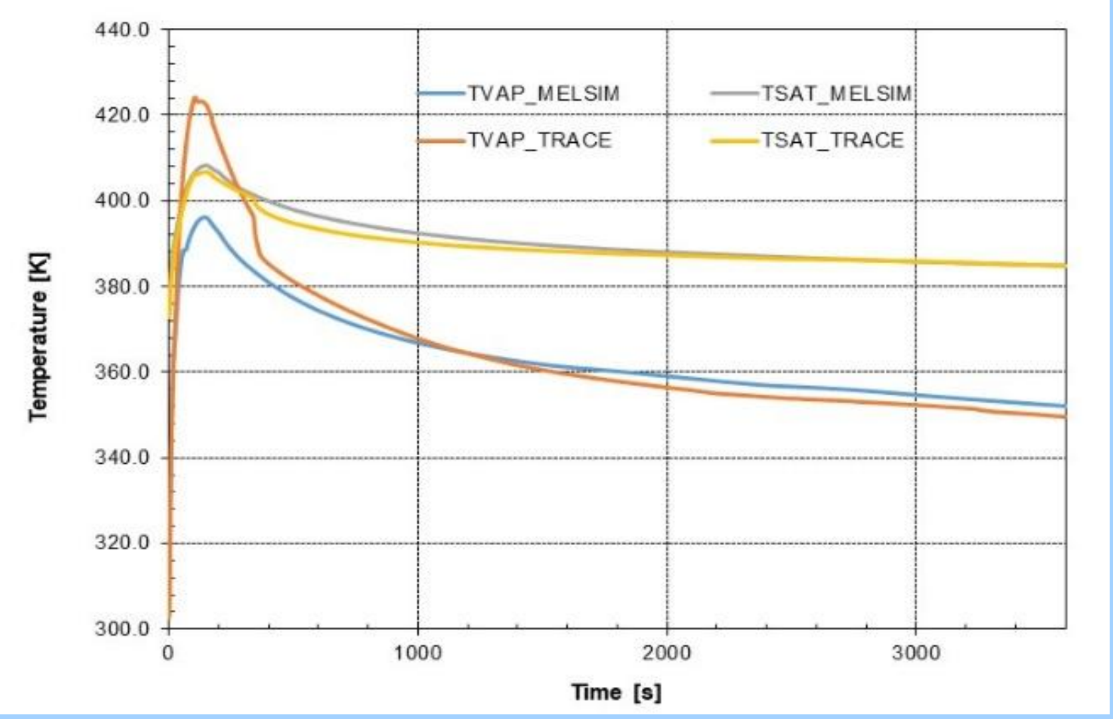


(b) Pressure in containment dome for MSLB

Figure 4A. Main results for the MSLB and LOCA scenarios with containment



(c) Pressure in containment dome for MB LOCA (stand-alone model)



(d) Temperature in containment dome for MB LOCA (stand-alone model)

Figure 4B. Main results for the MSLB and LOCA scenarios with containment

NOMENCLATURE

AFW	Auxiliary Feedwater
ARV	Atmospheric relieve valve
DBA	Design Basis Accident
ECCS	Emergency Core Cooling System
EFWS	Emergency Feedwater System
FDU	Steam dump to condenser (Frischdampfumleitung, plant terminology)
IE	Initiating Event
KKG	Kernkraftwerk Gösgen (NPP Gösgen)
KWU	Kraftwerk Union AG (pre-Konvoi design)
LOCA	Loss of Coolant Accident
LOOP	Loos of Offsite Power
MCP	Main Coolant Pump
MSIV	Main Steam Isolation Valve
MSLB	Main Steam Line Break
NPP	Nuclear Power Plant
SCRAM	Safety Control Rod Axe Man (reactor shut-down)
SEFWS	Special Emergency Feedwater System
SG	Steam Generator

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