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TRACE ASSESSMENT OF THE ACHILLES ISP-25 REFLOOD TRANSIENT

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Abstract

The purpose of this paper is to assess the capability of the best estimate thermal-hydraulic code TRACE Version 5.211 to predict the reflood process in a rod bundle test section using ACHILLES experimental data from the ISP-25 reflood transient. For the purpose of this assessment study, two detailed TRACE models representing the entire ACHILLES test section without the downcomer were developed and applied to simulate the ISP-25 transient. The TRACE models differed only in the hydrodynamic components, VESSEL and PIPE, which were used to represent the rod bundle region of the test section. Code predictions were compared against ISP-25 test measurements for both local- and integral-type quantities. These measurements included rod surface temperatures for individual rods at various axial elevations, sub-channel steam temperatures at different axial elevations, test section exit liquid and steam mass flow rates, quench front location, test section collapsed liquid level, test section overall pressure drop, and differential pressure drops across various axial sections of the test bundle. Considering the involvement of a non-uniform axial power profile combined with radial temperature variations among individual rods in the experimental rod surface temperature data, TRACE exhibited reasonable capability in predicting the ACHILLES ISP-25 reflood transient implementing an average-rod test bundle modeling approach. Consistent with other reflood simulations obtained with recent TRACE code versions, major differences between ACHILLES ISP-25 simulation results and experimental data for rod surface temperatures were observed mainly for the upper part of test section, also caused by lack of spacer grid models in TRACE.

Keywords: Thermal-hydraulics, reactor safety, code development, code validation.

1. Introduction

The International Standard Problem 25 (ISP-25) reflood test was performed in the ACHILLES Test Facility at the AEA Winfrith Technology Centre. The test was specified and carried out as a best-estimate natural reflood experiment. It was part of a series of reflood experiments on a model Pressurized Water Reactor (PWR) fuel assembly in the ACHILLES Test Facility. The experiment was aimed at studying heat transfer in the PWR core during the reflood phase of a postulated Large Break Loss-Of-Coolant Accident (LOCA).

The ISP-25 test, which can be classified as almost a separate-effects test, was performed to simulate the end of the accumulator discharge period during a postulated large break LOCA in a PWR. When the nitrogen gas, initially stored in the accumulator tank to pressurize its volume, enters into the primary circuit, the decrease in pressure drop between the accumulators and the pressure vessel causes an increase in the pressure at the top of the downcomer. In turn, the increased downcomer pressure produces a surge of water into the core followed by a subsequent oscillatory flow behavior involving the core and downcomer regions.

This paper describes the capabilities of the best estimate thermal-hydraulic code TRACE v. 5.211 to predict the reflood process in a rod bundle test section using ACHILLES experimental data from the ISP-25 reflood transient. Two TRACE models representing the entire ACHILLES test section without the downcomer were developed and applied to simulate the ISP-25 transient.

2. ACHILLES Test Facility Description

The ACHILLES test series, [1-4] performed in the late 80s at the Winfrith Atomic Energy Establishment (AEEW), included heat transfer experiments on a full-length replica of a Pressurized Water Reactor (PWR) fuel assembly comprising 69 electrically heated fuel rod simulators in both unblocked and partially blocked configurations. The ACHILLES test program was carried out following the THETIS series of tests, which utilized a 7x7 rod bundle test section with 12.2 mm fuel rods (compared to 9.5 mm for most PWRs) and no mixing vane grids. The ACHILLES test bundle was free of these significant limitations. A detailed description of the ACHILLES Test Facility that was used for all series of experiments can be found in AEEW-R2336 [1]. Figure 1depicts an isometric of the ACHILLES Test Facility. A cross sectional diagram of the cluster and shroud vessel is shown in Figure 2. The figure also shows the letters and numbers used to identify rod locations. The rig represented all major components of a PWR primary coolant system including the downcomer, lower plenum, core region and upper plenum.

2.1 ACHILLES ISP-25 Test Description

International Standard Problem number 25 (ISP-25) was organized by the Committee on the Safety of Nuclear Installations (CSNI) of the Nuclear Energy Agency (NEA). The test was performed in the ACHILLES Test Facility using a best-estimate rig configuration. The natural reflood experiment investigated the impact of nitrogen injection in a PWR following the end of accumulator discharge on the reflood behavior of the core during a postulated large break LOCA. The resultant decrease in pressure drop between the accumulators and the pressure vessel caused an increase in the pressure at the top of the downcomer. This produced an initial surge of water into the core followed by subsequent oscillatory flow occurring between the core and the downcomer regions. The ACHILLES ISP-25 experimental procedure and transient behavior along with initial and boundary conditions are described in the following sections. The test data were used by the ISP-25 participants for comparison against pre-test code predictions (blind calculations) as well as post-test computer analyses.

2.1.1 ACHILLES ISP-25 Transient Description

Main initial and boundary conditions for the ISP-25 test are shown in Table 1 and in Figure 3. In particular, Figure 3 a) shows the rod bundle power during the transient. The upper plenum pressure is presented in Figure 3 b). Figure 3 c) provides the core inlet water temperature and Figure 3 d) depicts the core inlet mass flow rate as measured by flow meter F101, which is shown in Figure 1. The initial axial temperature profiles for the rod bundle and shroud wall are plotted in Figure 3 e).

Although the original intention of the test procedure was to provide a constant system pressure as a boundary condition, it was found that the rate of increase in the flow rates from the core and downcomer were such that the control system was incapable of maintaining a constant pressure during the early period of the transient. This characteristic of the test facility was difficult to predict accurately and it had a significant impact on the early behavior of the experiment.

Table 1: Main Initial and Boundary Conditions for ISP-25 [Ref. 1]

Pressure (MPa)	Maximum Rod Power (kW)	Initial Rod Temperature at Elevation 2.13m (°C)	Inlet Subcooling (°C)
0.3	220	651	20

The nature of the ISP-25 transient exhibited two quite distinct phases. The early part of the transient was characterized by a highly oscillatory flow between the downcomer and core, which decayed over a period of approximately 20 seconds as the nitrogen vessel discharged into the top of the downcomer. The high flooding rates during this early period quenched the bottom of the rod bundle and the resulting large volumetric flow rate of steam entrained a significant amount of the remaining liquid and carried it out of the top of the bundle. Once the flow oscillations decayed, a steady rate of reflood was established by the pumped water injection. Thus, the lower elevations of the rod bundle quenched during the initial surge of water from the downcomer. This, combined with rewetting of the grids during the initial surge, lead to an overall improvement in heat transfer from the surface of the fuel rods. Considering the main aim of ISP-25 to investigate the ability of best-estimate codes to model the nitrogen injection phase of a large break LOCA, the early part of the transient was the most important in many respects. Thus, the first 50 seconds of the experiment in the comparing data with predictions allowed revealing various aspects of modeling this phase of the transient.

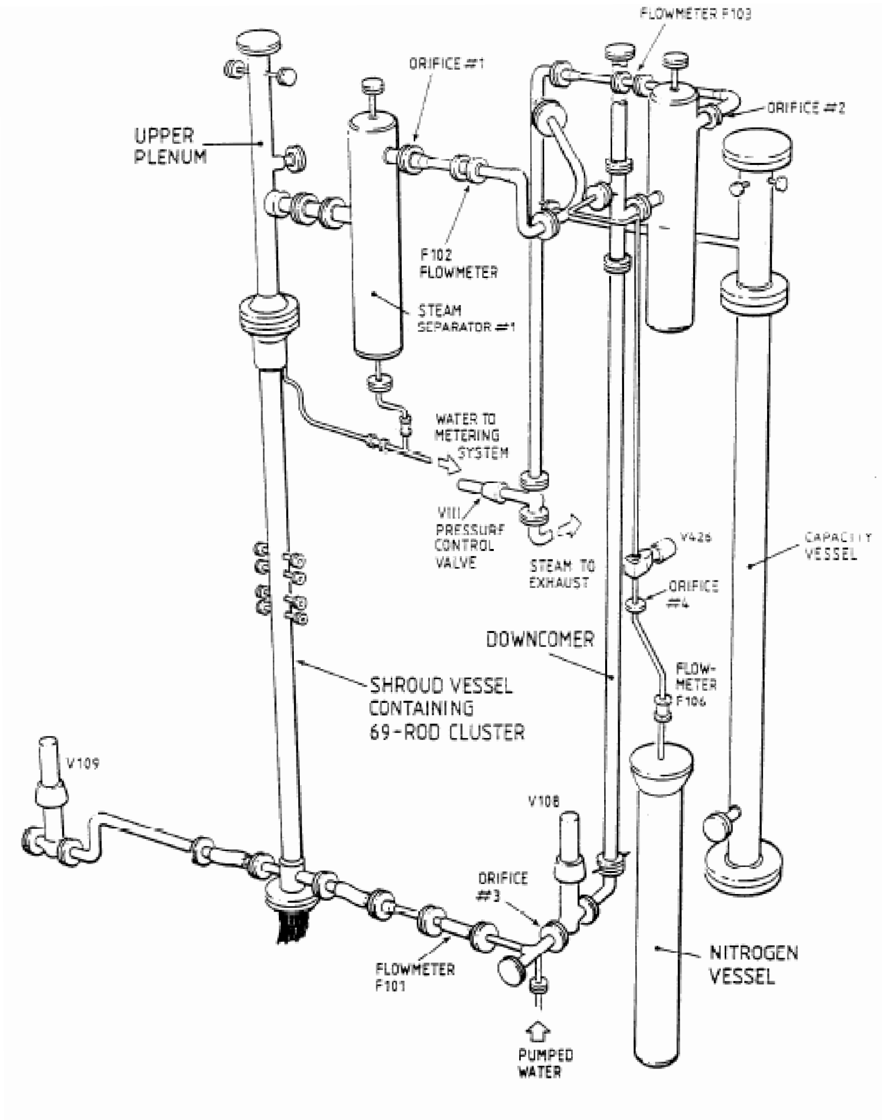


Figure 1. ACHILLES Test Facility

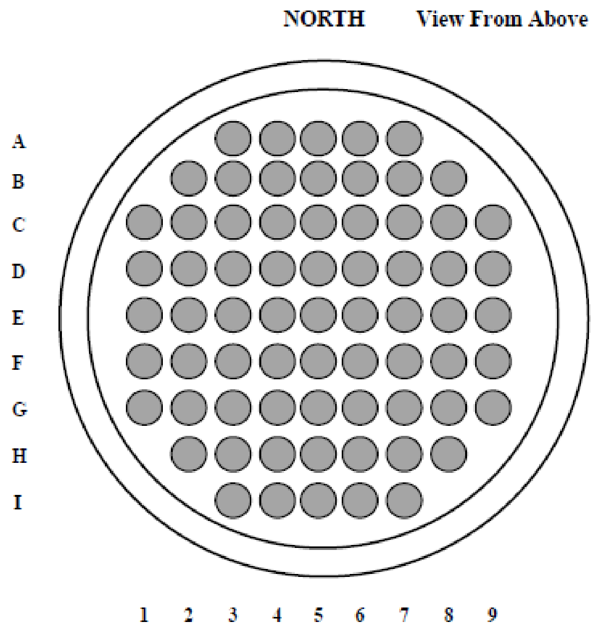
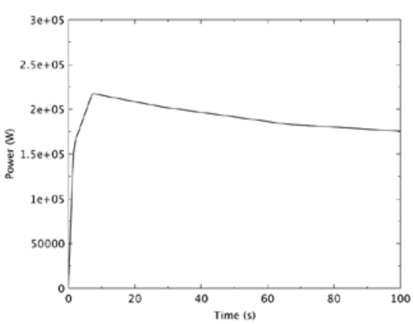
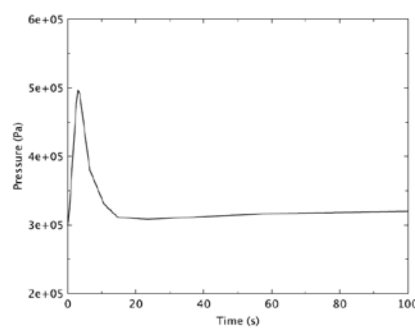


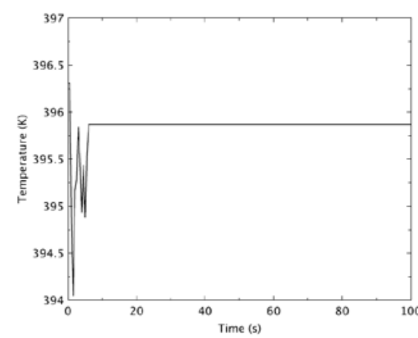
Figure 2. Cross Section through the Test Section



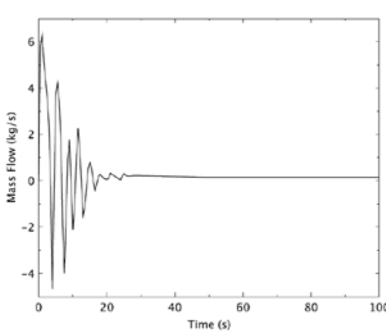
a) Rod Bundle Power



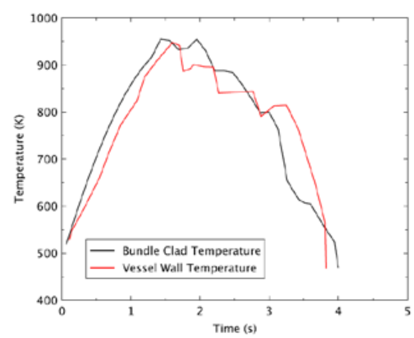
b) Pressure Outlet



c) Core Inlet Temperature



d) Core Inlet Mass Flow Rate



e) Test Section Axial Temperature Profile

Figure 3. Boundary Conditions

3. TRACE Model Development for ACHILLES Test Rig

The developed TRACE models simulated the test section part of the ACHILLES Test facility as shown in Figure 1 and included a detailed representation of the test bundle and shroud vessel with the upper and lower plena. Two TRACE models were developed. One of the models simulated the part of the shroud vessel housing the rod cluster with a PIPE component whereas the other one used a 1D VESSEL component to represent this portion of test section shroud vessel. The models were developed using the SNAP software [5] as illustrated in Figure 4.

The lower plenum nodalization was chosen so that major geometry changes in terms of hydraulic diameters and flow areas were properly accounted for. Contraction and expansion area changes were considered in defining the loss coefficients.

The PIPE and VESSEL components that represented the core region of the test section consisted of 37 axial nodes with 3 nodes between spacer grids. A finer axial nodalization scheme allowed capturing better the locations of the spacer grids, thermocouples and differential pressure taps. The VESSEL component model utilized one azimuthal segment and one radial ring to represent the shroud vessel.

The inlet boundary conditions were defined using FILL component. It was used to specify the measured liquid mass flow rate as illustrated in Figure 3 d) as well as the temperature of the coolant in accordance with Figure 3 c). The outlet boundary conditions were specified using BREAK component. It implemented a pressure table to define the pressure boundary as measured in the upper plenum of the test section and illustrated in Figure 3 b).

The rod cluster power during transient evolution, which is shown in Figure 3 a), was implemented using a power versus time table. The relative axial power profile was defined in accordance with Figure 3 e). Due to lack of detailed information regarding power distribution among individual rods, it was assumed that all fuel rod simulators were equally powered.

HEAT STRUCTURE components were associated with the heat transfer between the fuel rods and the cooling fluid, as well as the heat losses associated with the shroud. The material properties for the rod materials were defined according to the data specified in [1].

In simulating the ISP-25 transient, reflood model input options associated with core heat structure and the thermal-hydraulic components, which model the core region of the test section, PIPE 1 and VESSEL, were implemented accordingly. Axial conduction modeling in all heat structures was utilized. Radiative heat transfer was neglected. The liquid level tracking model was also activated. Details about the specifics of the heat transfer models can be found in [6] .

The computed results were stored at a frequency of 2 Hz for the first 200 seconds of the computational process and at a frequency of 1 Hz for the remainder of the transient. The total duration of the transient calculation was set at 500 seconds to model the quenching of the entire heated test section length as observed in ISP-25.

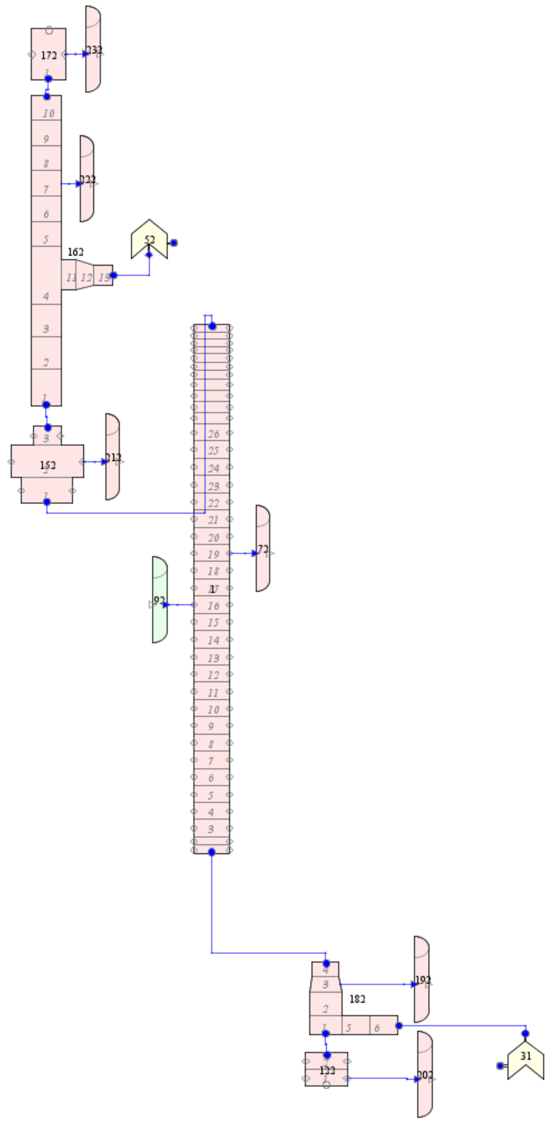


Figure 4. TRACE Model

4. Results and Discussions

Before proceeding toward the comparative analysis it is important to note that the TRACE models with both the pipe and vessel components, calculate only the average conditions in the bundle, whereas the thermocouples in the experiment were located at a particular rod and at a particular axial elevation. For example, as depicted in Figure 2, the thermocouples at rods E5 and E6 are located in the central region of the bundle while the thermocouples such as C5 and C4 are located in the periphery of the bundle, close to the vessel wall, and the thermocouples at rods E7 and F7 are located in between the central and peripheral rods. The detailed radial power distribution was not provided in the reference documentation.

The ISP-25 reflood transient is characterized by two distinctive periods, the period before and after 50 seconds of the transient. During the early part of the transient the core inlet mass flow rate has a major effect on determining the heat transfer in the test bundle. The initial surge of cold liquid water causes a significant increase in the heat transfer, which leads to sudden cladding temperature drop.

The comparative analysis is performed for the time evolution of the most important and relevant parameters and includes. Discussions for each parameter time evolution follows.

- **Core exit steam flow**
  The time evolution of core exit steam flow rate is shown in **Figure 5 a)**. The steam mass flow rate is dominated by the quenching of the lower elevations in the early phase of the transient when there is an initial surge of liquid mass flow rate. In [1], it is specified that the measured data clearly show evidence of peaks with progressively decreasing in magnitude in the steam mass flow rate caused by progressive quenching of the lower elevations as the downcomer water empties into the core. The TRACE result matches the overall shape of the steam flow rate, however significant oscillatory behavior is observed. TRACE over-predicts the peak flow rate in the first 10 seconds of the transient, since it quenches faster that the measured data. TRACE over-predicts the steam flow rate also into the later part of the transient around 380 seconds which contradicts with the slowed quenching in the upper section of the test bundle during the same period. Possible contributor to this could be the more extensive quenching at lower elevations of the assembly in the early part of the transient as compared to the measured data.

- **Test bundle exit liquid carry over**
  The time evolution of test bundle exit liquid carry over is shown in **Figure 5 b).** The amount of liquid carryover has an important impact on the heat transfer from the rods to the fluid above the quench front. The presence of spacer grids can lead to significant enhancement of heat transfer at downstream elevations. However, TRACE does not model spacer grids explicitly. In the early part of the transient it appears that the test data has a delay in the measurement due to the arrangement in the instrumentation. During the same period of the transient TRACE result has sporadic oscillatory behavior when predicting the core exit liquid carry over.

- **Test bundle liquid level**
  The time evolution of the test bundle liquid level is shown in **Figure 6 a)**. The collapsed liquid level is calculated by the static pressure drop measured across the core. This is complicated by the smaller hydraulic diameter and the addition of heat to the fluid which increases the frictional and accelerational components of the pressure drop. The main problem comes from the inability of TRACE to predict the frequency of oscillations, observed in the first 50 seconds of the transient. For the remainder of the transient period TRACE results show good agreement with the measured data and slightly tend to under-predict the core liquid level.

- **Quench front elevation**
  The quench front elevation is shown in **Figure 6 b).** The velocity of the quench front is governed by a combination of cooling and axial conduction. Acceptable agreement with measured data is necessary in order to provide confidence in the ability of a code to apply correctly and consistently the method of calculation of heat transfer above the quench front. TRACE is capable of predicting the overall trend of the quench front, however TRACE quenches faster than the measured data especially at lower and mid elevations. The early quenching is largely dominated by the rod axial temperature profile which is higher than the axial vessel wall temperature as shown in **Figure 3 e).** In the experiment early quenching has been observed to occur in some of the outer rods which were cooler due to close proximity to the shroud. In this study the radial temperature profile is assumed to be uniform.

- **Cladding temperature at elevation 0.56 of rod C4**
  The core cladding temperature time evolution at elevation 0.56 of rod C4 is shown in **Figure 7 a).** The thermocouple is located at peripheral rod C4. At that elevation the most significant impact on the cladding temperature is the heat transfer during the initial period of the transient. The initial rod temperature strongly affects the behavior of the prediction. The initial temperature predicted by TRACE is somewhat higher than the reference data but quickly decreases, and after the 30 second period it under-predicts the measurement. The reason for this is that TRACE over-predicts the heat transfer, which results in an extension of the cool down during the initial liquid surge.

- **Cladding temperature at elevation 1.08 of rod C5**
  The core cladding temperature at elevation 1.08 of rod C5 is shown in **Figure 7 b).** This measurement is performed just upstream of spacer grid 2 in order to minimize the impact of the grid during the initial period of high heat transfer. The cladding temperature rises due to the emptying of the down-comer. However, the down-comer was not modeled in the current study and the effect of emptying is imposed as an initial boundary condition. TRACE is able to predict the temperature recovery and in fact it is in excellent agreement with the measurement until the peak is reached. After the 30th second of calculation the temperature fall is rather quick and is caused by the accelerated quenching

- **Cladding temperature at elevation 1.61 of rod D5**
  The core cladding temperature time evolution at elevation 1.61 of rod D5 is shown in **Figure 8** a)**.** The location of the thermocouple is again upstream of the spacer grid. TRACE under-predicts the initial temperature at that elevation as well as the entire transient behavior. However, TRACE predicts correctly the overall temperature trend during the transient.

- **Cladding temperature at elevation 1.81 of rod E5**
  The core cladding temperature time evolution at elevation 1.81 of rod E5 is shown **Figure 8** b)**.** The thermocouple is located just downstream of the fourth spacer grid and was chosen for comparison in order to assess the impact of the grid heat transfer enhancement on the predictions. TRACE shows very good agreement with the reference

data. As mentioned in Ref. 1 the system codes are known to over-predict heat transfer above the quench front and those codes do not model spacer grids explicitly. Therefore in the simulation a certain compensating effect is observed. TRACE over-predicts the cladding temperature in the period of initial water surge before 50 seconds as well as the peak cladding temperature at around 70 seconds. TRACE under-predicts the temperature after 120 seconds when prolonged cooling occurs.

- **Cladding temperature at elevation 2.01 m of rod E5**
  The cladding temperature time evolution at elevation 2.01 m of rod E5 is shown in **Figure 9** a)**.** The temperature measurement at this elevation is located just between two spacer grids. It again shows the effect of heat transfer due to the spacer grids. When moving further away from the spacer grid TRACE tends to under predict the initial heat transfer increase in the early 20 s and the consequent temperature recovery until 130 seconds of the transient. The TRACE temperature peak prediction is somewhat later than the data. After that period the temperature behavior prediction is in excellent agreement with the measurement data for the TRACE model with pipe and vessel components.

- **Cladding temperature at elevation 2.13 m of rod E5**
  The cladding temperature time evolution at elevation 2.13 m of rod E5 is shown in **Figure 9 b).** The thermocouple at E5 is located in the central region of the core where the temperatures are higher than the average one, due to the particular radial power distribution. Therefore it is expected that TRACE will under-predict the temperature behavior during the reflood transient. Part of the discrepancy is caused also by the lower initial temperature given by TRACE. It should be kept in mind that 2.13 m is upstream of the grid and higher measured temperatures should be expected due to the reduced heat transfer. TRACE, however predicts correctly the overall temperature trend.

- **Cladding temperature at elevation 2.33 m of rods E5 and E6**
  The cladding temperature time evolution at elevation 2.33 m of rods E5 and E6 is shown in **Figure 10 a)**. Comparison of TRACE prediction was made with thermocouples' measurements at rods number E5 and E6. This elevation is located downstream of the spacer grid. It lets us assess TRACE on the predictions of enhanced heat transfer due to grid spacers. TRACE is unable to model explicitly spacer grids and at this elevation it over-predicts the initial temperature drop caused by the initial liquid surge as a result of the downcomer emptying (first 30 seconds of the transient). TRACE over-predicts the peak cladding temperature and it turns around later than the measured data. The quicker temperature drop after 230 seconds as predicted by TRACE is caused by the faster quench front than in the measured data.

- **Cladding temperature at elevation 2.65 m of rod E6**
  The cladding temperature time evolution at elevation 2.65 m of rod E6 is shown in **Figure 10 b)**. The TRACE temperature behavior prediction during the transient is very similar to the one at elevation 2.01 m. This could be explained by the similar axial location, relative to the positions of spacer grids and similar radial location of the thermocouples. TRACE under-predicts the temperature up to 75 seconds. After that it

over-predicts the peak cladding temperature as well as the temperature drop during the rewetting period. In Ref. 1 it is noted that at this elevation the thermocouples are quenched earlier than other thermocouples due to the falling quench front initiated by the grid situated just above this elevation. Therefore less significance should be paid to the comparison of the predictions with measured data at times later than 75 seconds.

- **Cladding temperature at elevation 3.18 m of rod E7**
  The cladding temperature time evolution at elevation 3.18 m of rod E7 is shown in **Figure 11 a).** TRACE calculation predicts a much faster and higher heat transfer than the measured data within the first 50 seconds of the transient. However after 60 seconds of the transient the heat transfer is reduced due to the rapid evaporation of the initial liquid front. The temperature rises quickly and TRACE cladding peak temperature over-predicts significantly the measured data. During the rewetting period TRACE cladding temperature drops more slowly but reaches saturation conditions almost at the same time as in the measurement (TRACE vessel model). Possible explanation for the quick temperature drop in the measured data could be again the falling quench front initiated from the grid above.

- **Cladding temperature at elevation 3.58 m of rod E7**
  The cladding temperature time evolution at elevation 3.58 m of rod E7 is shown in **Figure 11 b)**. At that elevation the TRACE temperature result initializes correctly but over-predicts the temperature drop in the first 30 seconds and significantly over-predicts the measured data later into the transient.

- **Maximum average test bundle clad temperature**
  Figure 12 a) shows the maximum average test bundle clad temperature, a comparison made for the two TRACE models with pipe and vessel components, due to lack of such data. The results show that there is a perfect agreement between the two until 375 seconds of the transient when due to the faster quenching in the vessel model, the temperature drops faster.

- **Fluid temperature at 1.641 m for sub-channel D5**
  The time evolution of fluid temperature at 1.641 m for sub-channel D5 is shown in **Figure 12 b)**. The thermocouples used to measure the vapor temperature at 1.64 m were attached to the spacer grids centrally in a sub-channel and facing both upstream and downstream. Therefore when comparing TRACE results with measured data one should take into account the premature quenching of the thermocouples due to the presence of the spacers.

- **Vapor temperature at 3.21 m for sub-channel D5**
  The time evolution of vapor temperature at 3.21 m for sub-channel D5 is shown in **Figure 13 a)**. At this elevation the thermocouples quenched earlier in the transient due to a combination of early quenching of spacer grids. This elevation appears challenging for TRACE prediction since the temperature of the steam stays above saturation for the majority of the transient.

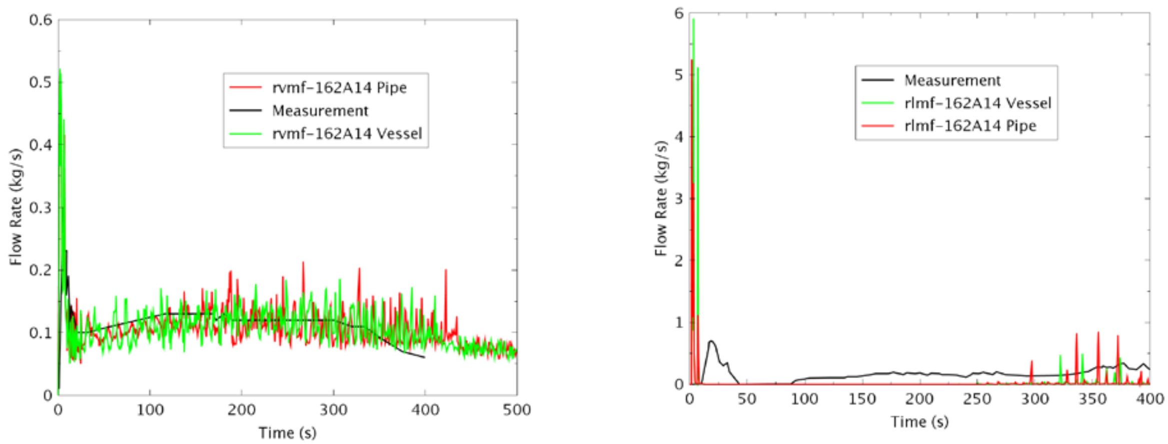
- **Overall pressure drop**
  The time evolution of overall pressure drop is shown **Figure 13 b)**. The TRACE calculated oscillations in the early 10 seconds of the transient are somewhat faster when compared with the measured data but still in very good agreement. Both TRACE models with vessel and pipe components over-predict the first and the third pressure peaks and under-predict the second pressure peak. However, TRACE is able to predict correctly the frequency of oscillations, which are caused by the oscillatory core inlet mass flow imposed as a boundary condition. For the remainder of the transient period the pressure drop prediction is in very good agreement with the measured data.

- **Pressure drop at elevations 0.518 – 0.78 m**
  The time evolution of pressure drop at elevations 0.518 – 0.78 m is shown in **Figure 14 a)**. The TRACE prediction shows significant oscillatory behavior, especially during the early period of the transient when flow regime switching occurs. After that period of time when the quench front passes through that pressure taps' span, TRACE gives very good agreement with the experiment. In the figure it is seen that TRACE with a 3D vessel component model over-predicts slightly the measured data while the pipe component model under-predicts slightly this data. The calculated pressure drop is more oscillatory than the measured data.

- **Pressure drop at elevations 0.78 – 1.041 m**
  The time evolution of pressure drop at elevations 0.78 – 1.041 m is shown in **Figure 14 b)**. The pressure drop calculations show similar oscillatory behavior as in the previous span measurement. The TRACE model shows very good prediction for the pressure drop at that elevation.

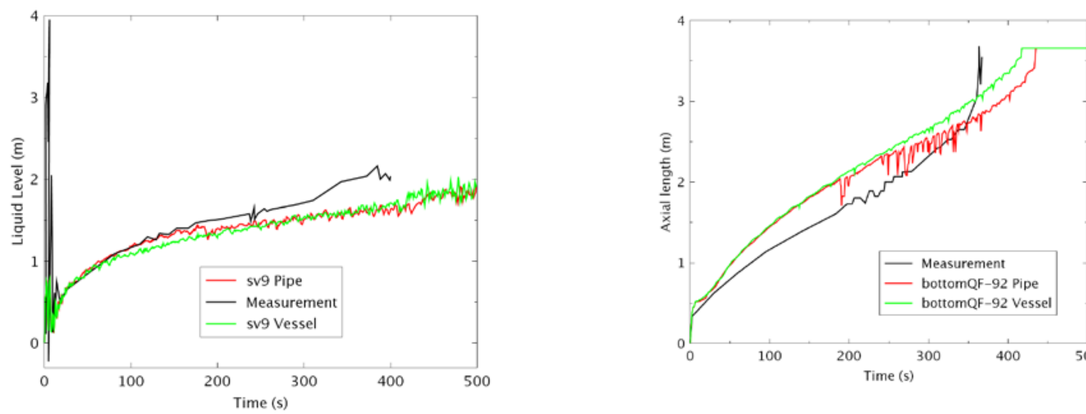
- **Pressure drop at elevations 1.826-2.087 m**
  The time evolution of pressure drop at elevations 1.826-2.087 m is shown **Figure 15 a)**. Similar oscillatory behavior is observed as in the previous pressure taps measurements but still in very good agreement with the measurement.

- **CPU time**
  Figure 15 b) shows the CPU time comparison between the vessel and pipe models. It is clear that since the vessel component model is a 3 D model and thus allows more accurate modeling of complex flows, will require more CPU time than the 1D pipe component model.



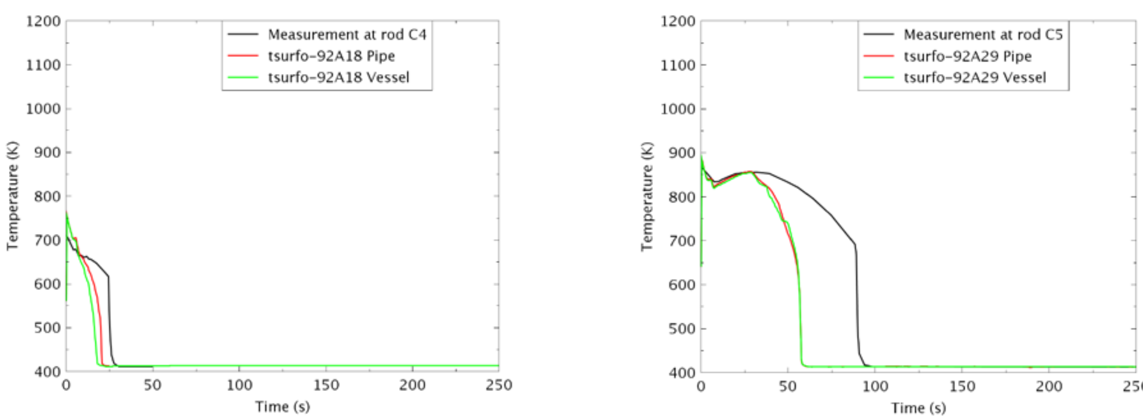
a) Test Bundle Exit Steam Flow Rate **b) Test Bundle Exit Liquid Flow Rate**

Figure 5. Flow Rate Time Histories



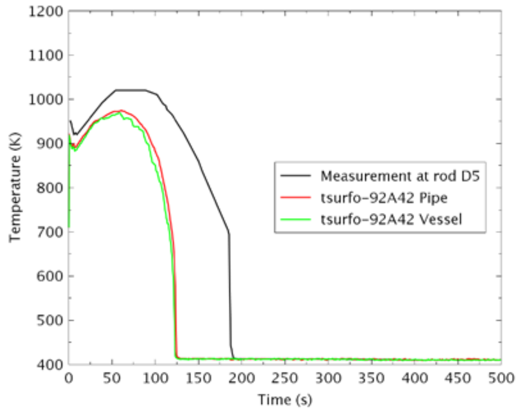
a) Test Bundle Collapsed Liquid Level **b) Test Bundle Quench Front Location**

Figure 6. Liquid Level and Quench Front Time Histories

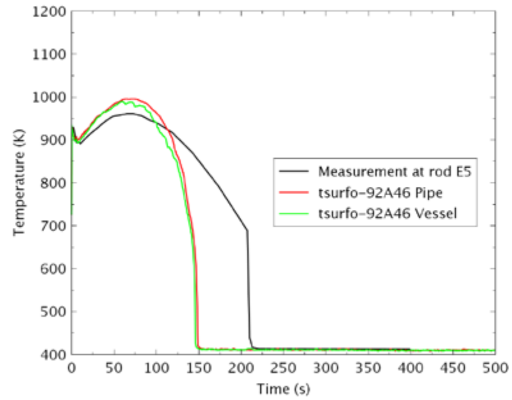


a) Surface Clad Temperature at Elevation 0.56 m **b) Surface Clad Temperature at Elevation 1.08 m**

Figure 7. Clad Temperature Time Histories

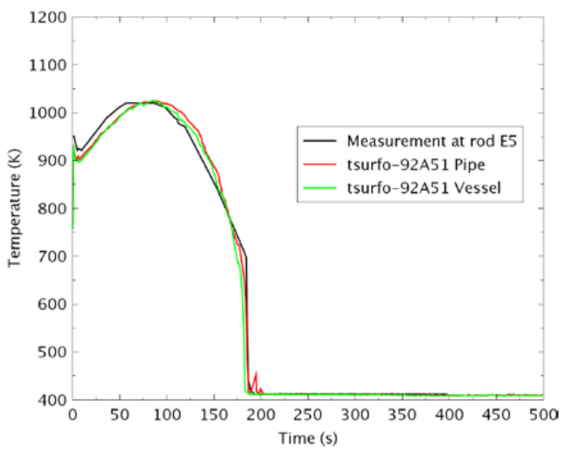


a) Surface Clad Temperature at Elevation 1.61 m

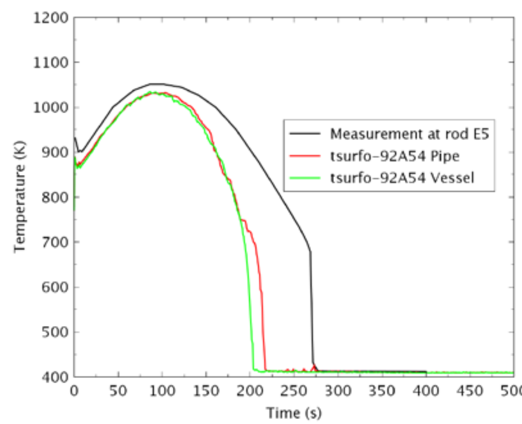


b) Surface Clad Temperature at Elevation 1.81 m

Figure 8. Clad Temperature Time Histories

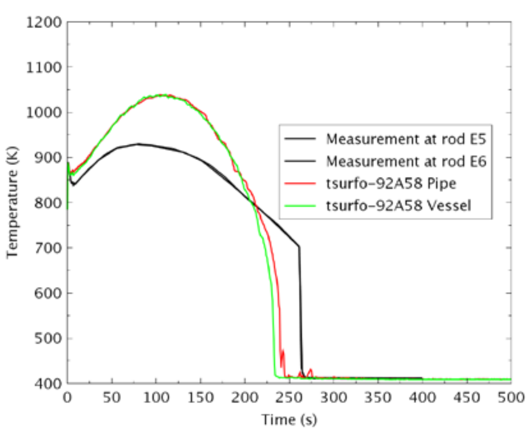


a) Surface Clad Temperature at Elevation 2.01 m

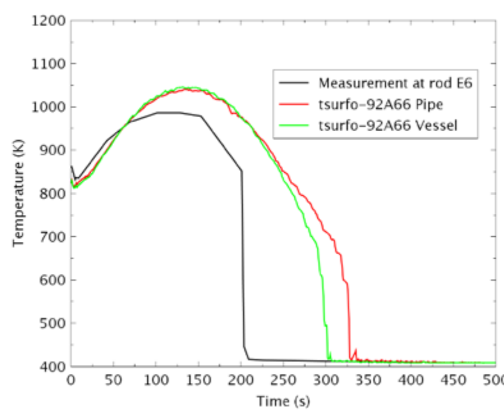


b) Surface Clad Temperature at Elevation 2.13 m

Figure 9. Clad Temperature Time Histories

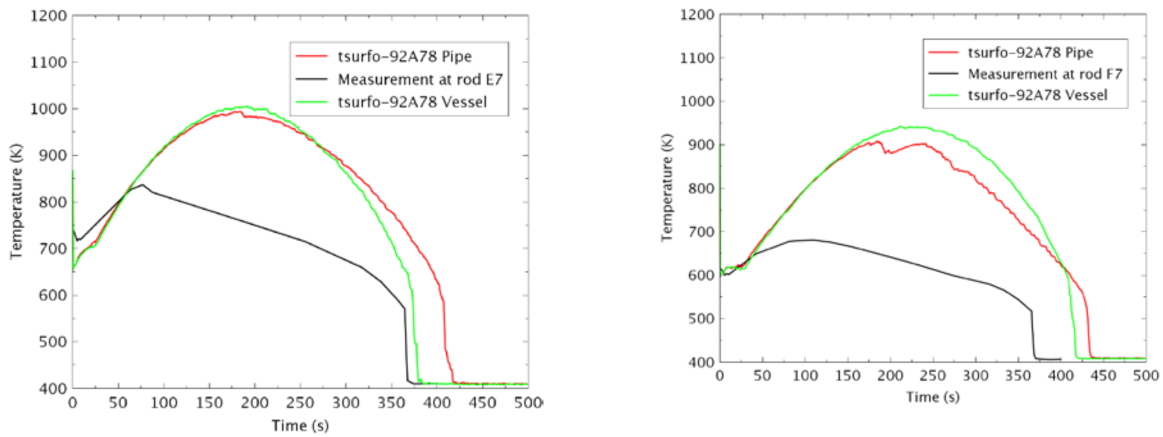


a) Surface Clad Temperature at Elevation 2.33 m



b) Surface Clad Temperature at Elevation 2.65 m

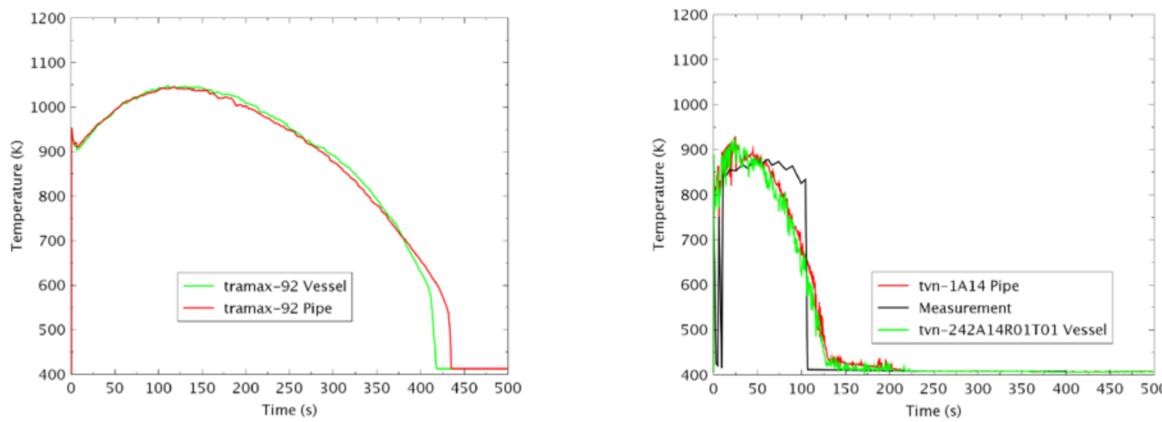
Figure 10. Clad Temperature Time Histories



a) Surface Clad Temperature at Elevation 3.18 m

b) Surface Clad Temperature at Elevation 3.6 m

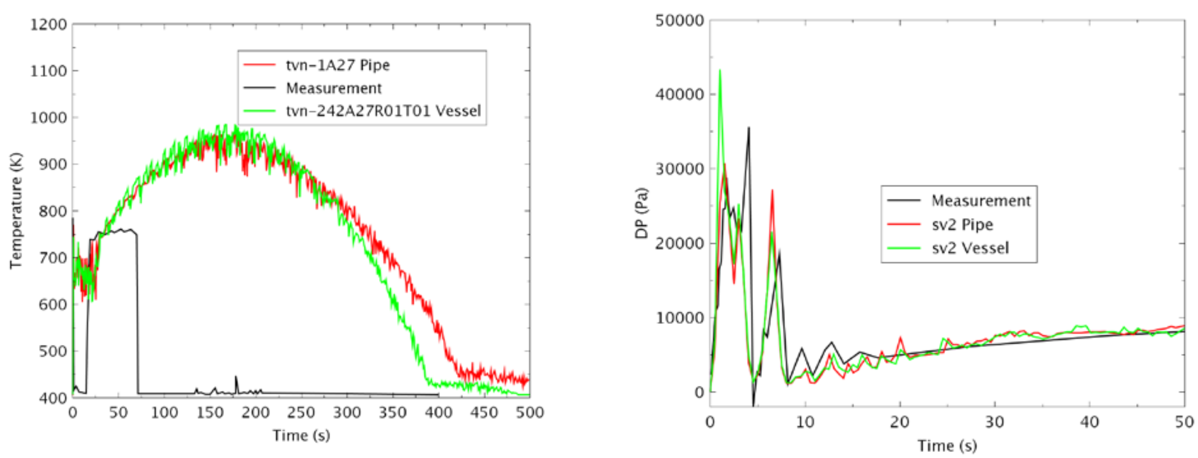
Figure 11. Clad Temperature Time Histories



a) Maximum Average Test Bundle Clad Temperature

b) Sub-channel D5 Fluid Temperature at 1.64 m

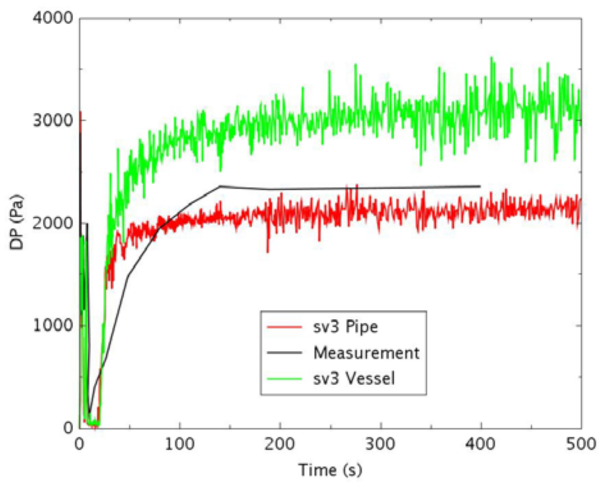
Figure 12. Temperature Time Histories



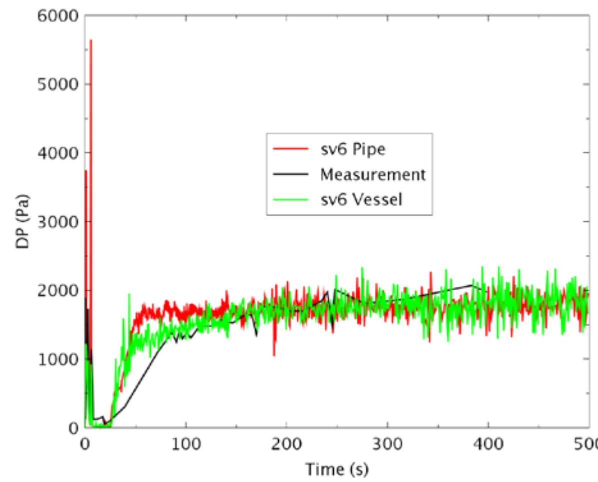
a) Sub-channel D5 Fluid Temperature at 3.21 m

b) Test Bundle Total Pressure Drop

Figure 13. Temperature and Pressure Drop Time Histories

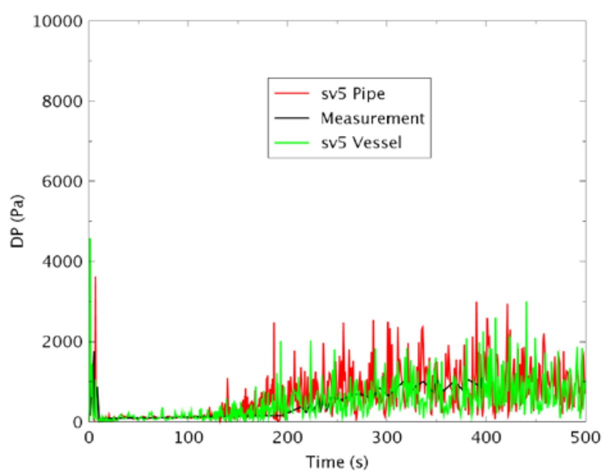


a) Pressure Drop between 0.518 – 0.78 m

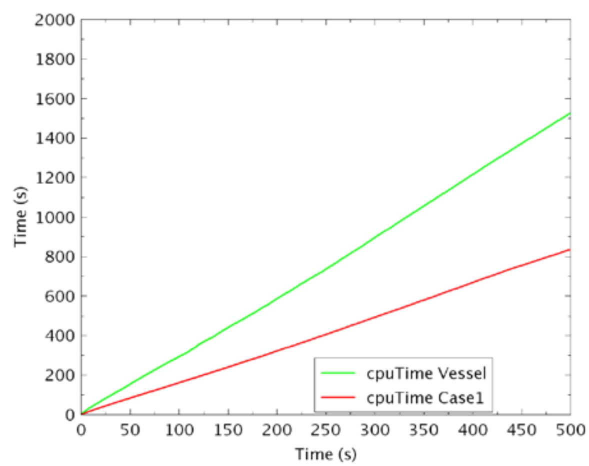


b) Pressure Drop between 0.778 – 1.041 m

Figure 14. Pressure Drop Time Histories



a) Pressure Drop between 1.826 – 2.087 m



b) CPU time

Figure 15. Pressure Drop and CPU Time Histories

5. SUMMARY AND MAIN OBSERVATIONS

The capability of the best-estimate thermal-hydraulic code TRACE to predict the thermal-hydraulic reflood process in a single rod-bundle test section was assessed using ACHILLES experimental data from the ISP-25 reflood transient. For the purpose of this assessment study, two detailed TRACE models representing the entire ACHILLES test section without the downcomer were developed and applied to simulate the ISP-25 transient. The TRACE models differed only in the hydrocomponent used to represent the bundle region of the test section. In one of the models, this region was modeled using a PIPE component and in the other model it was represented by a VESSEL component. A detailed axial nodalization of the test bundle region with approximately three cells between spacer grids was implemented to capture more accurately the spacer grid locations as well as the thermocouple positions. The measured test section inlet liquid rate and exit pressure were imposed as boundary conditions for the code simulations. TRACE Version 5.211 was used to carry out the transient simulations.

The ACHILLES ISP-25 reflood transient was analyzed for 500 s of transient time applying both TRACE models. Code predictions were compared against ISP-25 test measurements for both local- and integral-type quantities. These measurements included rod surface temperatures for individual rods at various axial elevations, sub-channel steam temperatures at different axial elevations, test section exit liquid and steam mass flow rates, quench front location, test section collapsed liquid level, test section overall pressure drop, and differential pressure drops across various axial sections of the test bundle.

Given the fact that rod surface temperatures for individual rods were compared against bundle-average clad temperature predictions at corresponding axial elevations, TRACE predicted reasonably well the overall test bundle thermal response exhibiting close results using both models. The overall observation is that the code predicted well the maximum clad temperature in the lower part of the test bundle for axial elevations of up to 3.18 m. At these elevations, the code predictions for the maximum clad temperature differed from the local temperature data by less than 100 K. At the elevation of 3.58 m near the top of the heated test bundle part, the code over-predicted the measured maximum clad temperature by about 250 K. For all axial elevations, the predicted quench time was reasonably well captured by the code with differences in quench times being less than 100 s.

Whereas the code over-predicted the quench front location for the significant part of the transient, the bundle collapsed liquid level was slightly under-predicted. TRACE predicted the steam flow rate at the test section exit in good agreement with the data. At the same time, the code did not calculate significant entrained liquid flow leaving the test section exit. This prediction differed from the ISP-25 experimental observations indicating almost continuously entrained liquid exiting the test section.

TRACE exhibited excellent capabilities in predicting all differential pressure drop measurements along the test section. Accordingly, the overall test section pressure drop was reproduced very well including the early differential pressure spikes during the first 10 s of the transient. However

TRACE is unable to predict the frequency of oscillations, observed in the first 50 seconds of the transient.

Overall, considering the involvement of a non-uniform axial power profile combined with radial temperature variations among individual rods in the experimental rod surface temperature data, TRACE exhibited reasonable capability in predicting the ACHILLES ISP-25 reflood transient implementing an average-rod test bundle modeling approach. Consistent with other reflood simulations obtained with recent TRACE code versions, major differences between ACHILLES ISP-25 simulation results and experimental data for rod surface temperatures were observed mainly for the upper part of test section where TRACE over-predicted the noticeably the measure rod surface temperature due to inexplicit grid spacer modeling.

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6. REFERENCES

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