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International Agreement Report

Analysis of KS-1 Experimental Data on the Behavior of the Heated Rod Temperatures in the Partially Uncovered VVER Core Model Using RELAP5/MOD3.2

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ABSTRACT

This report has been prepared as a part of the Agreement on Research Participation and Technical Exchange under the International Code Application and Maintenance Program.

KS-1 Test 35-1 data on the behaviour of the heated rod temperatures in the partially uncovered VVER Core model were simulated with RELAP5/MOD3.2 to assess the code, especially its non-equilibrium (unequal phase temperatures) heat transfer models for modeling phenomena in partially uncovered core under Small Break LOCA conditions.

The test has been carried out at experimental section KS-1 of the test facility KS (RRC KI) in 1991. KS-1 experimental section (VVER Loop model) includes models of all main elements of VVER type reactor, loop hot leg model and cold leg simulator, and also horizontal SG tube bundle simulator with passive heat removal. Core model consists of 19 electrically heated rod simulators with diameter 9 mm and height 2.5 m.

Test 35-1 models thermal and hydraulic processes during reflux condenser mode in primary circuit with low mixture level in partially uncovered VVER core under conditions of small residual heat power, middle pressure and counter current flow in the core.

First a study of the effect of the hydraulic nodalization to the code calculations was performed using different number of hydraulic volumes for Core model. After the choice of proper nodalization and maximum user-specified time step, base case calculations were done for the test. The differences between code predictions for behavior of rod simulator temperatures along the height of Core model and test data are described and analyzed.

Sensitivity studies were carried out to investigate the effects of modeling on the behavior of the rod simulator temperatures along the height of Core model.

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KS-1 Test 35-1 data on the behavior of the heated rod temperatures in the partially uncovered VVER Core model were simulated with RELAP5/MOD3.2 to assess the code. These calculations were performed to evaluate the general code prediction capability in modeling reflux condenser mode in the primary system of a reactor VVER , as well as specific problem areas of the code in modeling non-equilibrium (unequal phase temperatures) heat transfer in partially uncovered core under Small Break LOCA conditions with counter current flow.

Test 35-1 has been carried out at experimental section KS-1 of the test facility KS (RRC KI) in 1991. KS-1 VVER Loop model is semi-integral one loop model of VVER primary system for investigations hydrodynamics and heat transfer in transients and SBLOCA conditions of a reactor. KS-1 experimental section includes models of all main elements of VVER type reactor, loop hot leg model and cold leg simulator, and also horizontal SG tube bundle simulator with passive heat removal. Core model consists of 19 electrically heated rod simulators with diameter 9 mm and height 2.5 m.

Test 35-1 models thermal and hydraulic processes during steam and condensate circulation in primary circuit with low mixture level in partially uncovered VVER core under conditions of small residual heat power, middle pressure and counter current flow in the core. The objectives of the test are : - to obtain test data on core axial and FA radial distributions of rod simulators temperatures under quasi-steady conditions; - determination influence of thermal and hydraulic processes in the models of circuit elements on the processes in the Core model, including influence of heat losses from the circuit to environment on heat transfer in partially uncovered core. Specific feature of this test is relatively high intensity of heat transfer from rod simulators to the coolant in uncovered part of FA model under influence of circuit heat losses and steam condensation in the models of circuit elements on the processes. During cooling of FA model under conditions of counter current flow, non-uniform core axial and FA radial distributions of rod simulator temperatures were obtained. Measured maximum value of cladding temperature occurs inside the Core model.

First a study of the effect of the hydraulic nodalization to the code calculations was performed using different number of hydraulic volumes for Core model. After the choice of proper nodalization and maximum user-specified time step, base case calculations were done for the test. The differences between code predictions for behavior of rod simulator temperatures at various cross sections along the height of Core model and test data are described and analyzed.

Sensitivity studies were carried out to investigate the effects of modeling on behavior of rod simulator temperatures along the core height.

In this work some deficiencies of RELAP5/MOD3.2 in analysis of KS-1 Test 35-1 could be identified, and the following conclusions can be drawn:

- RELAP5/MOD3.2 gives a satisfactory agreement of calculation results and test data for overall picture of the two-phase flow behavior in KS-1VVER Loop model and heat transfer in partially uncovered Core model during reflux condenser mode with some exceptions.
- There is a significant quantitative and qualitative difference of calculated and measured core axial temperature profiles in the heated FA model. RELAP5/MOD3.2 under predicts TW (tcal) temperatures in the middle part of FA model and over predicts ones at the FA outlet.
- In considered "quasi steady regime" calculated TW (tcal) wall temperature is much higher (up to 130 K) than measured ones at the FA outlet. This is one of the main problems of the code base case calculations. The reason for these deviations between experiment and calculations is too low Hw1 (tcal) ≈ 50–60 $W/m^2 \cdot K$ (tcal) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper part of FA model calculated for CCF conditions. Therefor, calculated temperature increase rate dTW/dt is much more, than measured ones. In this case under prediction for interphase heat transfer may be the other reason for these deviations between experiment and calculations.
- In considered "quasi steady regime" calculated wall temperature TW (tcal) is much lower (100 K below) than measured ones in the middle part of FA model. This is the next one of the main problems of the code calculations. The reason for these deviations between experiment and calculation is too large Hw1 (tcal) ≈ 80 $W/m^2 \cdot K$ coefficient of heat transfer in the middle part of FA model calculated for CCF conditions.
- Sensitivity studies shows, that implementation experimental temperature profile in restart input deck allow to reduce large differences between code predictions and measurements for core axial temperature profiles at the initial moment t0exp and then during the test simulation. However, initial temperature conditions in FA model weakly influence on code simulation of heat transfer and interphase heat exchange in partially uncovered core under CCF conditions.

NOMENCLATURE

W – power of FA model, kW

qv- specific volumetric power, kW/m^3

qw- heat flux, kW/m^2

Pout – core model outlet pressure, bar

DP – pressure difference, kPa

DL13-12 – measured pressure difference on difmanometer, connected to points 13 and 12 of the UP model, in levelmeter regime, bar, Pa

DL2-4 - measured pressure difference on difmanometer, connected to points 2 and 4 of the downcomer model, in levelmeter regime, bar, Pa

DL4-14 - measured pressure difference on difmanometer, connected to points 4 and 14 of the downcomer model, in levelmeter regime, bar, Pa

DL4-3, DL5-4, DL6-5, DL7-6, DL8-7, DL9-8, DL11-10 - measured pressure difference on difmanometer, connected to the core model in corresponding points of heated part of rod bundle model, in levelmeter regime, kPa, Pa

Lm – mixture level, m

TFin – water temperature in lower plenum model, °C

TFup – coolant temperature in UP model inlet, °C

TFfa – coolant temperature in FA model outlet, °C

TFdc – coolant temperature in DC model, °C

TWi-k – inner side temperature of rod heated wall, °C

Ts – saturation temperature

Tg – vapor temperature

D – diameter, mm

Dh – hydraulic diameter of the channel, mm

ΔL – distance between points of pressure difference measurement, mm

ΔZ_k - distance between the bottom cross section of heated zone of FA model and cross sections k=00-24 along the FA height where thermocouples are installed, mm

ξ - local hydraulic resistance coefficient

G_L –liquid mass flow rate, kg/s

Gg –vapor mass flow rate, kg/s

V_L – liquid velocity, m/s

Vg – vapor velocity, m/s

Hw – heat transfer coefficient, W/m^2s

t – time, s

i = 01-19 – number of FE

k = 00-24 – number of cross sections from top to bottom of fuel assembly, where thermocouples have been installed

exp – experimental value

cal – calculated value

RRC KI – Russian Research Center "Kurchatov Institute"

VVER – Russian light water reactor

SBLOCA - small break loss of coolant accident

UP – upper plenum

DC – downcomer

SG – steam generator

FA – fuel assembly

MCC – main circulation circuit

DAS - data acquisition system

NC – natural circulation

CCF – counter current flow

CCFL – counter current flow limitation

1. INTRODUCTION

1.1. Objectives

The main goals of this work are: - analysis of the KS-1 experimental data on the behavior of rod temperatures in the partially uncovered VVER Core model using RELAP5/MOD3.2; investigation thermal and hydraulic processes during steam and condensate circulation in primary circuit with low mixture level in the Core model under conditions of small residual heat power, middle pressure and counter current flow in the core; evaluation of the general code prediction capability in modeling reflux condenser mode in the primary system of a reactor VVER under Small Break LOCA conditions; assessment of RELAP5/MOD3.2 code, especially its non-equilibrium (unequal phase temperatures) heat transfer models for modeling phenomena in partially uncovered core under conditions with counter current flow.

1.2. Background

To help ensure RELAP5 code can be used with confidence, Russian Research Centre "Kurchatov Institute" has agreed to perform and document independent assessment of the code for a wide range of applications. These exercises are necessary to help identify and quantify any code shortcoming, in particular for the Russian types of reactors VVER and RBMK. This report has been prepared as a part of the Agreement on Research Participation and Technical Exchange under the International Code Application and Maintenance Program. Analysis of semi-integral KS-1 Test 35-1 with partially uncovered VVER Core model under SBLOCA conditions was performed using the latest version of code RELAP5/MOD3.2.

1.3. Study Description

SBLOCA is one of the design basis accidents in VVER power pressure water reactor. KS-1 VVER Loop model is semi-integral (one loop) model of VVER primary system for investigations hydrodynamics and heat transfer in transients and SBLOCA conditions of a reactor. In this facility series of the tests with partially uncovered VVER Core model under SBLOCA conditions were performed during 1991 year.

Phenomena of hydrodynamics and heat transfer in VVER core under uncovering conditions are specific. So, it is necessary to estimate RELAP`5/MOD3.2 code models adequacy for modeling of these phenomena, because there are specific features in design of core and fuel assembly of VVER-440 and VVER-1000. These specific features are FA rod location (triangular grid), geometry of rod and FA elements, hydraulic diameters of rod bundle cells and number of space grids. Temperature of rods directly depends on these factors.

KS-1 Test 35-1 was chosen for assessment calculations with RELAP5/MOD3.2. This code capability was investigated. Special emphases were given to: - thermal and hydraulic processes during steam-condensate circulation in primary circuit with low mixture level in partially uncovered Core model under conditions of small residual heat power and of middle pressure; - non-equilibrium heat transfer and core axial temperature distributions in the uncovered part of Core model under quasi-steady conditions; - influence of thermal and hydraulic processes in the models of circuit elements on the processes in Core model, including influence of heat losses from the circuit to environment and of counter current flow on heat transfer in partially uncovered core.

1.4. Report Organization: The following sections present and describe the steps that were taken to facilitate the code assessment. In Section 2 the KS-1 VVER Loop model of the KS Test Facility is described, and KS-1 Test 35-1 is described in Section 3. Descriptions of released code version and base case input deck for the test modeling are given in Section 4. Nodalization, including variation from base case, the results for the base case input deck for the test and analysis of transients, the discussion of the calculated and measured values and conclusions are presented in Section 5. Sensitivity studies and run statistics are given in Section 5 too. In Section 6 summary of conclusions is presented. In the Appendix D one finds the base case input decks including listings for KS-1 Test 35-1 and sensitivity variation input deck listing.

2. EXPERIMENTAL FACILITY DESCRIPTION

2.1. Description and Characteristics of KS-1 VVER Loop Model

Experimental section KS-1 was developed on the base of the test facility KS (RRC KI) for modeling of thermal and hydraulic processes in VVER core under SB LOCA conditions.

Experimental section KS-1 VVER Loop model has been designed for modeling of boiling-condensing mode in VVER primary system and non-equilibrium heat transfer processes in partially uncovered core at small residual heat power and for middle and low pressure ranges. It is test facility designed for investigations both separate effects and integral thermal and hydraulic processes in primary circuit under SB LOCA conditions. Principle scheme of VVER Loop model is shown in Fig.2.1. Main parameters of Loop model are presented in Table 2.1.

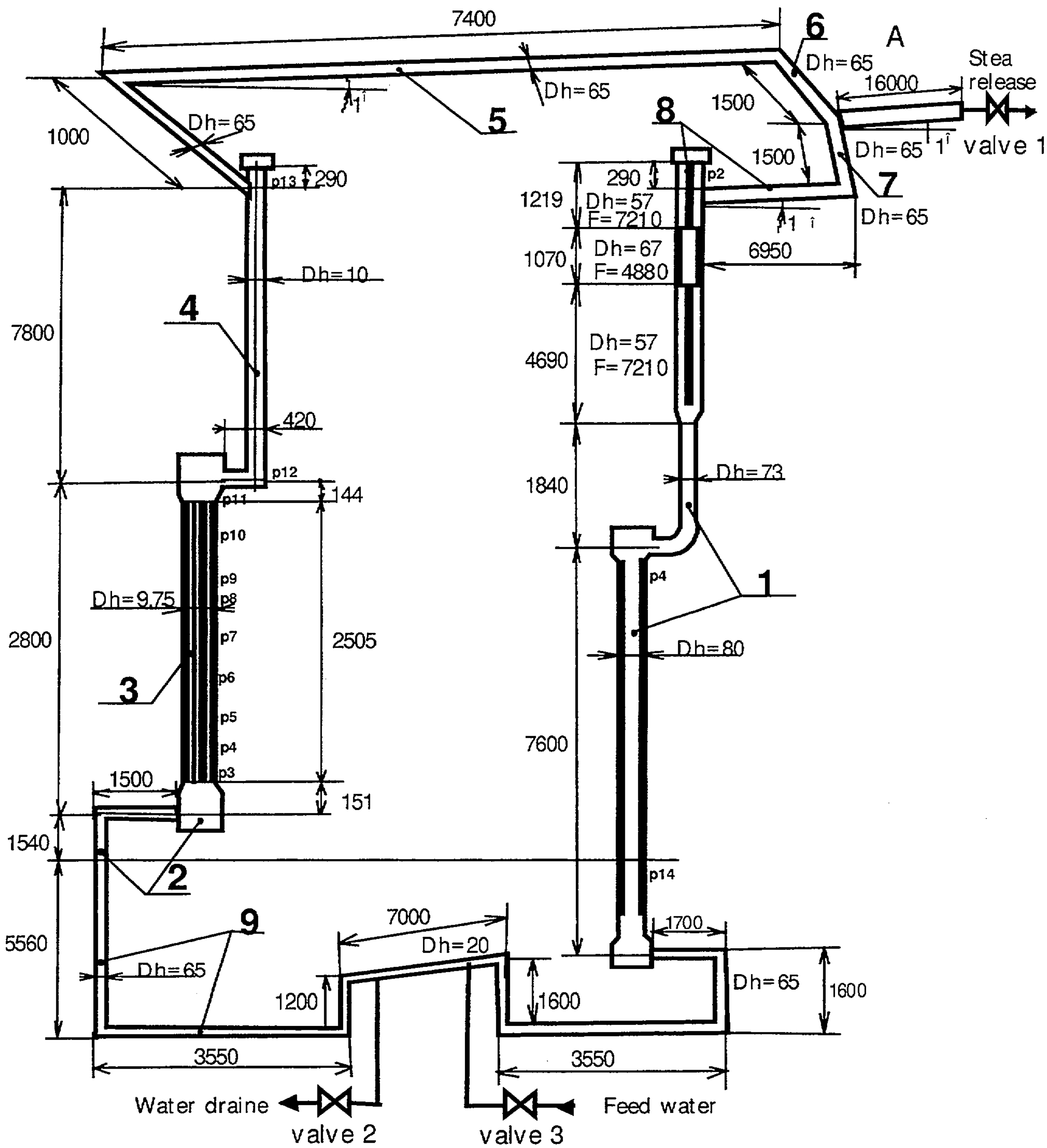


Fig.2.1. Scheme of KS-1 VVER Loop model.

1. Downcomer model	6. SG tube bundle simulator
2. Lower plenum model	7. SG tube bundle simulator
3. Core model	8. Loop cold leg simulator
4. Upper plenum model	9. Lower pipeline
5. Loop hot leg model	

Table 2.1. Main parameters of KS-1 VVER Loop model

Forced and natural circulation of coolant in the loop	
Height of up-coming branch of NC	17.7 m
Primary circuit pressure P	1-100 bar
FA model power W	0-100 kW
Heat flux in FA model q_w	0-75 Kw/m^2
Flow rate through the core model at forced circulation GL1	0-833 kg/s.

VVER Loop model consists of: Downcomer model 1, Lower Plenum model 2, Core model 3, Upper Plenum model 4, loop Hot Leg model 5, horizontal SG tube bundle simulator with sections 6, 7 with passive heat removal, and loop cold leg simulator 8.

SG simulator only qualitatively simulates hydrodynamics and heat transfer processes under steam condensation in the SG tube bundle. Downcomer model at bottom and Lower Plenum model are connected by a lower pipeline 9.

Up-coming and down-coming circuit branches are linked in upper part by pipelines of Hot Leg and Cold Leg and by SG tube bundle simulator. So, it forms coolant natural circulation circuit in semi-integral one loop model of VVER primary system.

Steam pipeline from SG tube bundle simulator into expansion tank to release steam through valve 1, water pipeline from lower pipeline 9 into expansion tank to drain water through valve 2, and also water pipeline into lower pipeline 9 to feed water through valve 3 serve for formation of initial conditions with break of coolant natural circulation and with partially uncovered Core model in the test section.

KS facility and DAS provide preparation and implementation of the planned experiments.

2.2. Main Components Characteristics

Downcomer model. The location of the DC model 1 in VVER Loop model is shown in Fig.2.1. The cross section area of the DC model channel with diameter of 80 mm is in 2.8 times greater than cross section area of the Core model channel with FA model. This fact provides small variations of collapsed level and hydrostatic water head in Downcomer model for time period of registration of rod simulator temperatures during investigation of heat transfer in partially uncovered FA model for quasi-steady regime.

Core model. Detail drawing of the Core model is presented in Fig.2.2. The cross section of the Core model is also shown in Fig.2.2. The Core model consists of: - electrically heated VVER-1000 fuel assembly model 1 enclosed by shroud 2 made of 12X18H10T steel with internal electric and heat insulator bushes of talkochlorite 3; pressure vessel tube 4; tubes 5 connected to differential manometers for pressure difference measurements along the core height; upper conductor 6 for supply of current to rod simulators; unit 7 for gas supply into the of rod simulators tubes with aim to unload rod simulators from external coolant pressure and for outlet of thermocouples 8 from FA model; lower conductor 9.

VVER-1000 fuel assembly model is shown in Fig.2.3. The cross section of FA model is presented on Fig.2.3b. The rod simulators are numbered as i=1-19. Parameters of Core model with fuel assembly model are presented in Table 2.2.

Table 2.2. Parameters of Core model with VVER-1000 fuel assembly model

Heated length of the FA model	2505 mm
Number of rod simulators	19
Outer diameter of rod simulators	9.0 mm
Distance between rod simulators	12.75 mm
Size of channel hexahedron	59 mm
Channel cross section area	0.001806 m^2
Heat transfer surface area of FA model	1.345 m^2
Hydraulic diameter of the channel	9.75 mm
Initial axial and radial power distribution	uniform
Height of Core model annular channel	2560 mm

The annular channel (with gap 51 mm along the whole height of the core) between shroud of the FA model and pressure vessel tube is closed at the top. It is connected with the Lower Plenum model and filled with coolant – water at the bottom, and saturated or superheated steam at the top.

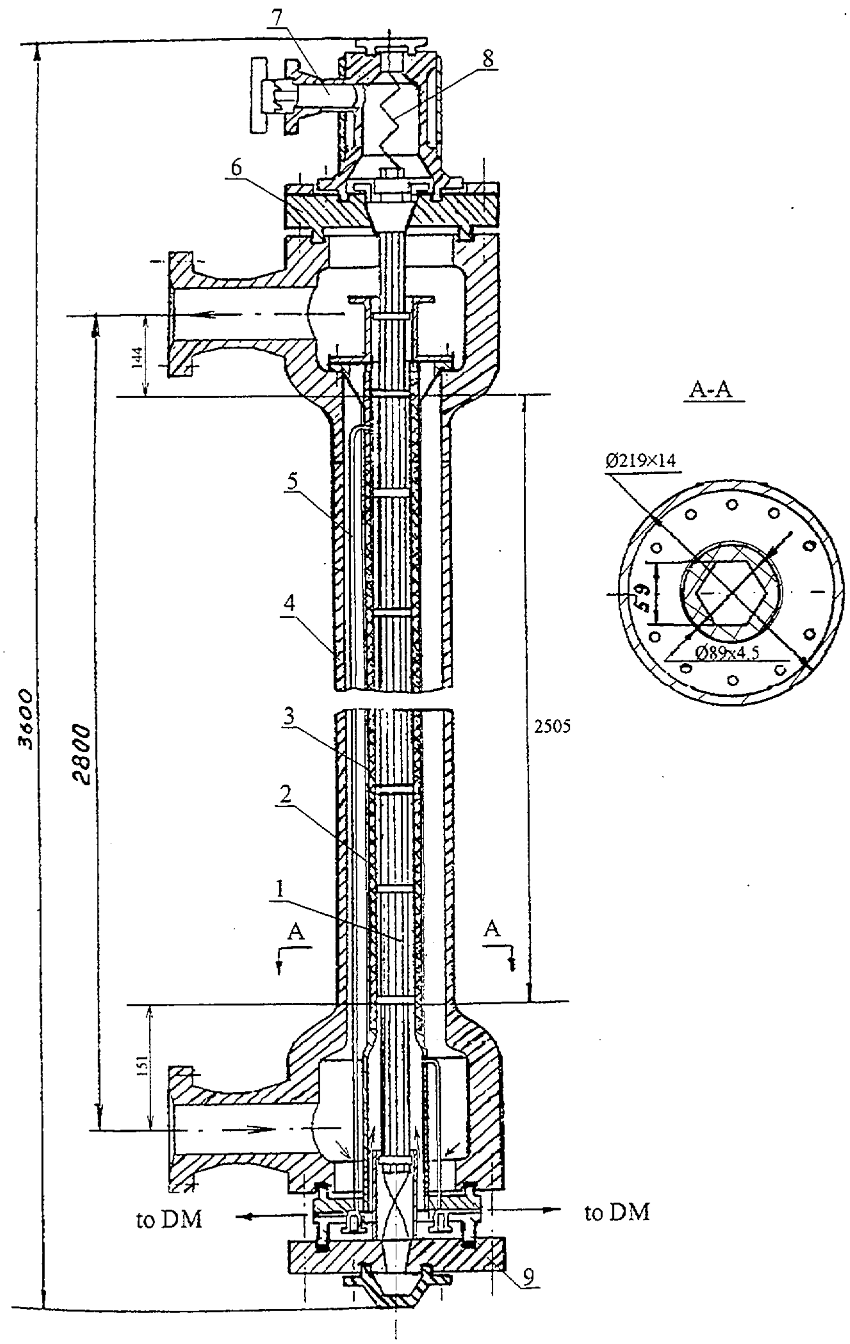


Fig. 2.2. Model of the VVER core.

1. Model of VVER fuel assembly
2. Shroud of FA model
3. Insulator bushes
4. Pressure vessel tube
5. Differential manometer lines
6. Upper conductor
7. Unit for gaseous unload of rod simulators
8. Thermocouples lines
9. Lower conductor

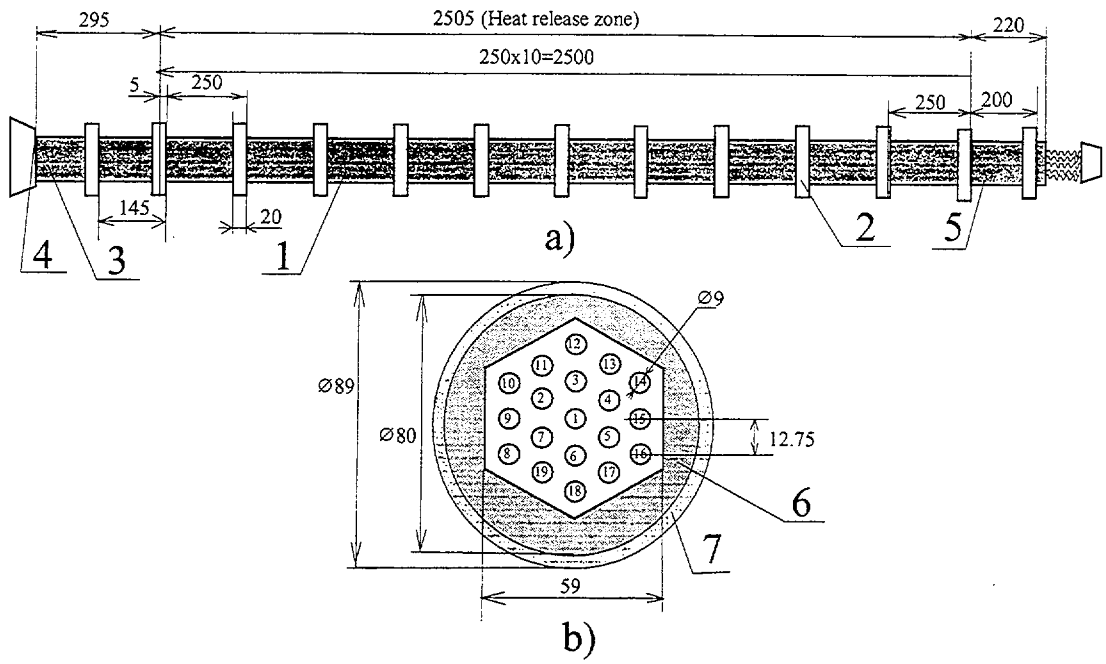


Fig.2.3. Model of the VVER-1000 fuel assembly.

a) bundle of the rod simulators
b) cross section of the FA model

1. Steel tube of the rod simulator
2. Space grid
3. Cooper tube of the upper conductor of the rod simulator
4. Upper cone of the conductor
5. Cooper pin of the lower conductor of the rod simulator
6. Insulator bush
7. Shroud

The rod simulators (see Fig. 2.3 a) have been made of 12X18H10T stainless steel tubes with outer diameter 9.0 mm and wall thickness of 1.53 mm, heated simulator length is 2505 mm. At the top of each tube there is a cooper conductor 3 with outer diameter of 9 mm and wall thickness of 2 mm. In the heated zone there are 11 space grids of VVER-1000 FA type. Distance between grids is 250 mm. All space grids are standard. All 19 sells of space grids have height of 20 mm. They are made of 12X18H10T stainless steel tubes with outer diameter 13 mm and wall thickness of 0.3 mm. From the experimental results the local hydraulic resistance coefficient of the grid is ξ=0.26.

The rod bundle is connected to conducting bus by cooper cones and heated directly by current through simulator tubes.

Upper Plenum model. The location of the Upper Plenum model 4 in VVER Loop model is shown in Fig.2.1. A difference between UP model and real VVER upper plenum is an occurrence of side coolant flow after its passing of the Core model. Steam-water mixture moves from the Core model into a vertical up-coming path of the UP model via a horizontal branch with inner diameter of 100 mm and length of 420 mm. There is a stagnation zone below conducting cone where steam and gas can be accumulated.

Loop Hot Leg model. Hot Leg model 5 (see Fig.2.1) is a pipeline made of tube ∅ 75x5 (Dh=65 mm). It consists of two straight sections with lengths of 1000 mm and 7400 mm linked by 90 ° bends with radius of 500 mm. The HL model has a small inclination with angle 1° for liquid drainage from HL and from section 6 of SG tube bundle simulator into UP model. The side outlet of the UP model is located below point A, which is the highest one of the VVER Loop model.

Simulator of the steam generator tube bundle. The SG tube bundle simulator (see Fig.2.1) with passive heat removal is a pipeline made of tube ∅ 75x5 (Dh=65 mm) divided by point A into two weakly inclined straight sections 6 and 7 with length of 1500 mm each. These sections are linked with HL and CL by 90 ° bends with radius of 500 mm. The section 6 is connected to the HL model. It is weakly inclined (angle is 1°) for liquid drainage to HL model and further into the UP model. Another end of this section is linked to section 7 of the SG tube bundle simulator. The section 7 is connected to CL. It is also weakly inclined to another side (1°) for liquid drainage to CL 8 and further into the DC model. A pipeline with a valve 1 is connected with tube bundle simulator in the point A. This pipeline is used for steam release from the circuit into expansion tank for initial condition preparation. It is a pipeline made of tube ∅ 75x5 (Dh=65 mm) with length 16000 mm. This pipeline is also inclined (1°) for liquid drainage to the section 6 and section 7. In the point A the total flow rate of steam condensate from this pipeline is uniformly distributed on sections 6 and 7.

Loop cold leg simulator. The cold leg simulator 8 (see Fig.2.1) has been made without loop seal. It consists of two sections: - pipeline section made of tube ∅ 75x5 (Dh=65 mm) with length of 6950 mm, weakly inclined (angle is 1°); vertical channel with following size: outer diameter is 114 mm, wall thickness is 6 mm. There are internal elements inside this channel.

Lower pipeline. The Lower pipeline 9 (see Fig.2.1) joins the DC model 1 with the Lower Plenum model 2.

Only SG tube bundle simulator is non-heat-insulated part of the experimental circuit. All other outer surfaces of the KS-1VVER Loop model have been covered by heat insulation for heat loss decrease.

2.3. Measurements and Errors

Locations of the gauges in the Downcomer model, Lower Plenum model, Core model, Upper Plenum model and Lower pipeline are presented on the scheme of measurements in KS-1 VVER Loop model, shown in Fig.2.4. List of measured parameters, and their ranges and measurement errors are presented in Table 2.3.

Table 2.3. List of measured parameters used in calculations, measurement ranges and errors

N	Indentifi-cator	Parameter description	Range	Error	Length, mm
1	U	Voltage in FA model, V	0÷50	±0.5 %	
2	BI1	Current, A	0÷1500	±0.5 %	
3	BI2	Current, A	0÷1500	±0.5 %	
4	W	Power, kW	0÷75	±2.5 %	
5	Pout	Core model outlet pressure, bar	0÷100	±0.16 %	
					ΔL, mm
6	DL13-12	Pressure difference in the UP model, bar	0÷1.0	±1.4 %	7800
7	DL2-4	Pressure difference in the DC model, bar	0÷1.0	±1.4 %	8875
8	DL4-14	Pressure difference in the DC model, bar	0÷0.63	±1.4 %	4550
9	DL4-3	Pressure difference in the heated zone of FA, kPa	0÷1.6	±1.4 %	75
10	DL5-4	Pressure difference in the heated zone of FA, kPa	0÷4.0	±1.4 %	385
11	DL6-5	Pressure difference in the heated zone of FA, kPa	0÷10.0	±1.4 %	720
12	DL7-6	Pressure difference in the heated zone of FA, kPa	0÷6.30	±1.4 %	480

13	DL8-7	Pressure difference in the heated zone of FA, kPa	0÷6.30	±1.4 %	480
14	DL9-8	Pressure difference in the heated zone of FA, kPa	0÷2.50	±1.4 %	145
15	DL11-10	Pressure difference in the heated zone of FA, kPa	0÷1.6	±1.4 %	40
16	TFin	Coolant temperature in the lower plenum model, °C	0÷300	±0.5 %	
17	TFdc	Coolant temperature in the DC model, °C	0÷300	±0.5 %	
18	TFup	Coolant temperature in the UP model inlet, °C	0÷400	±1.5 %	
19	TFfa	Coolant temperature in the FA model outlet, °C	0÷400	±1.5 %	
					ΔZk, mm
20	TW06-00	Temperature of rod simulator 06 in cross section 00, °C	0÷600	±3.0 %	2485
21	TW06S00	Temperature of rod simulator 06 in cross section 00, °C	0÷600	±3.0 %	2485
22	TW12-00	Temperature of rod simulator 12 in cross section 00, °C	0÷600	±3.0 %	2485
23	TW12S00	Temperature of rod simulator 12 in cross section 00, °C	0÷600	±3.0 %	2485
24	TW16-00	Temperature of rod simulator 16 in cross section 00, °C	0÷600	±3.0 %	2485
25	TW18-00	Temperature of rod simulator 18 in cross section 00, °C	0÷600	±3.0 %	2485
26	TW03-02	Temperature of rod simulator 03 in cross section 02, °C	0÷600	±3.0 %	2290
27	TW04-03	Temperature of rod simulator 04 in cross section 03, °C	0÷600	±3.0 %	2245
28	TW13-03	Temperature of rod simulator 13 in cross section 03, °C	0÷600	±3.0 %	2245
29	TW07-04	Temperature of rod simulator 07 in cross section 04, °C	0÷600	±3.0 %	2135
30	TW14-04	Temperature of rod simulator 14 in cross section 04, °C	0÷600	±3.0 %	2135
31	TW04-06	Temperature of rod simulator 04 in cross section 06, °C	0÷600	±3.0 %	1990
32	TW13-06	Temperature of rod simulator 13 in cross section 06, °C	0÷600	±3.0 %	1990
33	TW14-07	Temperature of rod simulator 14 in cross section 07, °C	0÷600	±3.0 %	1880
34	TW03-08	Temperature of rod simulator 03 in cross section 08, °C	0÷600	±3.0 %	1780

35	TW04-09	Temperature of rod simulator 04 in cross section 09, °C	0÷600	±3.0 %	1735
36	TW13-09	Temperature of rod simulator 13 in cross section 09, °C	0÷600	±3.0 %	1735
37	TW14-10	Temperature of rod simulator 14 in cross section 10, °C	0÷600	±3.0 %	1625
38	TW07-10	Temperature of rod simulator 07 in cross section 10, °C	0÷600	±3.0 %	1625
39	TW03-11	Temperature of rod simulator 03 in cross section 11, °C	0÷600	±3.0 %	1525
40	TW04-12	Temperature of rod simulator 04 in cross section 12, °C	0÷600	±3.0 %	1480
41	TW02-13	Temperature of rod simulator 02 in cross section 13, °C	0÷600	±3.0 %	1390
42	TW19-15	Temperature of rod simulator 19 in cross section 15, °C	0÷600	±3.0 %	1245
43	TW09-16	Temperature of rod simulator 09 in cross section 16, °C	0÷600	±3.0 %	1135
44	TW02-16	Temperature of rod simulator 02 in cross section 16, °C	0÷600	±3.0 %	1135
45	TW17-16	Temperature of rod simulator 17 in cross section 16, °C	0÷600	±3.0 %	1135
46	TW19-18	Temperature of rod simulator 19 in cross section 18, °C	0÷600	±3.0 %	990
47	TW09-19	Temperature of rod simulator 09 in cross section 19, °C	0÷600	±3.0 %	880
48	TW17-19	Temperature of rod simulator 17 in cross section 19, °C	0÷600	±3.0 %	880
49	TW19-21	Temperature of rod simulator 19 in cross section 21, °C	0÷600	±3.0 %	735
50	TW02-22	Temperature of rod simulator 02 in cross section 22, °C	0÷600	±3.0 %	625
51	TW17-22	Temperature of rod simulator 17 in cross section 22, °C	0÷600	±3.0 %	625
52	TW19-24	Temperature of rod simulator 19 in cross section 24, °C	0÷600	±3.0 %	480

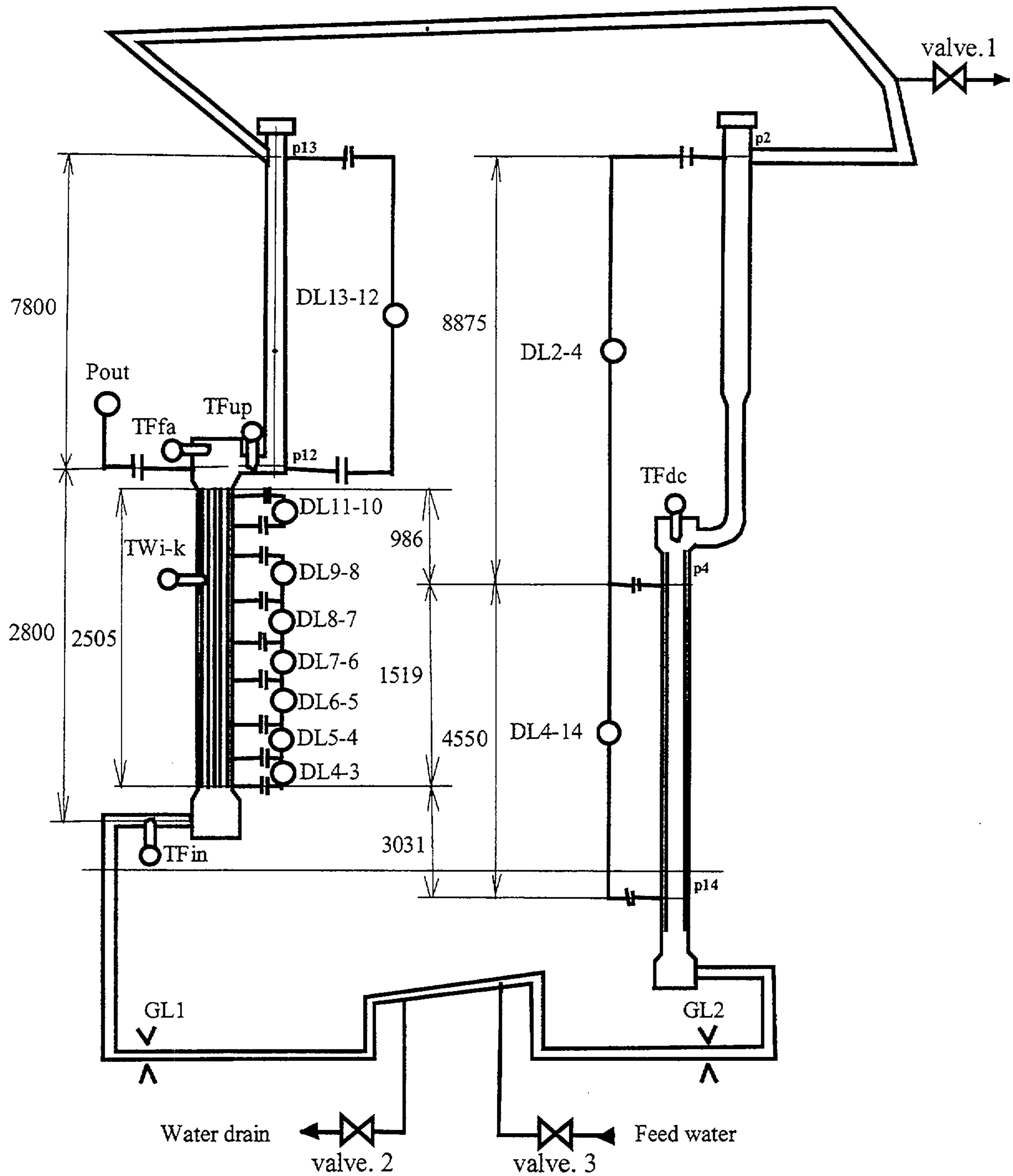


Fig. 2.4. Measurements scheme in the VVER primary system model.

The collapsed levels of the coolant in the UP and DC models were measured with DL13-12, DL2- 4 and DL4-14 differential manometers with their reverse connection to the pressure samplings. The collapsed level of the coolant in the Core model was measured with DL4-3, DL5-4, DL6-5, DL7-6, DL8-7, DL9-8, DL11-10 differential manometers with their reverse connection to pressure samplings. Location of pressure sampling points and distances ΔL between these points for the differential manometers are presented in Fig. 2.4, Fig. 2.5 and in Table 2.3.

The coolant temperatures in the Lower Plenum model TFin, at the FA model outlet TFfa, at the Upper Plenum model inlet TFup and in the DC model TFdc were measured with chromel-copel thermocouples. Measurements of FA model axial and radial temperature distributions were made with 33 thermocouples installed inside rod simulators (in 14 rods) on 20 elevations.

Scheme of location of the thermocouples TW_{i-k} along the FA model height is shown in Fig.2.5.

The electric power W of the FA model was determined on the base of measurements of voltage drop U on the FA model and current.

Data acquisition system, All above mentioned parameters, i.e. rod simulators temperatures TWi-k, coolant temperatures TFin, TFfa, TFup and TFdc, pressure Pout, pressure differences DL13-12, DL2-4, DL14-4, DL4-3, DL5-4, DL6-5, DL7-6, DL8-7, DL9-8, DL11-10, voltage U and current, were registered by computer. Duration of one sampling was ≈ 0.3 s. Sampling period was ≈ 0.5 s.

3. KS-1 TEST 35-1 DESCRIPTION

3.1. Experiment performance technique

KS-1 Test 35-1 models thermal and hydraulic processes during reflux condenser mode in VVER primary circuit with low mixture level in partially uncovered core under conditions of small residual heat power, middle pressure and counter current flow in the core. To establish test conditions it was performed preliminary heating of water and pipeline metal up to required coolant temperature at the Core model inlet under forced coolant circulation. Then VVER Loop model was isolated from the forced circulation circuit of the KS facility. After that a smooth increase of the FA power was realized to set single-phase NC regime. Water was heated. Coolant pressure was increased up to 80 bar, and then coolant drainage from SG tube bundle simulator to expansion tank through the valve 1 was started. Boiling NC regime was started under slightly greater pressure Pout and water temperature TFin than needed. Some amount of steam was released from the tube bundle simulator to expansion tank through valve 1.

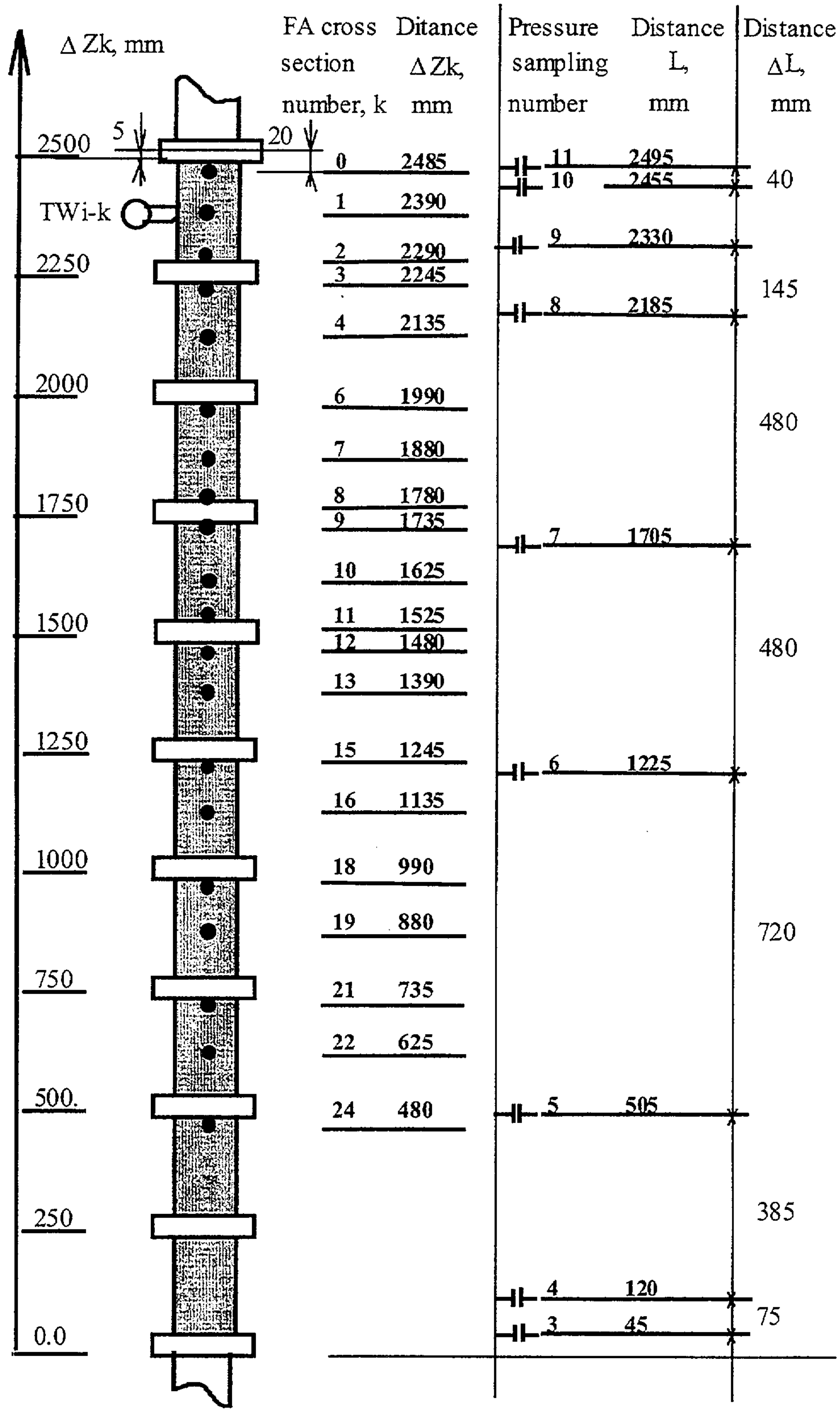


Fig. 2.5. Scheme of location of the thermocouples TW_{i-k} and pressure sampling points along the FA model height.

Full draining of the UP model was made after heating-up of pipeline metal in the upper parts of the VVER Loop model up to saturation temperature under near values of pressure Pout (t0exp) and water temperature TFin (t0exp) at the core inlet to specified ones. Coolant collapsed level in the UP model was controlled with differential manometer DL13-12. Also it was set partially uncovering of the Core model using water drainage from the lower pipeline to expansion tank through the valve 2. Coolant collapsed level was controlled with differential manometers DL2-4 and DL4-14 in the DC model and with differential manometers in the Core model.

After establishment of water temperature TFin (t0exp) and mixture level Lm (t0) in the Core model, main test for investigation of heat transfer in the partially uncovered FA was started. Due to condensation dominance (ΣQloss > W), in closed circulation circuit (valves 1,2 and 3 were closed) slow pressure Pout (t) decrease, slow mixture level Lm (t) increase and rod temperatures TW (t) variations were realized. Measurements of the TW_{i-k}(t) temperatures along the height of FA model with thermocouples on 20 elevations have provided temperature axial distribution in the FA model and test data about level of two-phase mixture in the FA channel with accuracy of ± 50 mm. Measurements, acquisition and registration of data were implemented in quasi-steady regime under constant FA power and water temperature TFin in the Lower Plenum model, and also under slow variations of pressure and mixture level in the Core model. The test has been carried out under initial conditions with pressure Pout (t0exp)=37.7 bar at the Core model outlet, water temperature TFin (t0exp)= 517 K in the Lower Plenum model, low mixture level Lm (t0exp) ≅ 0.57 m in the Core channel and constant power W (t) = 9.52 kW of FA model.

3.2. Initial and boundary conditions

3.2.1. Boundary conditions at the outer surfaces of KS-1 VVER Loop model. Heat losses

Only SG tube bundle simulator is non-heat-insulated part of experimental circuit. All other outer surfaces of the KS-1VVER Loop model have been covered by heat insulation.

Measured ambient temperature during experiments was 27°C.

Before the set of main experiment there were implemented preliminary experiments to determine heat losses from the VVER Loop model to environment and also heat balance in the Core model: electrical power of the FA model, single-phase (water) coolant heating and heat losses.

Determination of total power of heat losses ΣQloss (exp) from outer surfaces of the circuit to ambient air was made on the base of special experiment on boiling-condensing regime with natural circulation in the circuit during water boiling in full wetted FA model under constant pressure Pout (t)=51 bar and, hence, with equality W=ΣQloss (exp). Total heat losses were equal to 50.2 kW. Accuracy of experimental determination of the total heat losses ΣQloss was ± 5%. However, for code modeling of determinative parameters behavior (heat release power W (t) of the FA model, pressure Pout (t), coolant temperature TFin (t) in the core inlet and mixture level Lm (t) in the core) in the other Test 35-1 with ΣQloss>W and, hence, with gradual decrease of pressure and saturation temperature Ts (P) in the circuit, adjustment of heat losses power ΣQloss (tcal) is needed. This value must be such, that calculated time history of pressure decrease Pout (tcal) coincides with experimental curve Pout (texp) as well as possible. Therefore, experimental value W (t)=50.2 kW for above mentioned special experiment is only first approach for determination of ΣQloss (tcal) during code modeling of other experiment.

Distribution of heat losses on circulation circuit may essentially influence on calculation results. Value of heat losses and their distribution along circulation circuit determines rate of steam cooling and condensation, hence, flow rate of steam condensate, back flowing into the Core model and into the DC model. Theoretical calculations of the coefficients for heat transfer from outer surfaces of the pipes with different outer diameter Do to air were made on the base of data about geometry and thermal conductive coefficient for thermal insulation and, also, theoretical calculation of the coefficients for heat transfer from outer surfaces of heat insulation to air. It allows calculate relative distribution of the heat transfer coefficients Kloss for outer surfaces of different parts of experimental circuit. Estimated coefficients Kloss in the different parts of circuit are shown in Table 3.1.

Table 3.1 Estimated heat transfer coefficients Kloss (Do) for different parts of experimental circuit

Part of experimental circuit	Lower pipeline	MCC model	UP, MCC models	DC model tube	Pressure vessel tube	SG simulator tubes
Outer diameter Do, mm	28	75; 89	114	121	219	75
Coefficient Kloss (Do), $W/(m^2 \cdot K)$	5.6	3.2	3.2	3.4	2.8	5.9

All theoretical values of Kloss have to be multiplied by correctional coefficient Closs >1 for every particular experiment. It is explained by existence of air ventilation in the test facility compartment and also, presumably, by under estimation of thermal conductive coefficient of heat insulation in theoretical calculation of Kloss.

Power Qloss (Do) of heat losses from outer surfaces (with areas Sout) of pipelines with different diameters, pressure vessel tube of the Core model, UP and DC models, through thermal insulation layer to ambient air is calculated from equation (1):

$$Qloss\,(Do) = Closs \cdot Kloss\,(Do) \cdot Sout \cdot (Tout - Tair). \qquad (1)$$

Corresponding value of correctional coefficient Closs is adjusted that calculated and experimental curves of pressure decrease Pout (tcal) and Pout (texp) coincide as well as possible.

3.2.2. Initial and boundary conditions inside of coolant circulation circuit

Temperature regime of the heated rods in uncovered zone of the FA is directly coupled with coolant level dynamics in the core under boiling–condensing conditions. In this case level of two-phase mixture determines also steam mass flow rate in uncovered zone of the FA. Therefore adequate data about mixture level in the FA channel are required for calculation of the rod temperature regime.

The FA model consists of rod simulators, which are made of identical stainless steel tubes with the same wall thickness. Therefore, during water boiling in full wetted FA model under uniform distribution of the wall temperatures TW the specific volumetric power qv and heat flux qw distribution in parallel rod simulators is uniform on radius and height of the FA model too. But, under conditions of the partially uncovering of the FA model, temperature axial and radial distributions become essentially non-uniform. Under direct electric heating of the rod simulators, local power at the various elevations of the FA model is determined by electric resistance of stainless steel tubes, which essentially increases with wall temperature raising. The influence of the rod resistance variation with temperature on radial and axial power distributions in the FA model may be taken into account using results of rod simulators temperature distribution measurements and reference data [1] about electric resistance of 12X18H10T steel at various temperatures.

During the test coolant temperature was varied in relatively narrow range, so variations of heat conductivity and specific heat capacity of talkochlorite insulator in the Core model were negligible. However for modeling calculations, temperature dependencies of these parameters were used [2].

There are not heat losses inside of rod simulators, because they are closed in the top.

Initial and boundary conditions for modeling quasi-steady regime are:

- DC model and Lower Plenum model have been filled up with water under defined temperature TFin (t0exp) and mixture level Lm (t0exp) in the Core model, and corresponding collapsed level in the DC model, pressure Pout (t0exp) and power W (t0exp) in the FA model;
- the other parts of the circuit located above mixture level: Upper Plenum model, Hot Leg model, SG tube bundle and cold leg simulators and upper part of the Downcomer model have been filled up with saturated steam;
- the water flow rate at the core inlet is determined by driving head under steam-condensate circulation conditions;
- FA axial and radial distributions of wall temperature TW_{i-k} (t0exp) along the core height are determined in the test under slow pressure decrease due to ratio of the FA power W and total heat losses rate Qloss (W<Qloss).

Time interval for TW (t) wall temperature stabilization in some rod simulators was ≈ 400 s. This time is not enough for full temperature stabilization of the talkchlorite insulator, steel shroud tube and pressure vessel tube having essentially greater thermal inertia than rod simulators with thin wall thickness.

Non-steady heating of talkchlorite insulator and the steel shroud, steam in the Core model annular channel and, also, non-steady heating of Core model pressure vessel tube may be calculated, if specific densities, heat capacities and thermal conductivity coefficients of steel and talkchlorite are known [1, 2].

3.3. Experimental limitations and shortcomings

One of experimental shortcomings is a technique difficulty of superheated steam temperature measurement at the FA model outlet, since steam condensate may occur at the thermocouple TFfa and disturb measurements.

Temperature data about talkochlorite insulators and stainless steel shroud are absent. It makes difficulty for evaluation of heat flux from up-coming steam flow to these elements of the Core model during dynamic regimes.

Impulse tubes of differential manometers are located in annular channel of the Core model filled with water and partly with steam. Temperatures of these tubes are not measured.

3.4. Experimental Data used

The report presents experimental data on the behavior of the rod simulators temperatures

TW_{i-k} (texp), coolant temperatures TFin (texp), TFfa (texp), TFup (texp), pressure Pout (texp), pressure differences DL13-12, DL2-4, DL14-4, DL4-3, DL5-4, DL6-5, DL7-6, DL8-7, DL9-8, DL11-10 (texp) and mixture level Lm (texp) in the Core model with constant FA power W (texp)= 9.52 kW for Test 35-1. Initial values of determinative parameters of Test 35-1 for quasi-steady regime are presented in Table 3.2. Original data plots from Test 35-1are presented in Figures A-1÷ A-15 in Appendix A. Complete set of experimental data obtained at the experimental section KS-1 is in RRC KI report [3].

Table 3.2. Initial values of determinative parameters of KS-1 Test 35-1 for quasi-steady regime

Experiment	Power W(t0exp), kW	Pressure Pout(t0exp), bar	Mixture level Lm(t0exp), m	Temperature TFin(t0exp), K
KS1-35-1	9.52	37.7	0.57	517

To simulate experimental initial conditions using RELAP5/Mod3.2, it is necessary to know real mixture level Lm (t0exp) in the Core model at the initial moment t0exp. Therefore, in Table 3.2 initial mixture level Lm (t0exp) is presented. Real mixture level was determined on the base of preliminary analysis of behavior of rod simulator temperatures and of core axial distribution of rod temperatures TW_{i-k} (t0exp) along the height of heated zone at the initial moment t0exp.

KS1-Test 35-1 characteristics

During quasi-steady regime with constant FA model power W (t) = 9.52 kW (see Fig. A-1), slow pressure decrease took place with rate dPout / dt = 0.016 bar/s (see Fig. A-2). It was realized in closed circulation circuit for enclosed valves 1, 2 and 3 under steam-condensate circulation conditions. Initial value of pressure was Pout (t0exp)=37.7 bar. Pressure value at the moment t1exp=100 s was Pout (t1exp=100 s)=36.1 bar. This pressure decrease occurred due to predominance of steam condensation in the circuit over steam generation in the Core model (ΣQloss>W). Due to predominance of condensate flow down rate over coolant boiling-off, very slow increase of collapsed level in the DC model during experiment took place (see curve DL4-14 (t) in Fig. A-5). Due to this predominance and also due to pressure decrease, very slow increase of mixture level in the core channel took place with rate dLm / dt ≅ 0.22 mm/s. Initial value of mixture level was Lm (t0exp)=0.57 m. There is slow increase of rod simulators temperature TW (t) in uncovered part of the FA model at the level of 2.48 m with rate dTW / dt ≅ 0.14 K/s (see curve TW06-00 (t) in Fig. A-7). Wall temperatures of rod simulators in FA cross sections, located above mixture level, were practically constant during experimental time 0-100 s (see Fig. A-14).

Initial value of water temperature at the inlet of the Core model was TFin (t0exp)= 517 K, then one very slow decreased down to TFin= 515 K during experimental time 0-100 s (see Fig. A-3).

Essentially non-uniform FA model axial and radial distribution of rod simulator temperatures TW was obtained during FA cooling under conditions with CCF in Core model channel. Measured maximal values of rod simulators temperatures TW (t) max were realized in the middle part of the FA model (elevation is 1.525 m) in a middle row of rods (see curve TW07-10 in Fig. A- 11).

Presented above characteristics of chosen experiment show, that pressure Pout (t), coolant temperature TFin (t), mixture level Lm (t), rods temperatures TW (t) and their core axial distribution relatively slow vary in quasi-steady regime. Furthermore, there is such cross section of the FA model, that practically TW (t) temperature steady regime occurs for long time interval. This time interval essentially exceed time, which is necessary for stabilization of wall temperature of rod simulators, which have relatively small wall mass and heat capacity in comparison with large wall masses and heat capacities of talkochlorite insulators and steel shroud tube and pressure vessel tube.

Experimental initial values at the moment t0exp and behavior of determinative parameters for quasi-steady state, having to be adequate provided during code simulation, are listed below:

- Constant power of heat release in the FA model W(t)=9.52 kW;
- Pressure at the core outlet Pout (t0exp)=37.7 bar;
- Slow pressure decrease down to Pout (texp=100s)=36.1 bar with rate dP/dt =0.016 bar/s ;
- Coolant temperature at the Core model inlet TFin (t0exp)= 517 K;
- Mixture level location in the core model Lm(t0exp)=0.57 m;
- Slow level increase with rate dLm/dt = 0.22 mm/s;
- Distribution of steam void fractions above mixture level on the length of NC circuit and on steam release pipeline from point A to closed valve 1, and also on the height of the FA channel and annular channel, which are equal 1.0;
- Distribution of average temperature of water and steam on length of NC circuit and on steam release pipeline from point A to closed valve 1;
- Distribution of average (averaged on wall's thickness) wall's temperatures of pipelines, pressure vessel and internal parts of circuit (UP, MCC, DC, SG and steam release pipeline from point A to valve1);
- Distribution of average wall's temperatures of rod simulators on the height of the FA model, which are superheated above Ts temperature in uncovered part under Pout (t0exp);

- Distribution of average wall's temperatures of steel shroud, talkochlorite bushes and pressure vessel on the height of the Core model, which are Ts temperature under Pout (t0cal);
- Distribution of average temperatures of water in the LP and DC models under mixture level and in the lower pipeline, which are equal TFin (t0exp) temperature;
- Distribution of average wall's temperatures of the lower pipeline, which are equal TFin (t0exp) temperature;
- Distribution of power of heat losses Qloss (t0exp) from outer surfaces of the circuit to ambient air with constant temperature of 27 ^{o}C; heat losses is determined by particular heat transfer coefficient Kloss and adjusted correctional coefficient Closs (t0exp)=3.0 (see equation (1).

4. DESCRIPTION OF RELEASED CODE VERSION AND BASE CASE INPUT DECKS

4.1. Code Description

The code used for this work was RELAP5/MOD3.2 (Frozen version) [4, 5], with no further updates. This code was used for the Nodalization study and the base case calculations. The code has been installed on the IBM PC AT Pentium-166 computer with Windows 95 operating system and Watcom translator.

4.2. Input Deck Development

Figure 4.1 shows the nodalization to simulate the KS-1VVER Loop model and Test 35-1 with RELAP5/MOD3.2. The code modeling of the test followed the specific calculation procedures used for simulation of the experimental initial and boundary conditions.

The RELAP5/MOD3.2 model consists of all parts of the primary circuit of the KS-1 experimental section, in total of 11RELAP5 components with 198 hydrodynamic Volumes, 198 Junctions and 217 Heat Structures with 982 mesh points. A complete listing of the base case input set is listed in Appendix D.

Nodalization scheme for KS-1 VVER Loop model includes the following components of the primary circuit: - Lower plenum model (v. 21, sj 22, v. 23), Core model (sj 24, v. 5, sj 25, v. 7, sj 8), Upper Plenum model (v. 9, sj 10, v. 11), Hot Leg model and SG tubes simulator (sj 12, v. 14), Cold Leg simulator and SG tubes simulator (v. 106), Downcomer model (sj 101, v. 102, sj 103, v. 104) and Lower Water pipeline (v. 1, sj 2). All external solid components were specified in the input model to account for heat losses into the environment air. Hydrodynamic components and heat structures geometry data were taken from the RRC KI report [3].

A "pipe" hydrodynamic component Lower Water Communication Line 1 (sv. 101 - sv. 169) represents the test Lower Water pipeline fluid volumes with initial water temperature TFin (t0exp).

A "pipe" hydrodynamic component Core Channel 7 (sv. 701 - sv. 721), representing the test core channel fluid volumes, is connected to Lower Plenum model 23 at the bottom and to Upper Plenum model 9 at the top by the Single Junctions (SJ 25, SJ 8).

Volumes from 701 to 720 represent the part of the core channel with the heated bundle. The different nodalization were selected and tested using 10 and 20 volumes for the bundle by fixing the number of fine mesh nodes in the heat conduction elements. Here the core nodding pitch was chosen equal one or half spacer grid pitch (250 or 125 mm).

An “annulus” hydrodynamic component 5, representing annular channel in Core model, is connected with the Lower Plenum model 21 at the bottom by the Single Junction (SJ 24) and filled with saturated or superheated steam.

A "pipe" hydrodynamic components Upper Plenum 9, 11 (sv. 901- sv. 903, sv. 1101 - sv. 1111), representing the test UP fluid volumes, is connected to Core Channel at the bottom and to Hot Leg at the top by the Single Junction (SJ 12).

A "pipe" hydrodynamic component Hot Leg, SG, Steam Pipe 14 (sv. 1401 - sv. 1414), representing the test HL, SG and Steam pipe fluid volumes, is connected to UP at the bottom and to SG 106 at 1407 sub-volume side by Single Junction (SJ 107).

A "pipe" hydrodynamic components SG tubes simulator 106, Cold Leg simulator 104 and 106, Downcomer model 102, 104 and Lower Water pipeline 1 represent the test CL, SG and DC fluid volumes.

Heat structure scheme used to describe power distribution of the FA heated tube bundle and circuit heat losses into environment is shown in Figure 4.1.

In the analysis of the test the counter current flow limitation (CCFL) flag (f=1) was used with the Single Junction 22, representing local cross flow area decrease inside the Lower Plenum between v. 21 and v. 23. The default values of the four quantities Dj, $\beta=0$, c=1 and m=1 were used. Wallis CCFL model was used to correct modeling behavior of mixture level in the core channel with FA model under conditions of counter current flow.

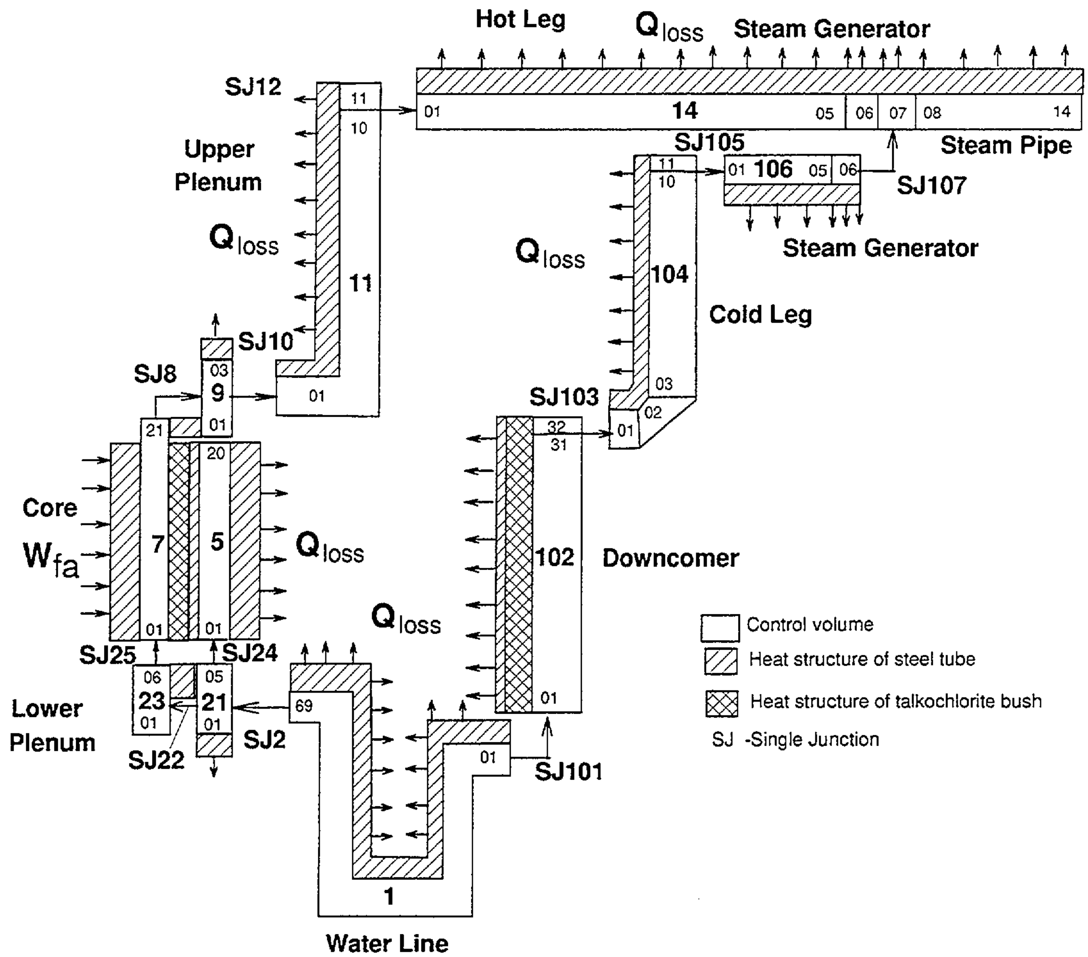


Fig. 4.1. Base case nodalization scheme for RELAP5/3.2 modeling of KS-1 Test.

CCFL model was not activated in the core channel with FA model. In the code calculations of processes in the core with the bundle for the interphase friction were used the correlation developed for rod bundles. To activate convective boundary conditions for non-standard geometry when modeling a vertical bundle, the rod pitch-to-diameter ratio was input.

4.3. Determinative and determined parameters for code simulation of the experimental conditions and analysis of investigated processes/phenomena

Mixture level location determines power portion for steam generation in covered part of FA and accordingly flow rate of saturated steam at inlet of uncovered FA part and power portion in uncovered FA part. Power portion in uncovered FA part determines heat-up and distributions of steam flow temperatures and rod simulator temperatures along the height of FA uncovered part.

Thus, it is necessary to have accurate data about initial location of mixture level Lm (t0exp) and its behavior during experiment to calculate rod temperature distribution along the core height.

In dry out zone it is possible local power excess over heat transfer from rod surface to steam flow. As a result, local wall temperature will increase with some rate dTW/dt, which depends on mentioned above power excess and on heat capacity of the rod simulator part. In other case, local cooling of rod simulator part is possible. Hereof, rate of temperature variation of rod simulator wall, during local heating or local cooling with certain local power and known heat capacity, is one of the main determined parameters of heat transfer in partly uncovered zone. This rate and absolute value of wall temperature TW characterize heat transfer in the considered part of core.

Local value of rod wall temperature is determined by local temperature of steam flow and by local temperature difference between steam and rod wall. This difference is determined by local heat flux value and by heat transfer coefficient.

Temperature distribution of steam flow along core height depends on steam mass flow rate, intensity of heat transfer of steam with rod walls and talkochlorite insulator surfaces, and also it depends on intensity of interphase heat transfer under CCF of generated steam and steam condensate.

Heat flux qw2 (t) from steam to insulator and its stabilization time, and also temperature regime of inner wall of insulator TWi (t) are determined by intensity of heat transfer: - between coolant and talkochlorite insulator, between steel shroud and inner wall of pressure vessel tube through annular gap and between outer surface of pressure vessel and ambient air. Heat flux qw2 (t) and its stabilization time also depend on thermal conductivity coefficients and relatively large heat capacities of considered massive parts of the Core model.

Thus, quality of the code modeling for rod temperature behavior in uncovered zone of FA model depends on both accurate simulation of hydrodynamic processes in the circuit and also accurate simulation of processes heat transfer from rod simulators to coolant flow and, further, to environment.

Therefore, it is necessary to provide close coincidence of calculated and experimental values of pressure Pout (tcal) and Pout (texp), mixture level location Lm (tcal) and Lm (texp) in the core channel, coolant temperature at the core inlet TFin (tcal) and TFin (texp) and steam generation rate for adequate simulation of heat transfer in partially uncovered FA model. Also it is important to take into account complex processes of heat transfer on rod surfaces under CCF conditions, interphase heat transfer and heat transfer from superheated steam flow into environment.

The following determinative parameters (which initial values and behavior are defined in the experiment) have to be adequate provided in code simulation using specified boundary conditions:

- Behavior of heat release power in the FA model W (t),
- Initial value of pressure at the Core model outlet Pout (t0exp),
- Initial value of coolant temperature at the Core model inlet TFin (t0exp),
- Initial distribution of average void fractions on the length of NC circuit and steam release pipeline from point A to closed valve 1, and also on the height of the FA channel and annular channel,
- Initial distribution of average temperatures of vapor and liquid on the length of NC circuit and steam release pipeline from point A to closed valve 1,
- Initial distribution of averaged on wall thickness wall's temperatures of pipelines, pressure vessel tube and others, which determine accumulated heat in the circuit elements,
- Initial distribution of average wall's temperatures of rod simulators and inside parts of the Core model (steel shroud with talkochlorite bushes),
- Power of heat loss ΣQloss (t) from outer surfaces of the circuit to ambient air. Heat losses power is determined by particular heat transfer coefficients Kloss and adjusted correctional coefficient Closs (see equation (1)).

All of mentioned above parameters govern further behavior of following determined parameters:

- Pressure at the Core model outlet Pout (tcal),
- Coolant temperature at the Core model inlet TFin (tcal),
- Mixture level in the core channel Lm (tcal),
- Mixture level in the DC model DL4-14 (tcal) and DL2-4 (tcal),

- Total pressure difference DPt (tcal) on the height of the core model and DP13-12 (tcal) on the height of UP and DL4-14 (tcal) on the height of DC model,
- Flow rate of coolant at the Core model inlet G_L in (tcal) under NC conditions,
- Flow rate of steam condensate G_L out (tcal), flowing down from circuit elements to the Core model outlet
- Flow rate of steam condensate G_L in (tcal), flowing down from circuit elements to the DC and then to the Core model inlet,
- Distribution of steam flow rate Gg (tcal) on the height of uncovered part of the FA model,
- Distribution of steam velocity Vg (tcal) on the height of uncovered part of the FA model,
- Distribution of steam temperature Tg (tcal) on the height of uncovered part of the FA model,
- Distribution of water flow rate G_L (tcal) on the height of uncovered part of the FA model,
- Distribution of water velocity V_L (tcal) on the height of uncovered part of the FA model,
- Distribution of water temperature TF (tcal) on the height of uncovered part of the FA model,
- Distribution of temperatures of inner surfaces of rod simulators TWi-k (tcal) in different levels k on the height of FA model; rates dTW/dt,
- Distribution of coefficient Hw1 (tcal) of heat transfer from outer surfaces of rod simulators to coolant on the height of FA model,
- Distribution of coefficient Hg2 (tcal) of heat transfer from coolant flow to the talkochlorite insulator on the height of FA model,
- Distribution of coefficient Hw3 (tcal) of heat transfer from outer surface of steel shroud to coolant on the height of annular channel,
- Distribution of coefficient Hg4 (tcal) of heat transfer from coolant to inner surface of the pressure vessel tube on the height of annular channel,
- Distribution of specific heat flux qw1 (tcal) from outer surfaces of the rod simulators to coolant on height of FA model,
- Distribution of specific heat flux qw2 (tcal) from coolant flow to the talkochlorite insulator on height of FA model,
- Distribution of specific heat flux qw3 (tcal) from outer surface of steel shroud to coolant on the height of annular channel,
- Distribution of specific heat flux qw4 (tcal) from coolant to inner surface of the pressure vessel tube on the height of annular channel,
- Distribution of specific heat flux qw_{loss} (tcal) from outer surface of pressure vessel to ambient air.

Location of mixture level Lm (t1cal) = Lm (t0exp) in the core channel and its behavior Lm (tcal) are determined by special analysis of calculation results and experimental data about temperatures TWi-k (t) of inner walls of rod simulators and their height distributions and temperature change rates dTW/dt. In this case the following assumption is used. Real mixture level is that level in the core channel, at which sharp increase of void fraction and local dry out of rod simulators take place. And then a sharp decrease of heat transfer coefficient Hw1 (t), specific heat flux qw1 (t) from outer surfaces of rods to coolant and local increase of temperatures TW (t) of rod simulators above saturation temperature take place also.

Results of comparison of calculated and experimental values of mentioned determinative and determined parameters are a base for conclusion about adequacy of the code simulation of initial and boundary conditions, realizing in experiment at the initial moment t0exp, and then about adequacy of simulation of quasi-steady regime of whole experiment.

4.4. Method of code simulation of initial and boundary conditions with RELAP5/MOD3.2

Goals and method of implementation of KS-1experiments in 1991, and also way of the results treatment to obtain dependence of heat transfer coefficient Hw1 on steam flow rate under conditions with known pressure and mixture level in the Core model do not stipulate the achievement of completely steady state in all components of the circuit. Furthermore, steady state is impossible under conditions of slow decrease of pressure due to heat loss predominance and partially uncovering of the Core model. In particular, it is impossible to obtain simultaneously stationary temperature regime of rod simulators and talkochlorite insulator, of the shroud and pressure vessel at different elevations of uncovered part of the FA model under achievement of allowable rod simulator temperatures. It is explained both by slow variation of hydrodynamic parameters and different heat capacity and thermal conductivity for the Core model elements.

Therefore, these experimental data are considered ones, obtained in quasi-steady regime under constant FA power W (t) and relatively slow variations of determinative parameters. Probably, in certain stages of the process, it is possible to consider regimes of heat transfer to the massive parts of the test facility in partially uncovered Core model as stable ones with constant heat transfer coefficients.

During definition of the assessment problem main attention has been paid on evaluation of RELAP5/MOD3.2 adequacy to simulate separate phenomena/processes of heat exchange under low mixture level, middle pressure and small FA model power. Simulations of hydrodynamic phenomena in main circuit parts, presumably, have to be considered as auxiliary tasks. Solution of these tasks is necessary to provide required initial and boundary conditions in partially uncovered Core model.

This approach is governed by fact, that essential uncertainties may occur during code simulation of such hydrodynamic parameters as mixture level location, void fraction distribution, CCF liquid and vapor mass flow rate distribution and interphase heat transfer along the height of uncovered part of FA. Special analyses of code adequacy for simulation of reflux condenser mode in closed circuit need to be additionally implemented. Therefore, to diminish probable influence of these uncertainties on calculation results for heat transfer coefficients and rod's wall temperatures distribution, it is necessary to develop special method of code simulation of adequate initial and boundary conditions in partially uncovered Core model.

RELAP5/MOD3.2 code simulation requires definition of certain steady state with known boundary conditions at the time t0cal. Starting with this point and using certain transition procedures, it is possible to achieve such quasi-steady state, that one most adequate describes a state of circuit and Core model in the experiment at the initial moment t0exp.

It should be taken into account that code simulation of auxiliary problems concerning of transient hydrodynamic processes in the circuit parts and in the whole circuit can lead to essential inaccuracies of calculated parameters both under steam-condensate circulation (reflux condenser mode) and, especially, under down flow of steam-water mixture. This fact can take place in the case of modeling of experimental procedure of coolant drainage from lower pipeline through the valve 2 for partially uncovering of the FA model and establishment of needed mixture level. Experimental scenario of water drainage from the circuit through the valve 2 was very complicated for particular experiment. It is very difficult for code simulation. Evidently, seeming coincidence of simulation method for coolant drainage calculation procedures with experimental procedures does not provided simplicity of selection of necessary flow rate of drained water, drainage duration, initial pressure Pout (t0cal), initial coolant temperature TFin (t0cal) and also values of correctional coefficients Closs (t).

Skilled modeling user can propose several different methods and simplified procedures for code simulation of initial and boundary conditions of KS-1 Test 35-1. For example, first variant of such method may be as following. At the first step, for code simulation of the experiment, simple initial steady state may be defined. This state is characterized by full separation of certain amounts of saturated steam Mg and liquid M_L in the FA channel, in the Core model annular channel, in the

Lower Plenum model and DC model. It is realized under constant initial pressure Pout (t0cal >Pout (t0exp), zero FA heat release and zero heat losses {W (t0cal)=0, Closs (t0cal)=0} during certain time interval tcal=0-100 sec, for example. During calculation of this quasi-steady state, correction of probable inaccuracy of definition of collapsed level and stabilization of temperatures of coolant and temperatures of metal parts take place.

At the second step, transition to a quasi-steady state at the moment t1cal is carried out. This state has to be the closest one to experimental conditions at the moment t0exp.

Mentioned above transition may be done by following smooth and parallel in time procedures:

- Linear increase of heat release power in the FA model with certain rate dW/dt up to experimental value W (tcal) = W (t0exp). It is necessary for providing of required power and mixture level location;
- Increase of heat losses power by definition of certain law (may be linear) of increase of correctional coefficient Closs (tcal) up to required value Closs (tcal) to provide the best coincidence of calculated curve Pout (t)cal with experimental one Pout (t)exp.

For this method variant, curves of possible variations of regime parameters (FA model power W (tcal), correctional coefficient Closs (tcal), pressure Pout (tcal), coolant mass inventory $M=M_L+Mg$, full pressure difference on the core model DPt (tcal) and, accordingly, level location Lm (tcal), and also flow rate of generated steam Gg out (tcal) at the Core model outlet and flow rate of steam condensate G_L out (tcal) flowing down to the Core model are shown on Fig.4.2 - 4.5.

In this case, it is possible to adjust mixture level location by selection of liquid mass and value of initial pressure Pout (t0cal). Coordination of calculation time interval (t1cal – t2cal) for required variation of pressure from Pout (t1cal)=Pout (t0exp) to Pout (t2cal)=Pout (t1exp) with calculation time interval for required variation of mixture level from Lm (t1cal)=Lm (t0exp) up to Lm (t2cal)=Lm (t1exp) and with time of experiment realization Dtexp=(t1exp – t0exp) is possible by means of selection initial values for liquid mass inventory M_L (t0cal) , pressure Pout (t0cal) and for correctional coefficient Closs (tcal).

To simplify development of special method of code simulation of initial and boundary conditions for the experiment, preliminary analysis of interdependent thermal and hydraulic processes in KS –1 Test 35-1 was made. This analysis was carried out with RELAP5/MOD3.2 code in frame of the first method of simulation of initial and boundary conditions.

Experimental initial values at the moment t0exp and behavior of determinative parameters for quasi-steady state, having to be adequate provided during code simulation, are listed in Section 3.4.

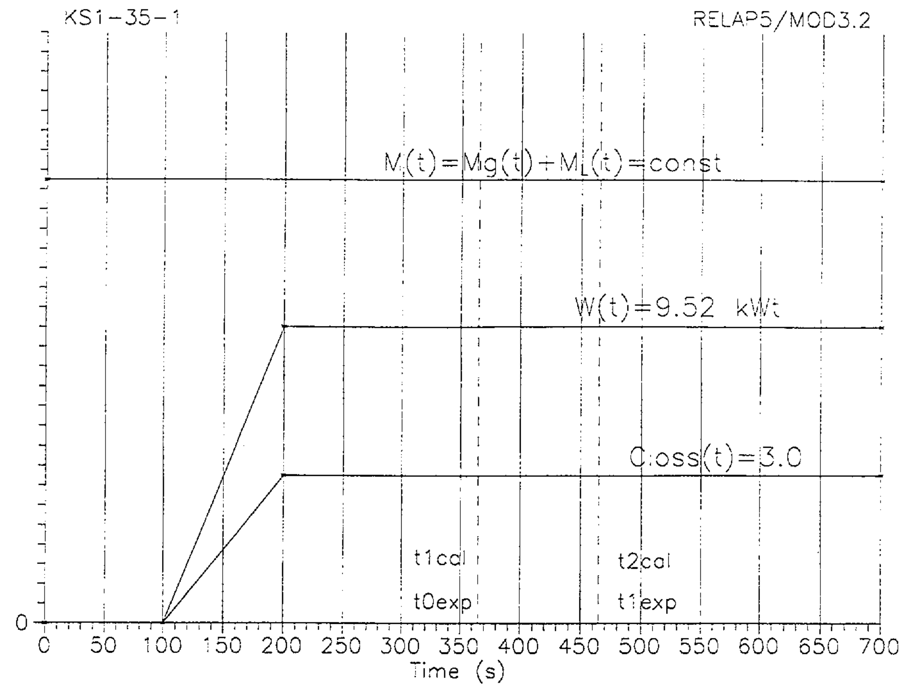


Fig. 4.2. Variation of FA Model power W(t), correctional coefficient of heat losses Closs(t) and coolant mass inventory $M=M_L+Mg$ in the closed loop during calculation procedures for modeling of KS-1 Test (tcal=0-600 s).

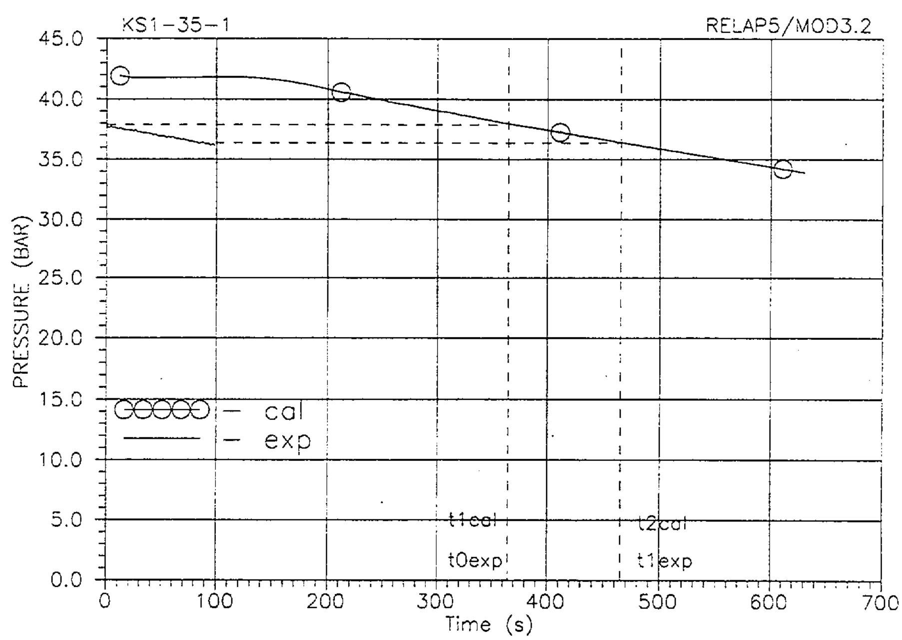


Fig. 4.3. Comparison of RELAP5/MOD3.2-calculated Pout(t)cal (tcal=0-700 s) and experimental Pout(t)exp curves of pressure decrease, and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp for KS-1 Test.

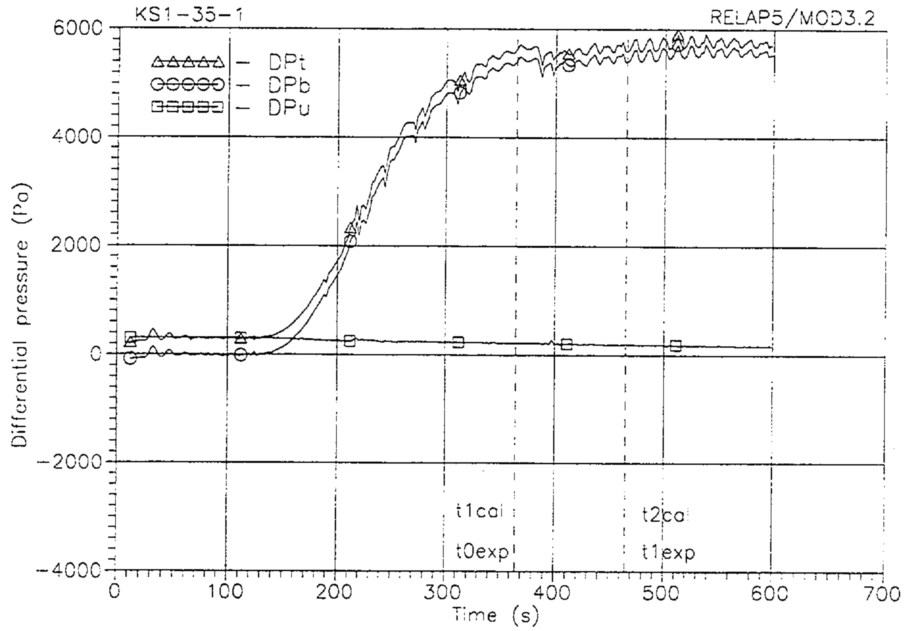


Fig. 4.4. RELAP5/MOD3.2-calculated Dpt(t) Core Model total differential pressure, DPu(t), core upper half part differential pressure and DPb (t) core bottom half part differential pressure histories, and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp for KS-1 Test (tcal=0-600 s).

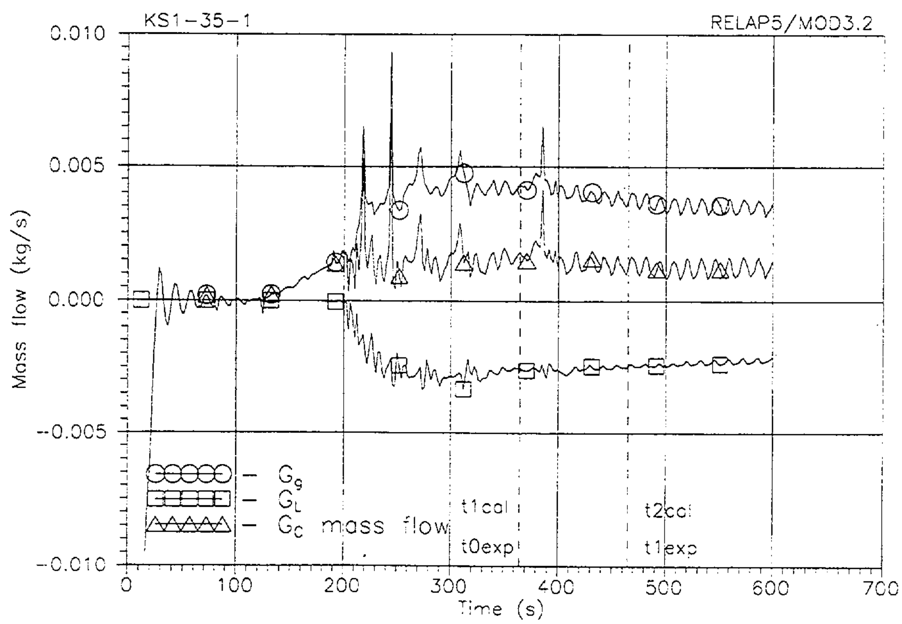


Fig. 4.5. RELAP5/MOD3.2- calculated Ggl(t) mass flow rate of generated steam and $G_L1(t)$ steam condensate mass flow rate histories under CCF conditions at Core Model outlet (tcal=0-600 s), and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp for KS-1 Test.

Description of base steady state at the moment t0cal, initial and boundary conditions at this moment and also possible code procedures and features of transient to quasi-steady state for first method is presented below.

During code simulation of KS-1 Test 35-1 with RELAP5/MOD3.2 we defined simple initial and boundary conditions of the base steady state at the moment t0cal. Starting from this state and using procedures of the first transition method, it is possible to transit to required quasi-steady state at the moment t1cal, which is adequate to experimental state at the moment t0exp.

Taking into account our preliminary analysis of this experiment, following initial and boundary conditions for base steady state at the calculation moment t0cal may be set up with W (t0cal)=0 and Closs (t0cal)=0:

- initial pressure Pout(t0cal)= 42 bar, which is greater than Pout (t0exp)=37.7 bar;
- model of Downcomer, model of Lower Plenum and also lower pipeline are filled with water with temperature TFin(t0cal)=TFin(t0exp); water level in the core channel and the DC model are special selected for subsequent coincidence of calculated level Lm(t1cal) with experimental one Lm(t0exp);
- remaining part of circuit, namely, UP model, HL model, SG simulator, CL simulator, upper part of DC model and also steam release pipeline, are filled with saturated steam with initial pressure Pout(t0cal)>Pout(t0exp);
- temperatures of steel shroud, talkochlorite insulator in the Core model, rod simulators, pressure vessel tube, tubes of the UP and MCC model, tube and talkochlorite bushes of upper part of the DC model (above water level) are equal saturation temperature for Pout(t0cal).

During calculation from t0cal=100 s (without heat power in FA and without heat losses under W (t0cal)=0 and Closs (t0cal)=0) , correction of inaccuracies and stabilization occur for collapsed levels in FA channel, in annular channel and DC model under constant total mass inventory of liquid and vapor in the circuit $M=Mg+M_L$.

After calculation of quasi-steady state during tcal = 0-100 s, it is possible to transit from quasi-steady state at the moment tcal=100 s to required quasi-steady state at the moment t1cal=365 sec, which closely corresponds to experimental quasi-steady state at the moment t0exp. Following smooth and parallel in time procedures may do this transition:

- Linear increase of heat release power from zero to W=9.52 kW at the moment tcal=200 sec; then power is maintained constant to provide necessary heat release for modeling of smooth development of boiling process and steam generation process in the Core model and for setting of required mixture level and steam generation rate;

- Smooth increase of heat losses power from particular parts of the circuit by determination of linear raise of correctional coefficient Closs (t) from zero at the moment tcal=100 sec to Closs (t)= 3.0 at the moment tcal=200 sec; then this value is held constant. It provides the best coincidence of calculated Pout (tcal) and experimental Pout (texp) curves, development of steam-condensate circulation and establishment of specified flow rates of steam condensate in the FA model from the bottom and the top.

Code simulation of calculation procedures for setting up initial and boundary conditions in the base steady state, and further transition to the quasi-steady state of KS-1Test 35-1 were realized during tcal=0 - 600 s.

Calculation results of code simulation of KS-1 Test 35-1 initial and boundary conditions are presented on Fig.4.2. - 4.7. These figures show heat release power W (tcal), correctional coefficient Closs (tcal), pressure Pout (tcal), total pressure difference DPt (tcal) in the Core model, flow rate of generated steam Gg out (tcal) at the core outlet, flow rate of steam condensate G_L out (tcal) flowing down to the core channel. These parameters are shown under realization of calculation procedures of transition from base steady state at the moment t0cal to quasi-steady state at the moment t1cal, which corresponds to experimental conditions at the moment t0exp for "quasi-steady regime". As may see, behaviors of determinative and determinate parameters during time interval t1cal – t2cal closely correspond to their variations in the experiment during time interval t=(t0exp+Dtexp), where Dtexp=100 s is time of experiment realization.

Location of mixture level Lm (t1cal) = Lm (t0exp) in the core channel and its behavior Lm (tcal) are determined by analysis of calculation results and experimental data about temperatures TWi-k (t) of inner walls of rod simulators and their height distributions and temperature change rates dTW/dt. RELAP5/MOD3.2-calculated TW (t) heated tube inside wall temperatures histories in the upper, middle and bottom parts of the FA model (tcal=0-600 s), and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp for KS-1Test 35-1 are shown in Fig. 4.6. There is slow increase of mixture level in core channel and decrease of rod simulators temperature TW (t) in covered bottom part of the FA model at the levels equal 0.0 - 0.562 m (see curves TW (tcal) for heat structures 0071001 - 0071005 in Fig. 4.6).

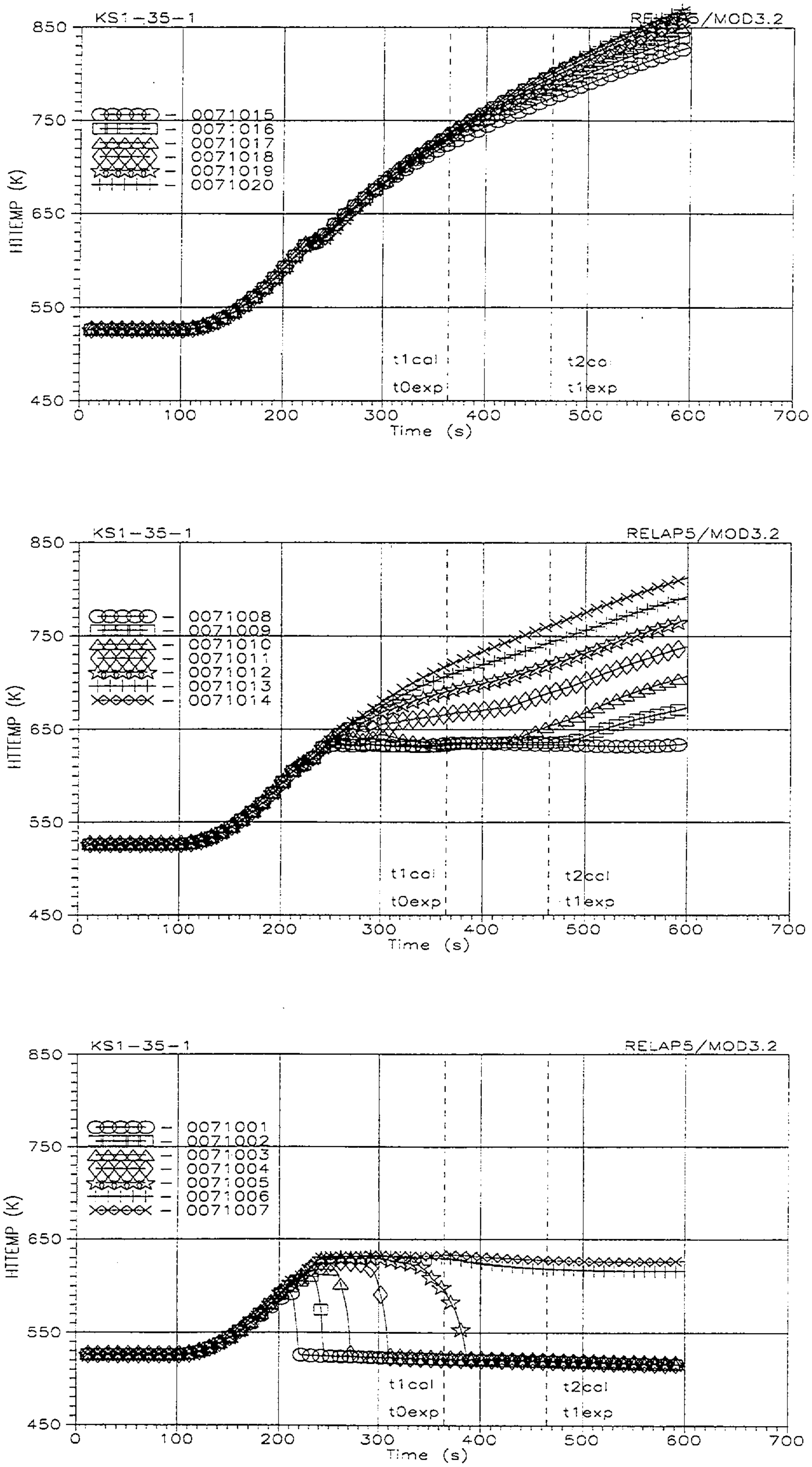
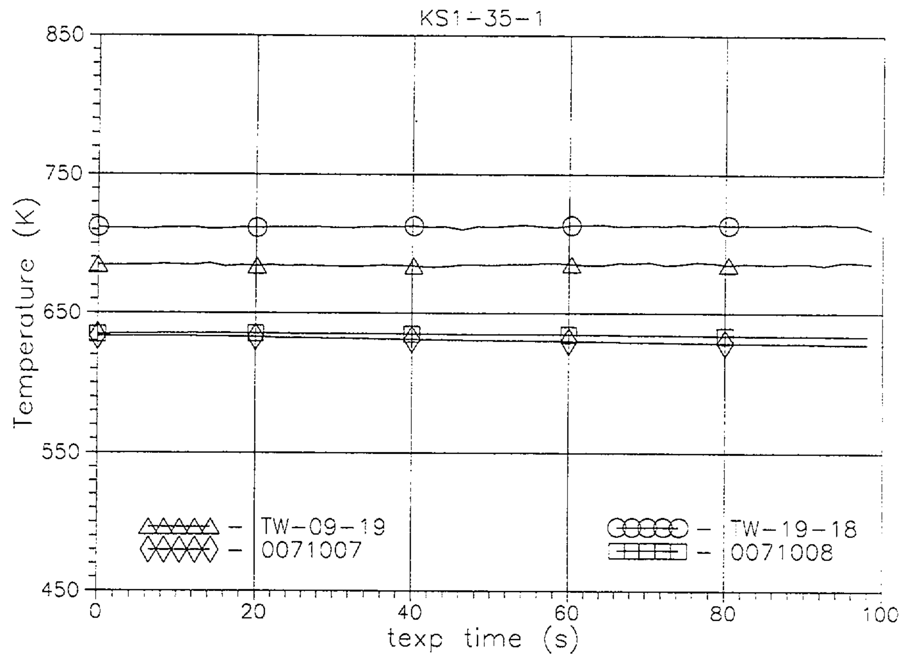


Fig. 4.6. RELAP5/MOD3.2-calculated TW(t) heated tube inside wall temperatures histories in the upper, middle and bottom parts of the FA Model (tcal=0-600 s), and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp for KS-1 Test.



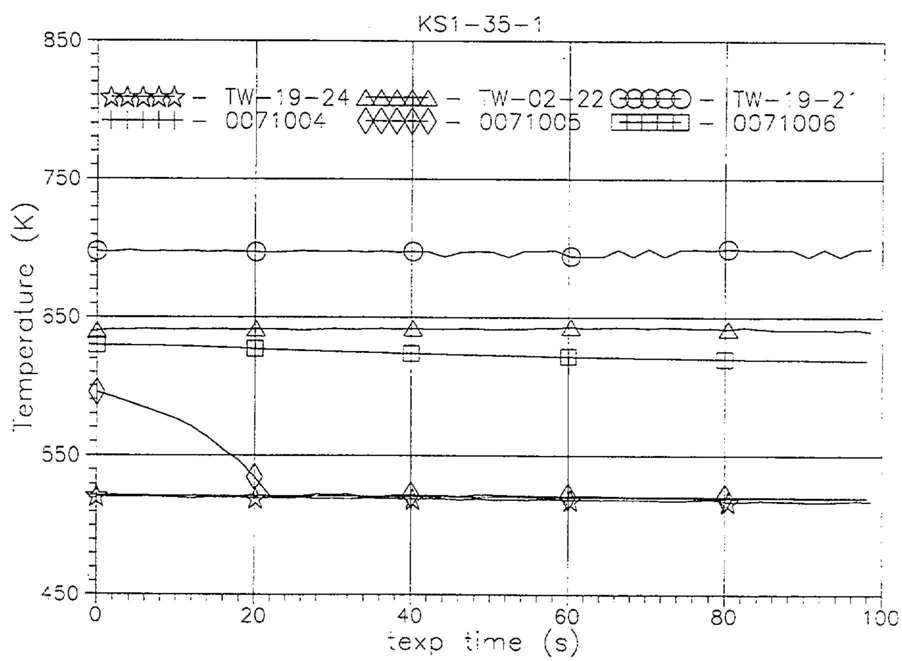


Fig. 4.7. Comparison of measured and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the bottom part of FA Model and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp for KS-1 Test.

Wall temperatures of rod simulators in FA cross sections, located above mixture level, were practically constant during experimental time 0-100 s (see curve TW (tcal) for heat structure 0071006 in Fig. 4.6, 4.7). Comparison of measured and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the bottom part of FA model, and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp for the test, are shown in Fig. 4.7.

In this case, we used possibility to adjust mixture level location by variation of liquid mass inventory and value of initial pressure Pout (t0cal).

Adjustment of calculation time interval (t1cal - t2cal) for required variation of pressure from Pout (t1cal)=Pout (t0exp) to Pout (t2cal)=Pout (t1exp) with calculation time interval for required variation of mixture level from Lm (t1cal)=Lm (t0exp) up to Lm (t2cal)=Lm (t1exp) and with time of experiment realization from t0exp till t1exp was done by means of selection of initial values for liquid mass inventory M_L (t0cal), pressure Pout (t0cal) and correctional coefficient Closs (tcal).

All mentioned above parameters determine subsequent behavior of determined parameters in the experiment.

5. RESULTS

5.1. Nodalization, including variations from base case

Before choosing a final model, the effect of different nodalization to the results of RELAP5/MOD3.2 calculations was investigated for KS-1Test 35-1. Of interest was the influence of the number of hydraulic volumes chosen. The different nodalizations were studied using 10 and 20 volumes for the core channel (hydrodynamic component 7) with heated bundle of FA model and for the Core model annular channel ("annulus" hydrodynamic component 5) by fixing the number of fine mesh nodes in the heat conduction elements. Here the core nodding pitch was chosen equal one or half spacer grid pitch (250 or 125 mm). As quality of the code modeling for rod temperature behavior in partially uncovered FA depends on accurate simulation of mixture level in the core channel, it is necessary to provide close coincidence of Lm (tcal) calculated and Lm (texp) experimental values of mixture level. Also it is important when complex processes of heat transfer on rod surfaces under CCF conditions and interphase heat transfer are simulated.

Higher number of volumes results in more accurate code simulation of mixture level in the core channel. And, also, higher number of volumes results in smaller error (± 62.5 mm), when real mixture level Lm (t1cal) = Lm (t0exp) and its behavior Lm (tcal) are determined by special analysis of calculation results for TW (tcal) and experimental data about rod simulator temperatures Twi-k (t). Measurements of the $TW_{i-k}(t)$ temperatures along the height of FA model with thermocouples on 20 elevations have provided temperature axial distribution in the FA model and test data about mixture level in the FA channel with accuracy of ± 50 mm.

All the calculations to be presented latter in this report were performed by selecting the nodalization with 20 volumes for the core channel with heated bundle as the base case (Fig. 4.1).

5.2. Base Case Results of calculations, Comparison to KS-1 Test 35-1 and Conclusions

Using nodalization scheme mentioned above, base case calculations were performed for KS-1 Test 35-1 using maximum user-specified time step dt max = 0.01 s, which was suggested in [5], concerning the use of the code reflood model. Code simulation of the procedures was realized during the time interval tcal= 0 - 365 s for modeling initial and boundary conditions in the quasi-steady state at the moment t1cal=365 s. Then further simulation of transient for "test quasi-steady regime" was realized during the time interval tcal= 365 – 465 s. Further calculation ran till 600 s.

Calculated histories of determinative and determinate parameters under calculation procedures are shown in Figures to examine hydrodynamic interactions between adjacent components and conditions for heat transfer in The Core model with FA during "quasi-steady regime" in the test. Additional code results are shown in Figures B-1÷B-17 in Appendix B. The results give also the indications for activation the code models for modeling counter current flow limitation and interphase heat transfer.

These Figures show behavior of determinative parameters under calculation procedures for transient from base steady state at the moment t0cal to quasi-steady state at the moment t1cal=365 s, which corresponds to experimental initial and boundary conditions at the test moment t0exp=0 s.

As may see, behaviors of determinative parameters during time interval from t1cal=365 s till t2cal=465 s closely correspond to their variations in the experiment during time interval from t0exp=0 s till t1exp=100 s. It is a base for conclusion about adequacy of the code simulation of initial and boundary conditions for hydrodynamics, realized in the experiment, and then about adequacy of simulation of "quasi-steady regime" of whole experiment.

Comparison of RELAP5/MOD3.2-calculated Pout (tcal) and experimental Pout (texp) curves of pressure decrease, and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp are shown in Fig. B -1. Comparison of measured and calculated pressure during time interval, corresponding texp=0-100 s, illustrates good coincidence of the curves under test conditions with Closs (tcal) =3.0 (see Fig. B-2). It provides also setting up certain flow rate G_L out (tcal)≅ 0.0022 kg/s of steam condensate down flowing to the core channel (see Fig. 4.5) when mass flow rate of generated steam at FA outlet Gg out (tcal)≅ 0.004 kg/s.

Comparison of measured and calculated TFin (tcal) coolant temperature at Core model inlet is shown in Fig. B-3. The results are in a good agreement with test data. It provides needed mass flow rate of generated steam under test conditions with known pressure and mixture level in the FA channel. Initial mixture level Lm (t1cal) = Lm (t0exp) in the FA channel and its behavior Lm (tcal) are determined by analysis of calculation results and experimental data about temperatures TWi-k (t) of inner walls of rod simulators and their height distributions and temperature change rates dTW/dt. Calculated TW (tcal) wall temperatures histories in the upper, middle and bottom parts of the FA model, and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp for KS-1Test 35-1 are shown in Fig. B- 4. There is slow increase of mixture level in core channel and decrease of rod simulators temperature TW(tcal) in covered bottom part of the FA model at the level equal 0.562 m (see curves TW (tcal) for heat structures 0071001 - 0071005 in Fig. B-4). This calculation value for mixture level is nearly equal initial value of real mixture level 0.57 m in the test.

Real mixture level is that level in the core channel, at which sharp increase of void fraction (see Fig. B-5) and local dry out of rod simulators, sharp decrease of heat transfer coefficient Hw1 (tcal) and of specific heat flux qw1 (tcal) from outer surfaces of rods to coolant (see Figures B-6 and B-7, accordingly), local increase of temperatures TW (tcal) of rod simulators above saturation temperature take place (see Fig. B-4).

Calculated Vg (tcal) vapor and V_L (tcal) liquid velocities histories in the upper, middle and bottom parts of FA channel are shown in Figures B-8, B-9, accordingly. During "quasi-steady regime" stable Vg (tcal) vapor velocities at different elevations in the core channel increase along the uncovered part of FA and ones maximum value is equal ≅ 0.22 m/s in the upper part of the FA (see Fig. B-8). Reinolds number $Re_g = Vg \cdot Dh / \nu_g$ is equal ~ 900–1100.

During "quasi-steady regime" V_L (tcal) liquid velocities at different elevations in the FA channel increase along the height of FA uncovered middle part and decrease along the FA uncovered upper part. Maximum V_L (tcal) value equals ≈ - 1.7 m/s in the upper and middle parts of the FA model. Therefor, maximum value of drift velocity for CCF in the FA channel is equal (0.22 m/s +1.7m/s) ≅1.92 m/s.

Behavior of calculated TW (tcal) wall temperature histories in the upper, middle and bottom parts of the FA model are presented in Fig. 4. There is TW (tcal) temperature increasing in the upper part of FA model with rate dTW/dt $\approx$ 0.85 K/s, which is larger then measured one at the level of 2.48 m with rate dTW/dt $\cong$ 0.14 K/s (see curve TW06-00 (texp) in Fig. A-7, B-15).

Calculated Ti (tcal) insulator inside wall temperatures increase to 572 K at the moment tcal= 365 s with rate dTW/ dt =0.19 K/s in the upper part of the FA model (see Fig. B-10), which is smaller than ones for rod simulator due to relatively large heat capacity of are considered massive parts of the Core model.

Behavior of RELAP5/MOD3.2-calculated Hw1 (tcal) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper part of FA model is nearly steady during time interval tcal=365 - 465 s with very slow decrease due to Pout (tcal) decrease (see Fig. B-6). Maximum Hw1 (tcal) value equals $\approx$ 80 $W/m^2 \cdot K$ in the middle part of the FA model, when Hw1 (tcal) is equal $\approx$ 50–60 $W/m^2 \cdot K$ in the upper part of the FA model.

Unsteady behavior of Hw2 (tcal) coefficient of heat transfer from coolant to the insulator, Hw3 (tcal) coefficient of heat transfers from outer surface of steel shroud to coolant in annular channel and Hw4 (tcal) in the upper and middle parts of the Core model are shown in Figures B-11, B-12 and B-13, accordingly.

Comparisons of measured and calculated rod simulator temperatures are shown in Figures B-14 $\div$ B-23. As seen in Fig. B-15, in "quasi-steady regime" calculated TW (tcal) wall temperature is much higher (up to 130 K) than measured ones at the FA outlet. This is one of the main problems of the code for our case. The reason for these deviations between experiment and calculations are too low Hw1$\approx$ 50–60 $W/m^2 \cdot K$ (tcal) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper part of FA model calculated by the code for CCF conditions in FA channel. Therefor, the temperature increase rate dTW/dt in calculations is much more, than measured ones. In this case under prediction for interphase heat transfer may be other reason for these deviations between experiment and calculations, also.

As seen in Figures B-20 and B-21, in "quasi-steady regime" calculated wall temperature TW (tcal) is much lower (100 K below) than measured ones in the middle part of FA model. This is one of the main problems of the code for base case calculations with maximum time step dt max=0.01 s.

The reason for these deviations between experiment and calculations are too large Hw1$\approx$ 80 $W/m^2 \cdot K$ (tcal) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the middle part of FA model calculated by the code for CCF conditions in FA channel. Sensitivity studies are needed to determine the main reasons for these deviations between test data and calculations.

As seen in Fig. B-18, only for temperatures TW03-08 (texp) and TW04-09 (texp), which were realized at the elevation ~ 1.78 m, code gives a good agreement with data in the upper part of FA model. However, code does not give the same temperature increase rate dTW/dt, as measured ones.

Comparisons of base case (time step dt max=0.01 s) calculated core axial temperature profiles in the heated bundle at the moment tcal= 365 s and experimental core axial distribution of rod simulator temperatures TWi-k at the moment t0exp=0 s are shown in Fig. 5.1. As seen, there is a significant quantitative and qualitative difference of calculated and measured core axial temperature profiles in the heated FA model. RELAP5/MOD3.2 under predicts TW (tcal) temperatures in the middle part of FA model and over predicts ones at the FA outlet.

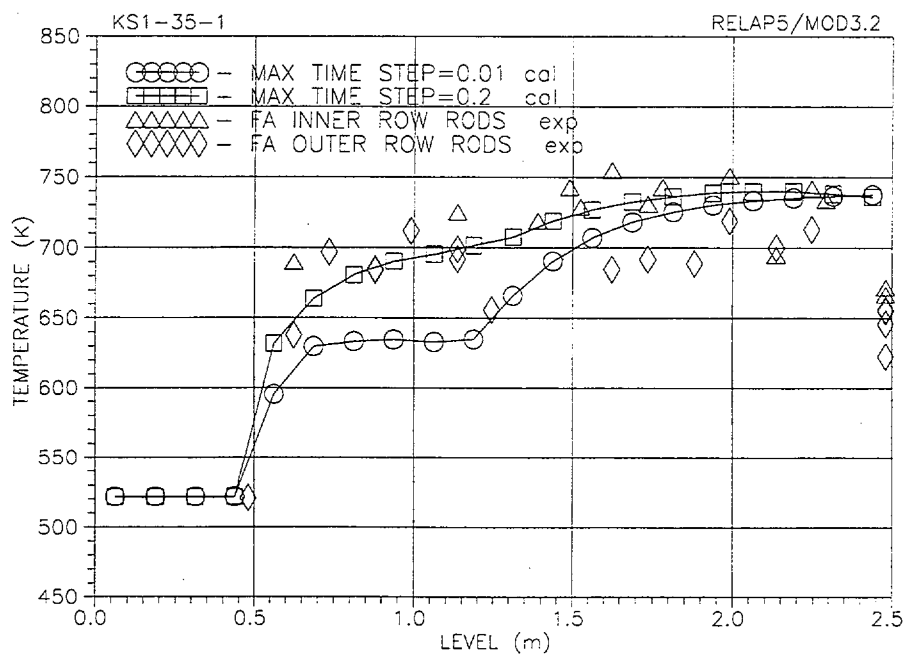


Fig. 5.1. Comparison of RELAP5/MOD3.2-calculated core axial inside wall temperatures profile in the bundle heated tube for time moment tcal= 365 s, corresponding t0exp for KS-1 Test, and experimental core axial distribution of temperatures of rod simulators TWi-k of the FA Model for time moment t0exp.

Conclusions

• Base case method of code simulation experimental conditions for the KS-1 Test 35-1 provides adequacy of the code simulation of initial and boundary conditions only for hydrodynamics, realized in the experiment.

• RELAP5/MOD3.2 gives a satisfactory agreement of calculation results and Test 35-1 data for overall picture of the two-phase flow behavior in KS-1VVER Loop model and heat transfer in partially uncovered Core model during reflux condenser mode with some exceptions.

• Behavior of calculated Hw1 (tcal) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper part of FA model is nearly steady during considered time interval. Maximum Hw1 (tcal) value equals ≈ 80 $W/m^2 \cdot K$ in the middle part of the FA model, when Hw1 (tcal) is equal ≈ 50–60 $W/m^2 \cdot K$ in the upper part of the FA model.

• Behavior of calculated Hw2 (tcal) coefficient of heat transfer from coolant to the insulator, Hw3 (tcal) coefficient of heat transfers from outer surface of steel shroud to coolant in annular channel and Hw4 (tcal) is unsteady in the upper and middle parts of the Core model.

• In considered "quasi steady regime" calculated TW (tcal) wall temperature is much higher (up to 130 K) than measured ones at the FA outlet. This is one of the main problems of the code for base case calculations. The reason for these deviations between experiment and calculations is too low Hw1 (tcal) ≈ 50–60 $W/m^2 \cdot K$ (tcal) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper part of FA model calculated for CCF conditions. Therefor, the temperature increase rate dTW/dt in calculations is much more, than measured ones. In this case under prediction for interphase heat transfer may be the other reason for these deviations between experiment and calculations.

• In considered "quasi steady regime" calculated wall temperature TW (tcal) is much lower (100 K below) than measured ones in the middle part of FA model. This is the next one of the main problems of the code base case calculations. The reason for these deviations between experiment and calculation is too large Hw1 (tcal) ≈ 80 $W/m^2 \cdot K$ coefficient of heat transfer from outer surfaces of rod simulators to coolant in the middle part of FA model calculated by the code for CCF conditions in FA channel.

• Only for temperatures TW03-08 (texp) and TW04-09 (texp), which were realized at the elevation ~1.78 m, code gives a good agreement with data in the upper part of FA model. However, code does not give the same temperature increase rate dTW / dt, as measured ones.

• There is a significant quantitative and qualitative difference of calculated and measured core axial temperature profiles in the heated FA model. RELAP5/MOD3.2 under predicts TW (tcal) temperatures in the middle part of FA model and over predicts ones at the FA outlet.

• Sensitivity studies are needed to determine the main reasons for these deviations between test data and calculations.

5.3. Sensitivity Studies, including input deck modifications

This assessment work has shown, that the frozen version of the RELAP5/MOD3.2 and base case method of code simulation experimental conditions for KS-1 Test 35-1 provides adequate simulation of initial and boundary conditions only for hydrodynamics, realized in the test under reflux condenser mode.

There is a significant quantitative and qualitative difference of calculated and measured core axial temperature profiles in the heated FA model at the initial moment t0exp. The code under predicts TW (tcal) temperatures in the middle part of FA model near mixture level and over predicts ones at the FA outlet. This is one of the main problems of the code base case calculations with maximum time step dt max=0.01s.

The reasons for these deviations between experiment and calculations may be over estimation for Hw1 coefficient of heat transfer from rod simulators to coolant in the middle part of FA and its under estimation in the upper part of FA model under CCF conditions. Sensitivity studies are needed to determine the main reasons for these deviations between test data and calculations.

The main goal of Sensitivity studies is an attempt to reduce large differences between RELAP5/MOD3.2 predictions and measurements for core axial temperature profiles in the heated FA model at the initial moment t0exp in considered “quasi-steady regime” during the test simulation.

For comparison the effect of maximum time step dt max = 0.2 s on calculated TW (tcal) wall temperatures histories in the upper, middle and bottom parts of the heated bundle is shown in Fig. 5. 2. The effect of dt max = 0.01 s on calculated TW (tcal) is shown in Fig. B-4.

Selection of time interval, corresponding texp= 0 - 100 s, and selection of time moment t1cal, corresponding t0exp, are shown too in Fig. 5.2 and Fig. B-4, accordingly. The effect of maximum time step dt max = 0.2 s on the calculated axial temperature profiles in the heated bundle at the moment tcal= 365 s is shown in Fig. 5.1. One can see, in the case with maximum time step dt max = 0.2 s calculated axial temperature profiles in the heated bundle in the middle part of FA nearly coincides with measured one, and in the upper FA part this profile dose not coincide with measured one. In the FA upper part both calculations give the same results, when the code over estimates rod simulator temperatures significantly (up to 130 K). Thus, using time step 0.2 s results in improvement code simulation axial temperature profiles in the heated bundle only for middle part of FA model.

To simulate real axial temperature profile in the heated bundle at the moment t1cal =365 s, RESTART input deck of KS-1 Test 35-1 was used with setting up an experimental profile for FA model heat structures. Axial temperature profile was measured at the moment t0exp= 0 s in the rod simulators, located in the inner row in the bundle. In these rods the highest temperatures were obtained during the test. In restart calculation maximum time step was used equal dt max=0.01 s.

The effect of RESTART calculation, with maximum time step dt max = 0.01 s being used up to the RESTART point in previous simulation, on calculated TW (tcal) wall temperatures histories in the upper, middle and bottom parts of the heated bundle is shown in Fig. C-1.

The effect of RESTART calculation, with maximum time step dt max = 0.2 s being used up to the RESTART point in previous simulation, on calculated TW (tcal) wall temperatures histories in the upper, middle and bottom parts of the heated bundle is shown in Fig. C-2.

Comparison of behavior measured and calculated rod simulator temperatures with RESTART calculation, with maximum time step dt max = 0.01 s in previous simulation, are shown in Figures C-3 ÷ C-12 in Appendix C.

Analysis of code results shows, that implementation experimental temperature profile in restart input deck allow to reduce large differences between code predictions and measurements for core axial temperature profiles in the heated FA model at the initial moment t0exp and then in considered "quasi-steady regime" during the test simulation. However, because of restart calculated Hw1 (tcal) coefficient of heat transfer in the upper part of FA model practically does not increase on comparison previous simulation results, rod temperatures stay increase with high rate. As consequence, a significant quantitative and qualitative difference of calculated and measured core axial temperature profiles in the heated FA model was achieved again with in the test time interval Dtexp.

This fact shows that initial temperature conditions weakly influence on code simulation of heat transfer and interphase heat exchange in partially uncovered core under CCF conditions.

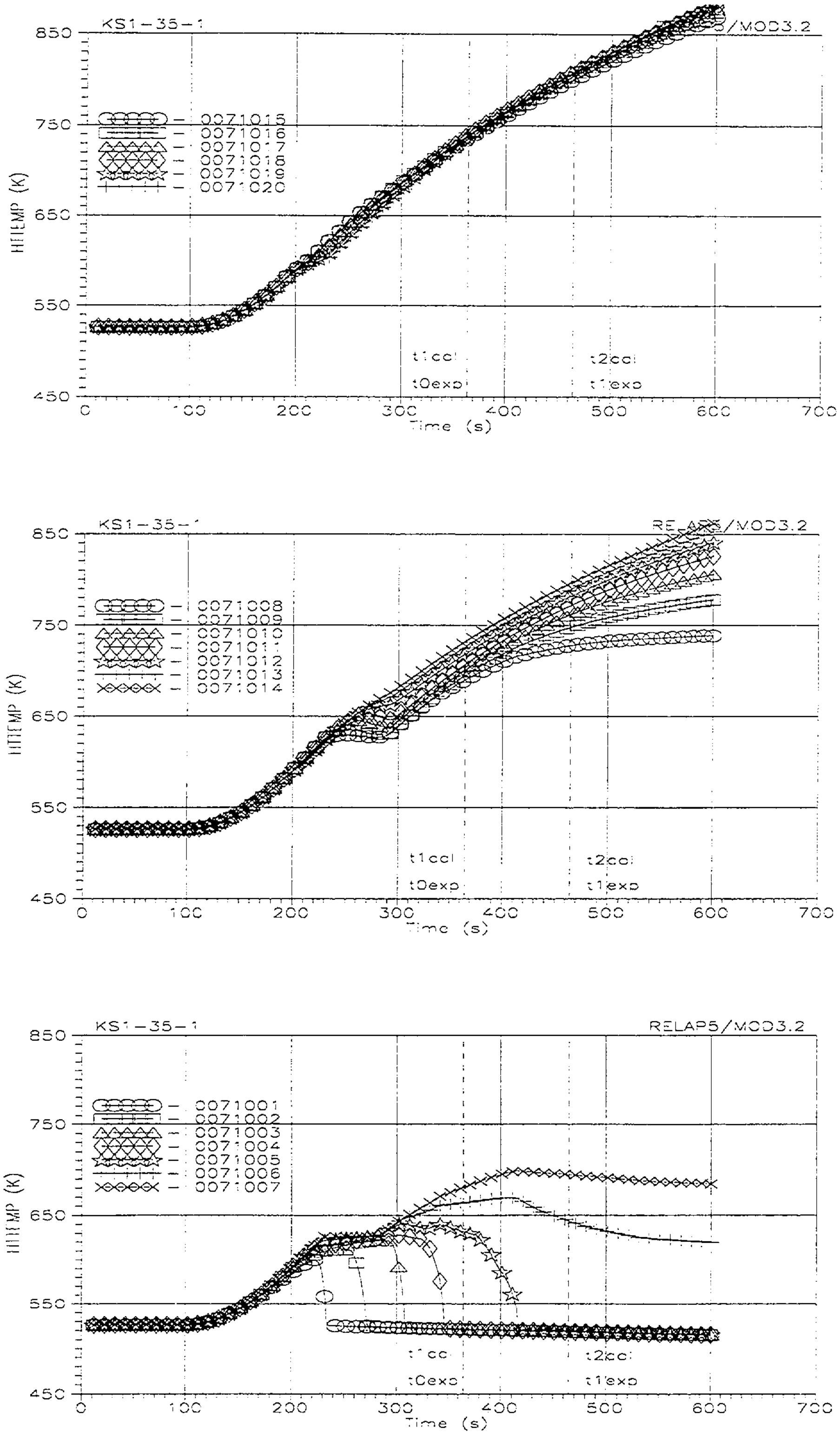


Fig. 5.2. The effect of maximum user-specified time step on the calculated inside wall temperatures histories in the upper, middle and bottom parts of the bundle heated tube (tcal=0-600 s), and also selection of time interval, corresponding Dtexp, and selection of time moment t1cal, corresponding t0exp for KS-1 Test. dtmax=0.2 s.

5.4. RUN STATISTIC

The input model for RELAP5/MOD3.2 calculation for KS-35-1 test encompassed:

198 - Volumes, 198 - Junction, 217 - Heat Structures, 982 - Mesh Points.

During the transient calculation the following resources were used:

Computer time CPU time = 7674.62 sec, Number of time steps DT = 60000,

Number of volumes C – 198.

Resulting in the following **grind time** (code efficiency factor):

$$\textbf{Grind Time} = \frac{\text{CPU} \cdot 10^3}{\text{C} \cdot \text{DT}} = \mathbf{0.0646}$$

The computer used was IBM PC AT with processor INTEL Pentium-166. Operation system Windows 95 was used. The CPU time of KS-35-1 test can be seen in Figure . In figure the time step chosen by the code and the Courrant time step are shown.

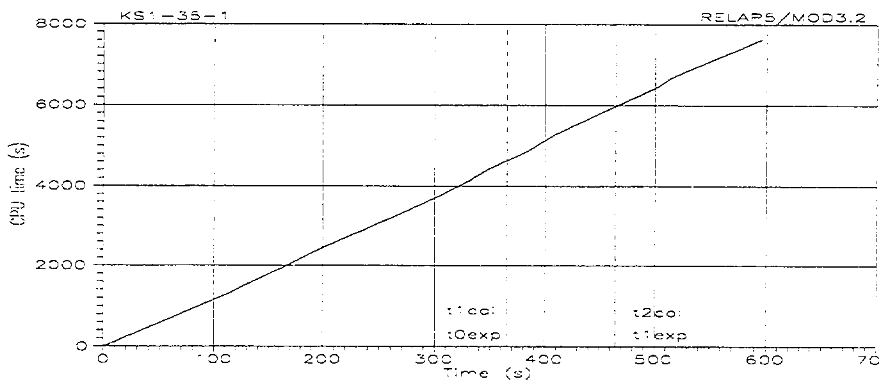


Fig. 5.3. The required CPU time in the base case calculation.

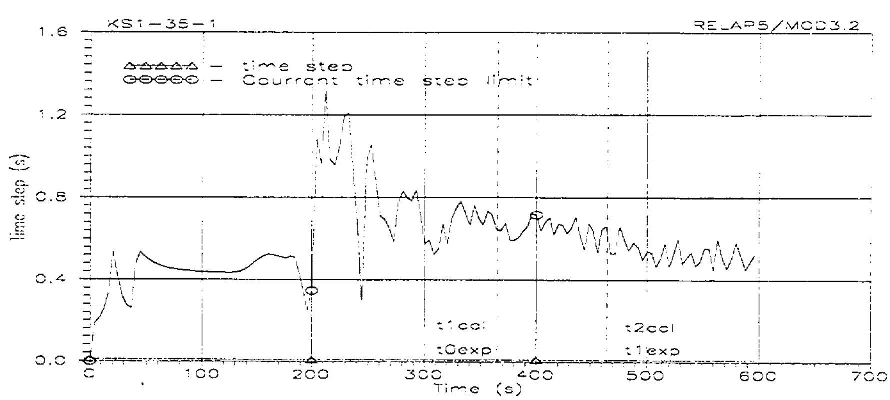


Fig. 5.4. Time step size of base case calculation.

6. SUMMARY OF CONCLUSIONS

In this work some deficiencies of RELAP5/MOD3.2 in analysis of KS-1 Test 35-1 could be identified, and the following conclusions can be drawn:

- Base case method of code simulation experimental conditions provides adequacy of the code simulation of initial and boundary conditions only for hydrodynamics, realized in the Test 35-1.
- RELAP5/MOD3.2 gives a satisfactory agreement of calculation results and test data for overall picture of the two-phase flow behavior in KS-1VVER Loop model and heat transfer in partially uncovered Core model during reflux condenser mode with some exceptions.
- There is a significant quantitative and qualitative difference of calculated and measured core axial temperature profiles in the heated FA model. RELAP5/MOD3.2 under predicts TW (tcal) temperatures in the middle part of FA model and over predicts ones at the FA outlet.
- Behavior of calculated Hw1 (tcal) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper part of FA model is nearly steady during considered time interval. Maximum Hw1 (tcal) value equals $\approx$ 80 $W/m^2 \cdot K$ in the middle part of the FA model, when Hw1 (tcal) is equal $\approx$ 50–60 $W/m^2 \cdot K$ in the upper part of the FA model.
- In considered "quasi steady regime" calculated TW (tcal) wall temperature is much higher (up to 130 K) than measured ones at the FA outlet. This is one of the main problems of the code base case calculations. The reason for these deviations between experiment and calculations is too low Hw1 (tcal) $\approx$ 50–60 $W/m^2 \cdot K$ (tcal) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper part of FA model calculated for CCF conditions. Therefor, calculated temperature increase rate dTW/dt is much more, than measured ones. In this case under prediction for interphase heat transfer may be the other reason for these deviations between experiment and calculations.
- In considered "quasi steady regime" calculated wall temperature TW (tcal) is much lower (100 K below) than measured ones in the middle part of FA model. This is the next one of the main problems of the code calculations. The reason for these deviations between experiment and calculation is too large Hw1 (tcal) $\approx$ 80 $W/m^2 \cdot K$ coefficient of heat transfer in the middle part of FA model calculated for CCF conditions.
- Sensitivity studies shows, that implementation experimental temperature profile in restart input deck allow to reduce large differences between code predictions and measurements for core axial temperature profiles in the heated FA model at the initial moment t0exp and then during the test

simulation. However, because of restart calculated Hw1 (tcal) coefficient of heat transfer in the upper part of FA model practically does not increase on comparison previous simulation results, rod temperatures stay increase with high rate. As consequence, a significant quantitative and qualitative difference of calculated and measured core axial temperature profiles in the heated FA model was achieved again with in the test time interval.

- Sensitivity studies show, initial temperature conditions in FA model weakly influence on code simulation of heat transfer and interphase heat exchange in partly uncovered core under CCF conditions.

REFERENCES

1. V.G.Sorokin, A.V.Volosnikova, S.A.Vyatkin. Types of steels and alloys. M. Mashinostroenie, 1989 (In Russian).

2. Electrotechnical hand book. M.-L., GEI, 1962 (In Russian).

3. L.L. Kobzar, V.A.Vinogradov, A.Y. Balykin. Investigation of temperature regimes for partly uncovered core at the KS test facility. RRC KI Report N32/1-1386-91, 1991, 117 p.

4. RELAP5/MOD3 Code Manual Volume 4: Models and Correlations. INEL-95/0174, NUREG/CR-5535. 1995.

5 RELAP5/MOD3 Code Manual Volume 2: User's Guide and Input Requirements INEL-95/0174, NUREG/CR-5535. 1995.

APPENDIX-A

ORIGINAL DATA PLOTS FROM KS-1 TEST 35-1

Original Data Plots from KS-1Test 35-1

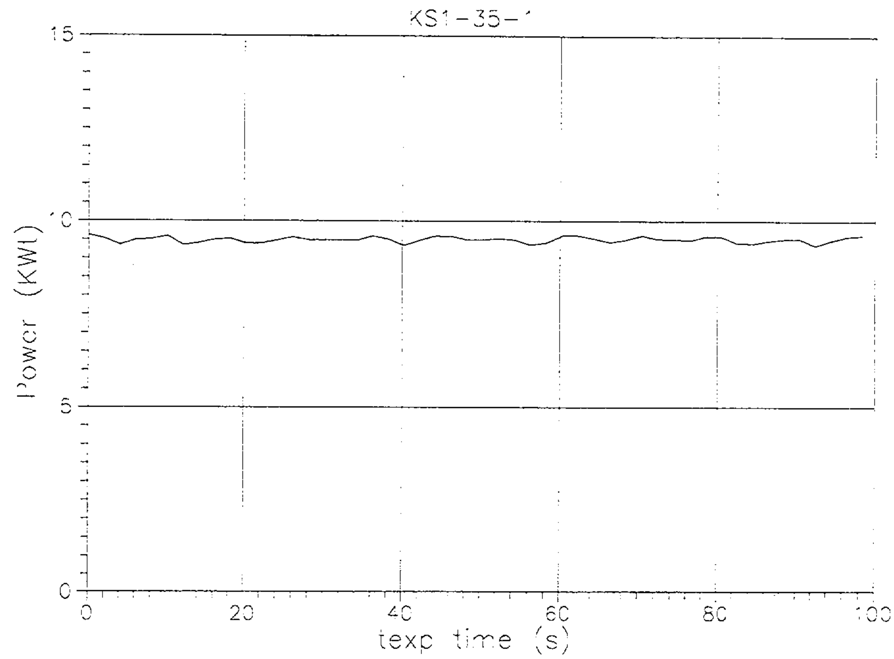


Fig. A-1. FA model heat release power history W(t) (texp=0-100 s).

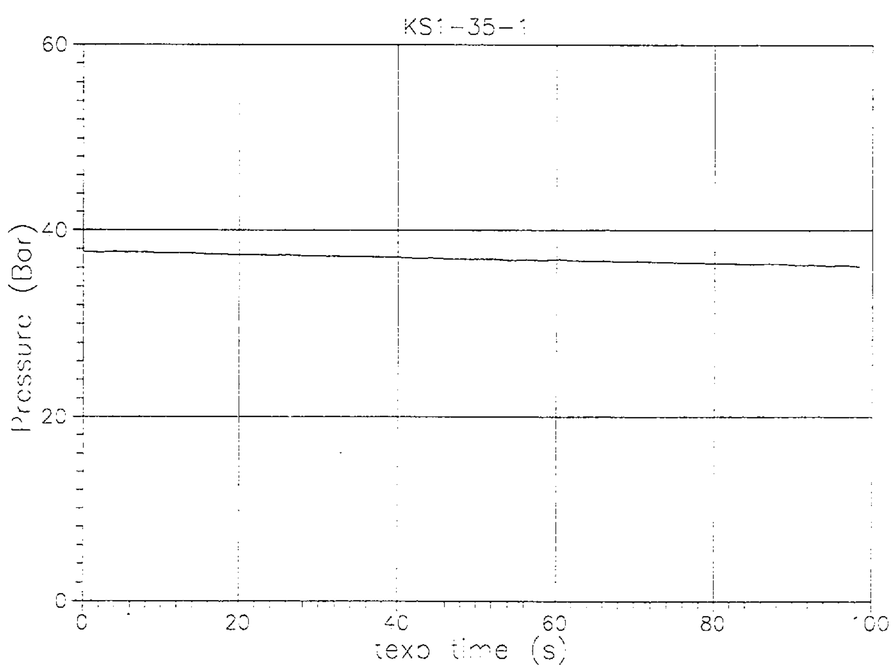


Fig. A-2. Measured Pout(t) Core model outlet pressure history (texp=0-100 s).

Original Data Plots from KS-1Test 35-1

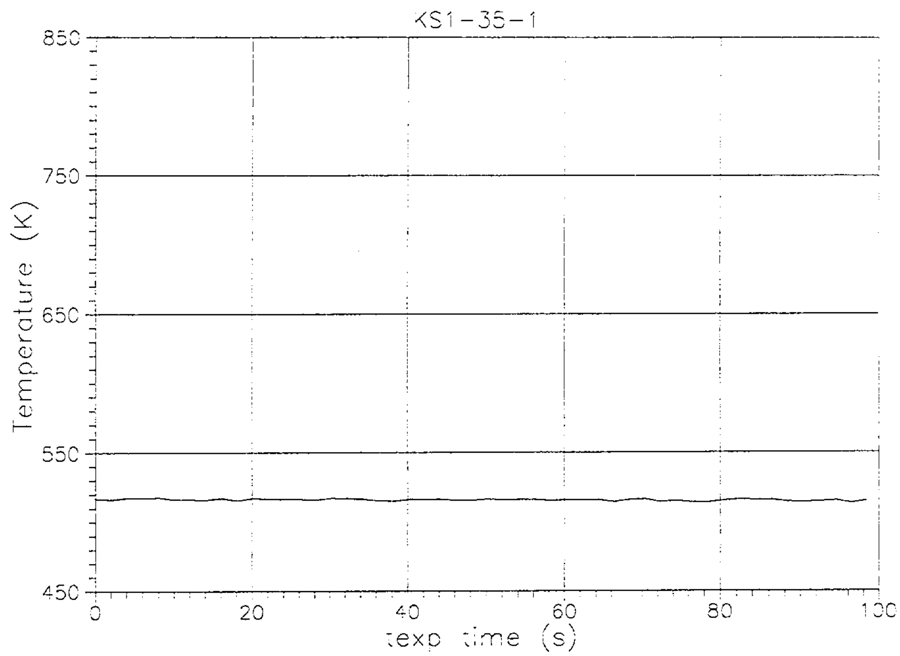


Fig. A-3. Measured TFin(t) Core model inlet coolant temperature history (texp=0-100 s).

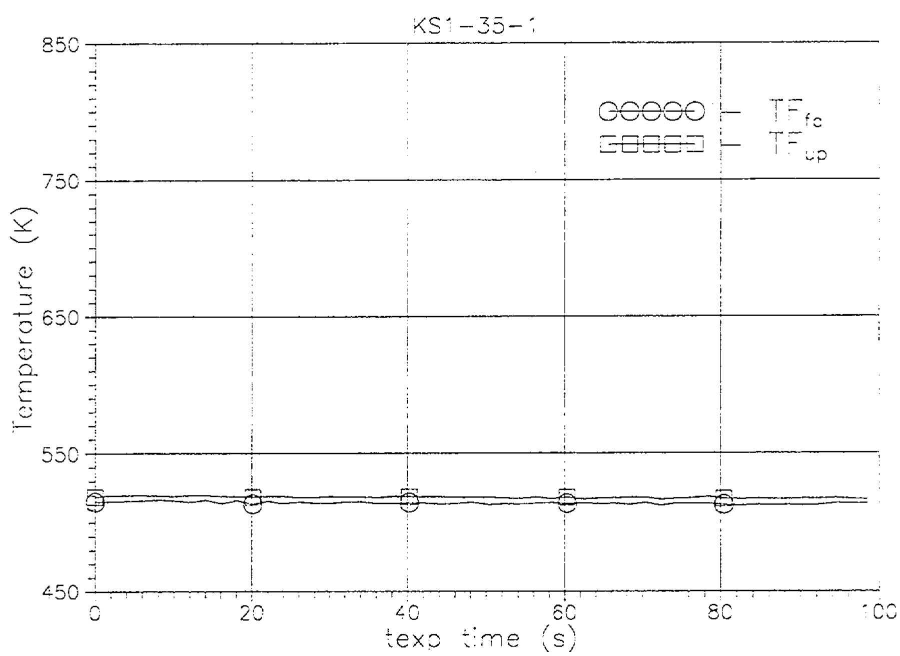


Fig. A-4. Measured TFfa(t) FA model outlet and TFup(t) UP model inlet coolant temperatures histories (texp=0-100 s).

Original Data Plots from KS-1Test 35-1

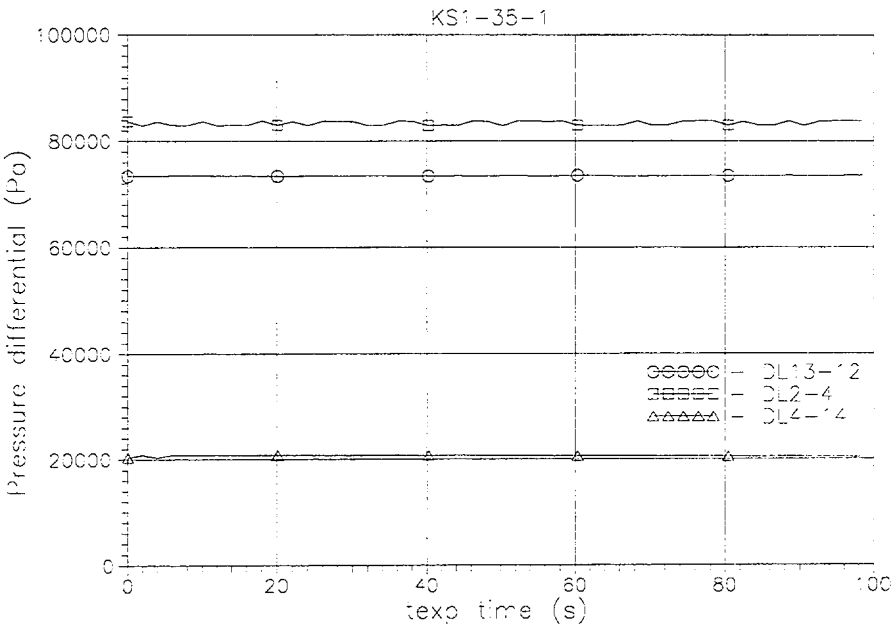


Fig. A-5. Measured DL13-12(t) UP model, DL2-4(t) and DL4-14(t) DC model differential pressure histories (texp=0-100 s).

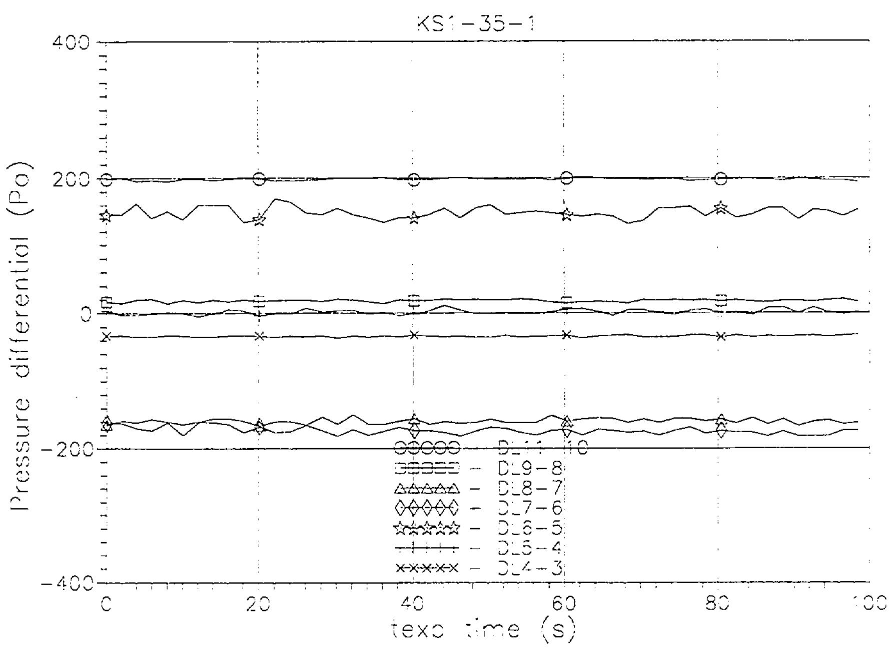


Fig. A-6. Measured DP4-3(t), DP5-4(t), DP6-5(t), DP7-6(t), DP8-7(t), DP9-8(t) and DP11-10(t) Core model differential pressure histories (texp=0-100 s).

Original Data Plots from KS-1Test 35-1

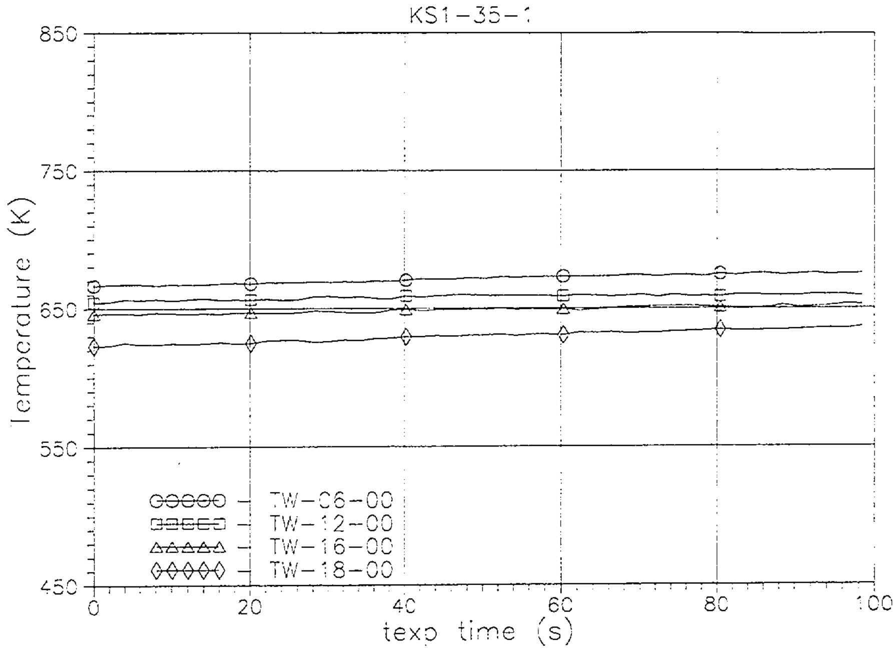


Fig. A-7. Measured TW06-00(t), TW12-00(t), TW16-00(t) and TW18-00(t) heated tube inside wall temperatures histories at the top of the FA model (texp=0-100 s).

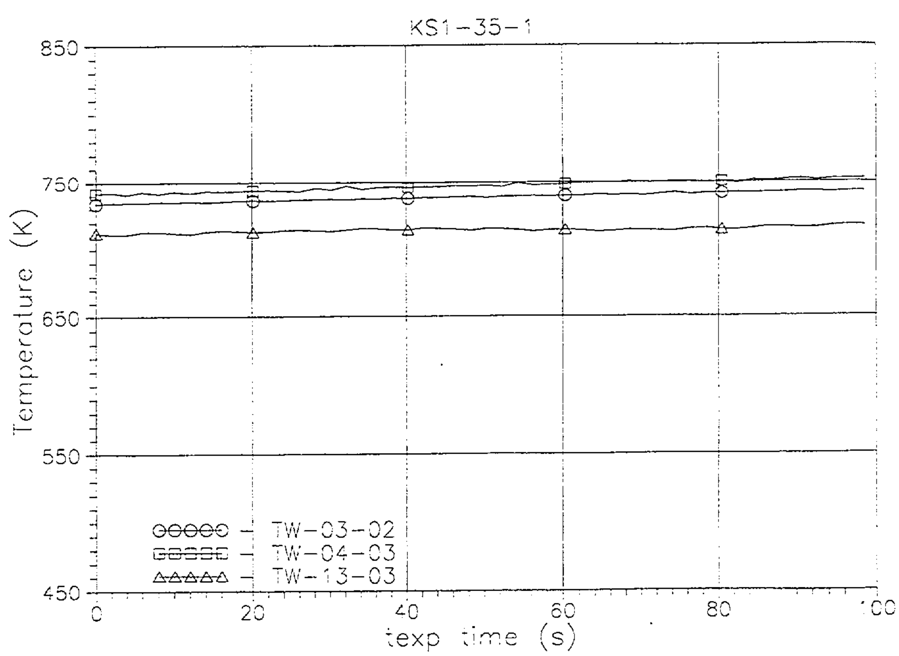


Fig. A-8. Measured TW03-02(t), TW04-03(t) and TW13-03(t) heated tube inside wall temperatures histories in the upper part of the FA model (texp=0-100 s).

Original Data Plots from KS-1Test 35-1

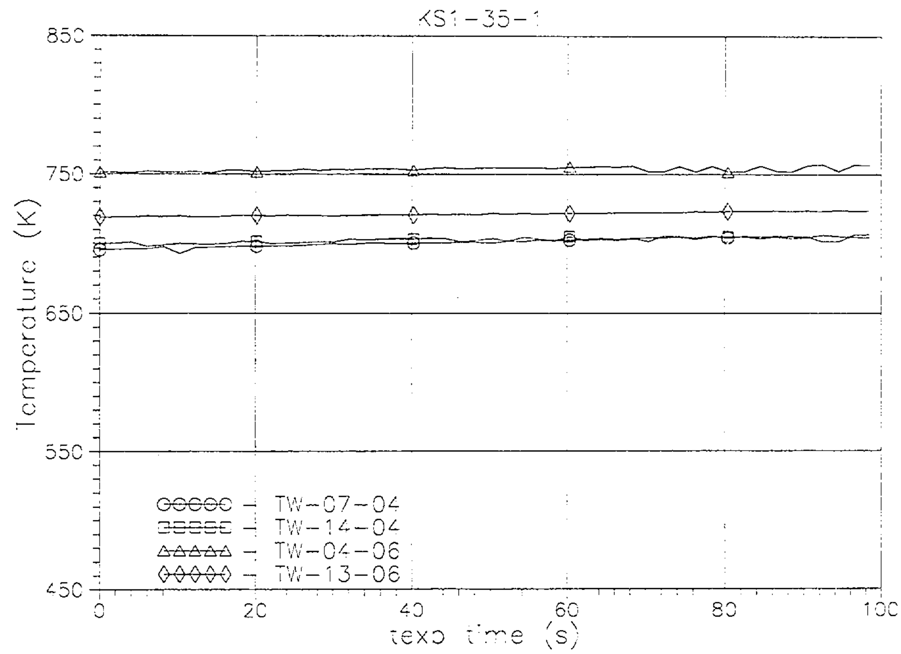


Fig. A-9. Measured TW07-04(t), TW14-04(t), TW04-06(t) and TW13-06(t) heated tube inside wall temperatures histories in the upper part of the FA model (texp=0-100 s).

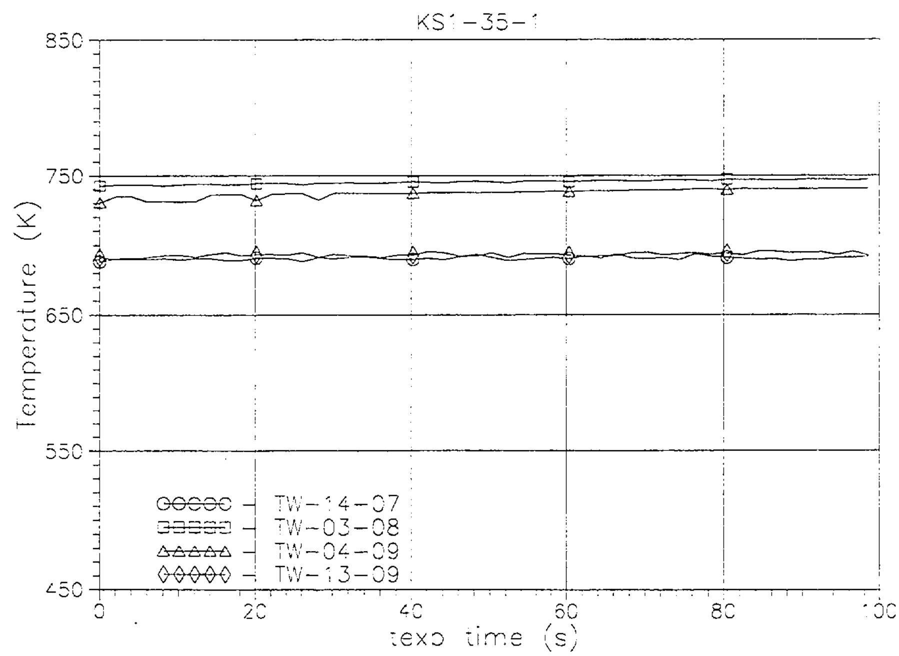


Fig. A-10. Measured TW14-07(t), TW03-08(t), TW04-09 (t) and TW13-09(t) heated tube inside wall temperatures histories in the upper part of the FA model (texp=0-100 s).

Original Data Plots from KS-1Test 35-1

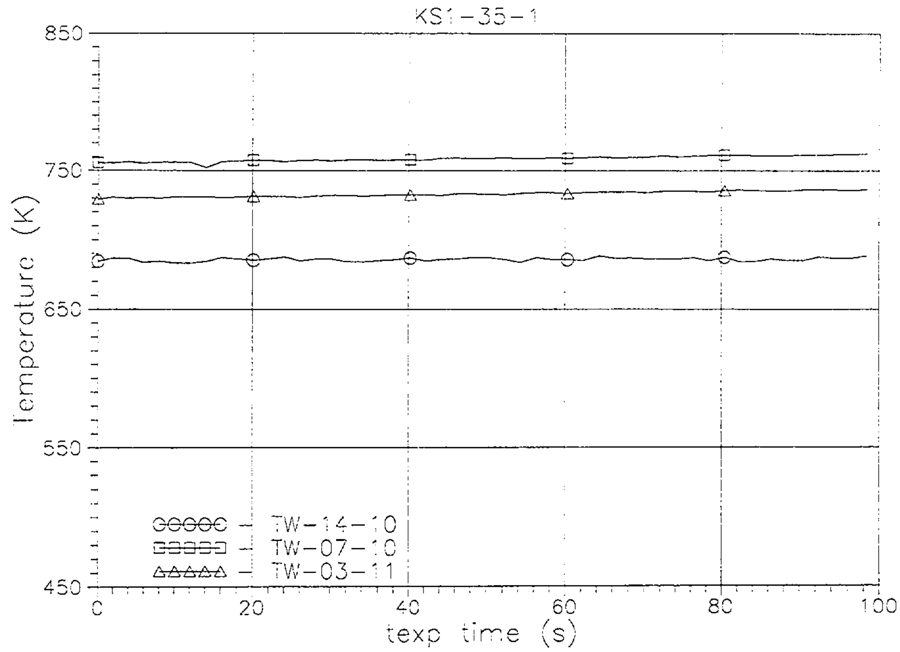


Fig. A-11. Measured TW14-10(t), TW07-10(t) and TW03-11(t) heated tube inside wall temperatures histories in the middle part of the FA model (texp=0-100 s).

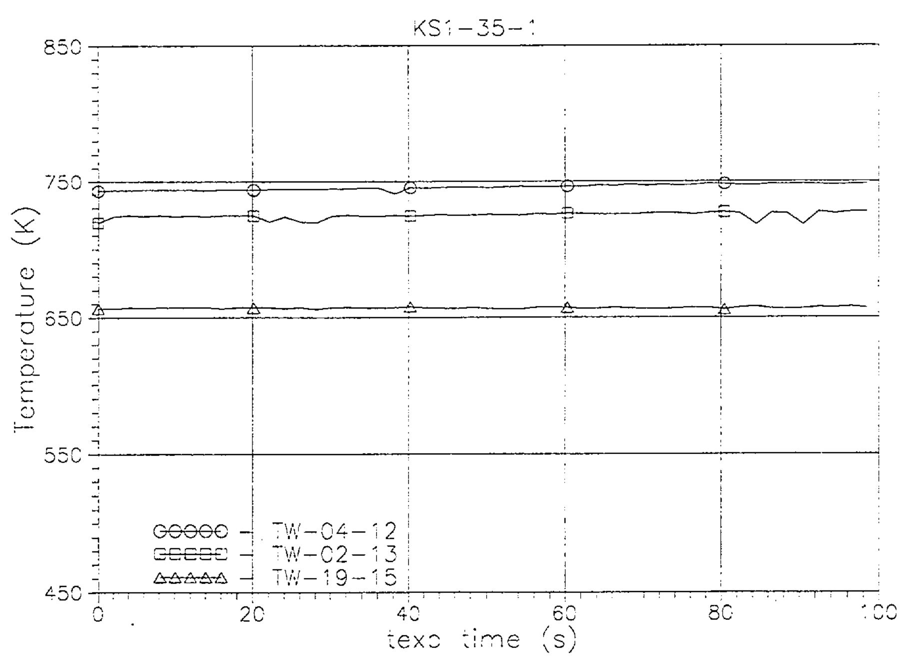


Fig. A-12. Measured TW04-12(t),TW02-13(t) and TW19-15(t) heated tube inside wall temperatures histories in the middle part of the FA model (texp=0-100 s).

Original Data Plots from KS-1Test 35-1

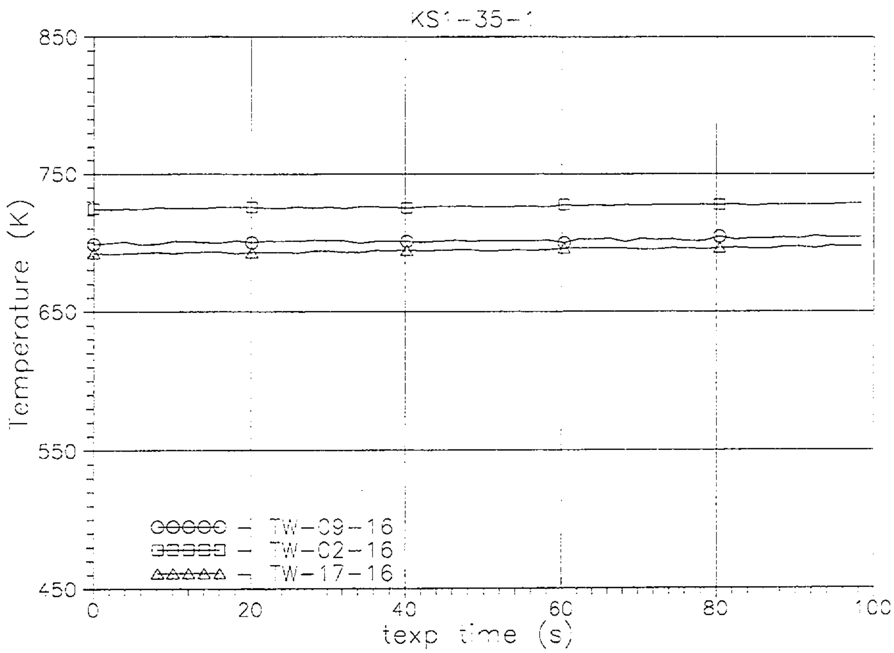


Fig. A-13. Measured TW09-16(t), TW02-16(t) and TW17-16(t) heated tube inside wall temperatures histories in the middle part of the FA model (texp=0-100 s).

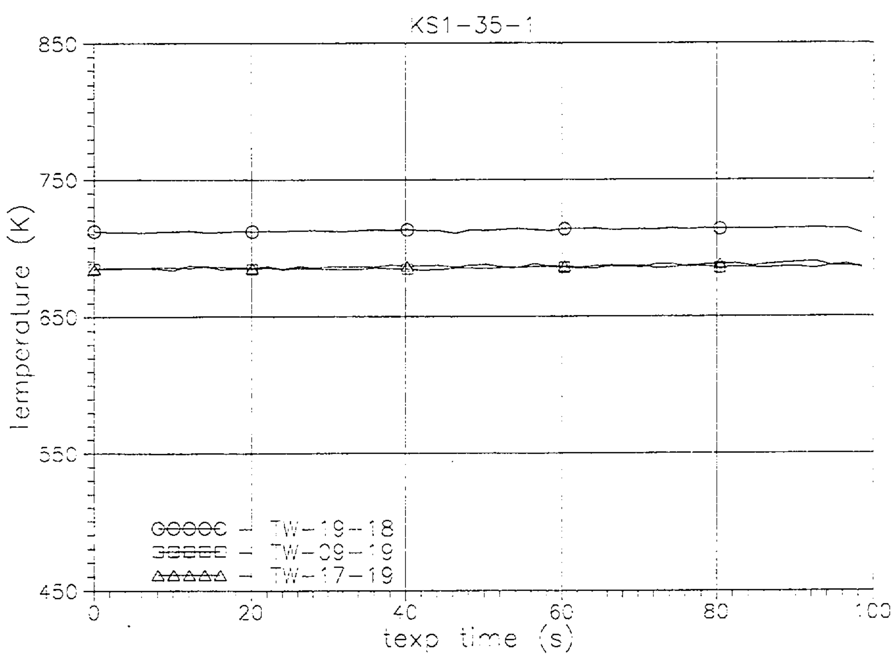


Fig. A-14. Measured TW19-18(t), TW09-19(t) and TW17-19(t) heated tube inside wall temperatures histories in the bottom part of the FA model (texp=0-100 s).

Original Data Plots from KS-1Test 35-1

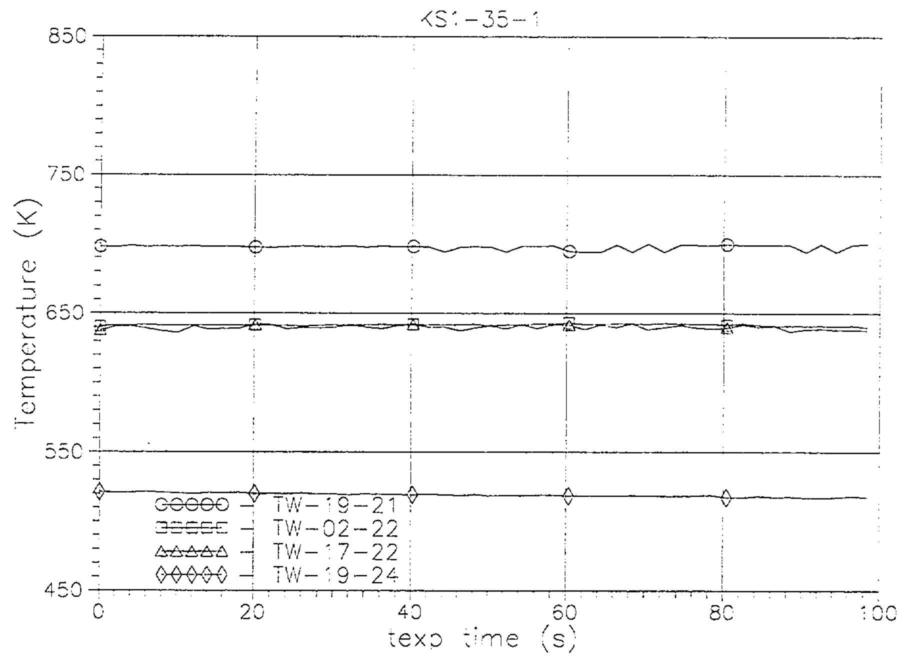


Fig. A-15. Measured TW19-21(t), TW02-22(t) ,TW17-22(t) and TW19-24(t) heated tube inside wall temperatures histories in the bottom part of the FA model (texp=0-100 s).

APPENDIX- B

BASE CASE RESULTS

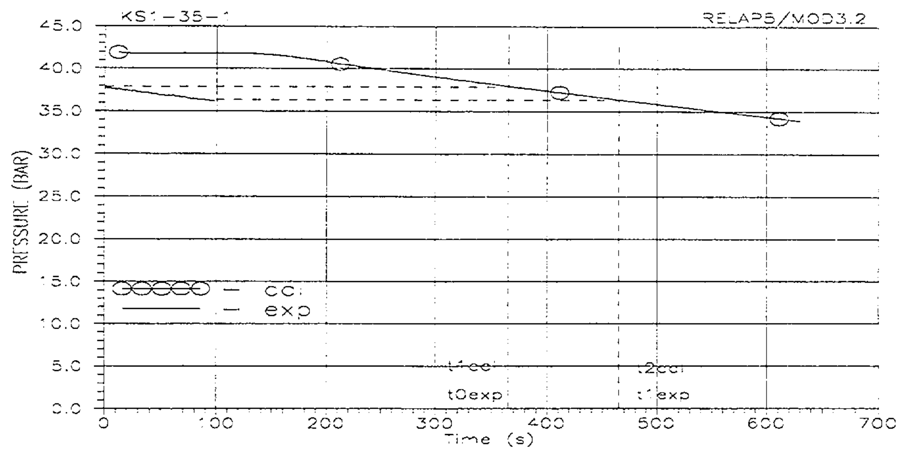


Fig. B-1. RELAP5/MOD3.2-calculated Pout(t)cal pressure at Core model outlet (tcal=0-600 s).

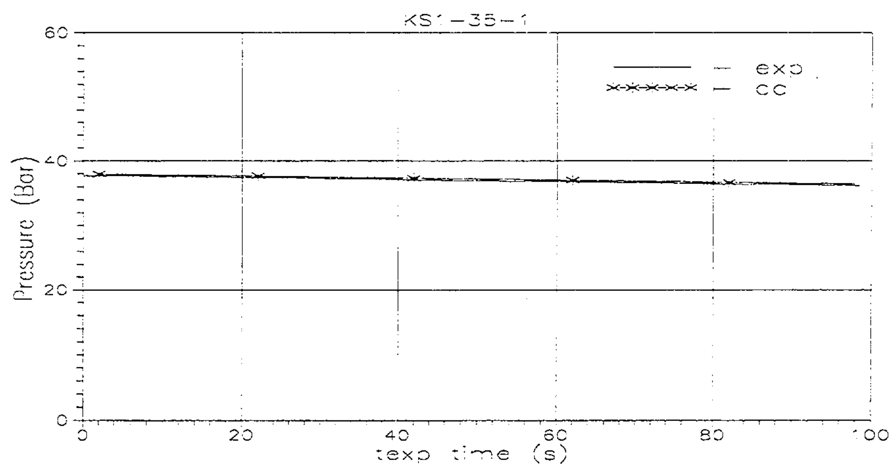


Fig. B-2. Comparison of measured Pout(t)exp and RELAP5/MOD3.2-calculated Pout(t)cal pressure at Core model outlet (texp=0-100 s).

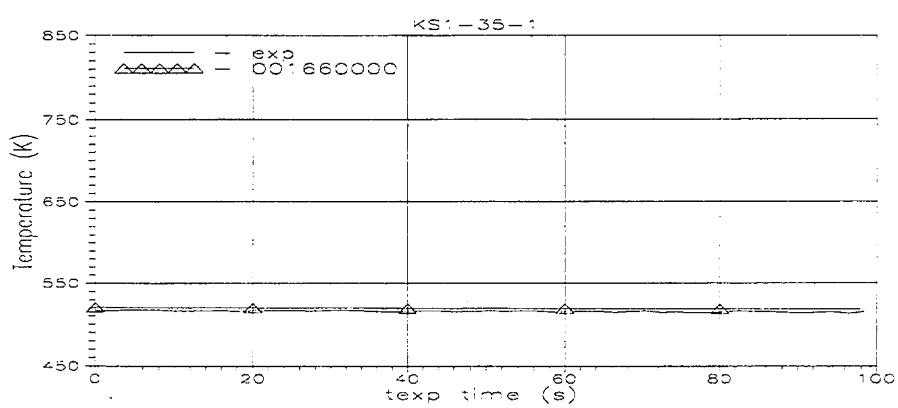


Fig. B-3. Comparison of measured and RELAP5/MOD3.2-calculated TFin(t) coolant temperature at Core model inlet (texp=0-100 s).

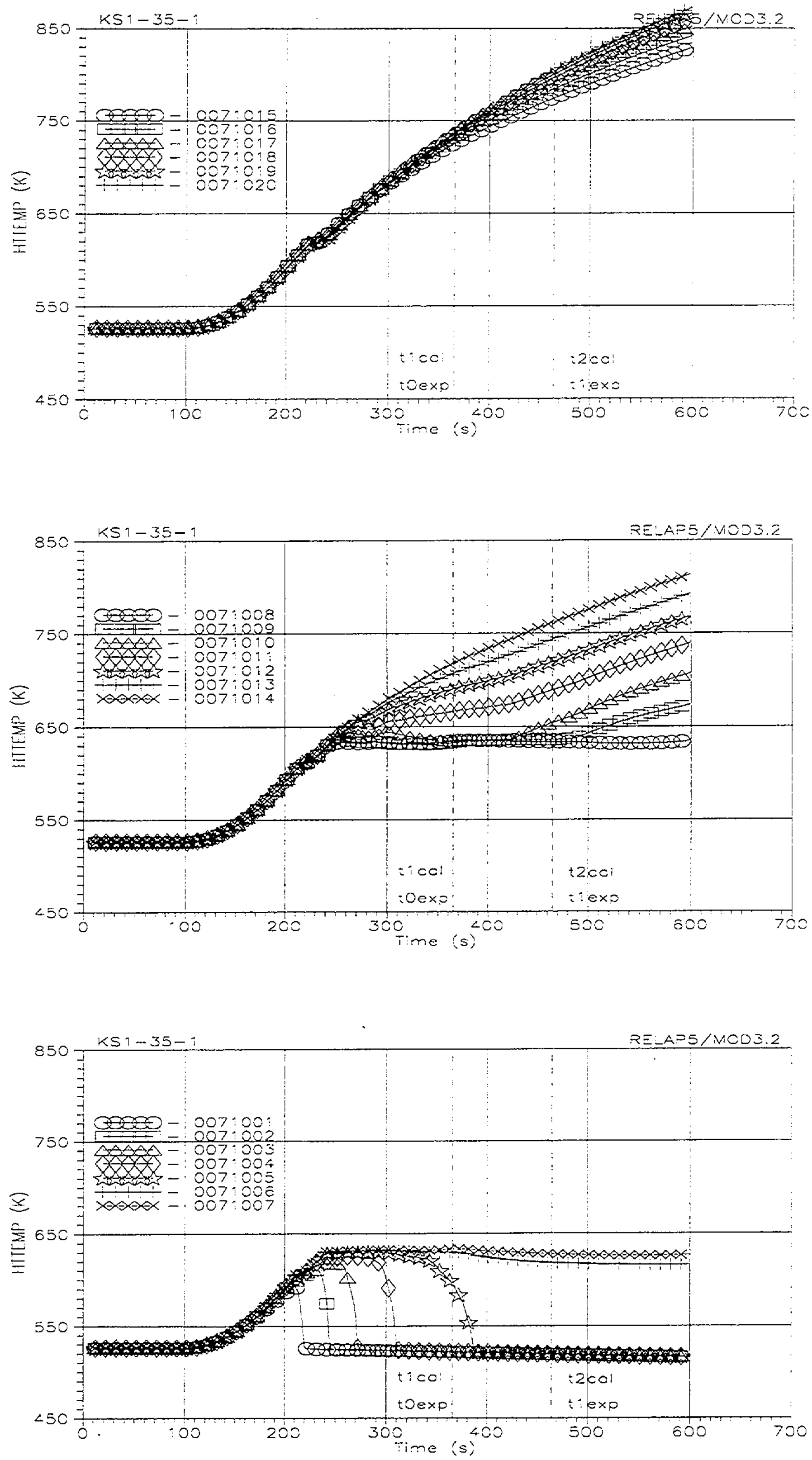


Fig. B-4. RELAP5/MOD3.2-calculated TW(t) heated tube inside wall temperatures histories in the upper, middle and bottom parts of the FA model (tcal=0-600 s).

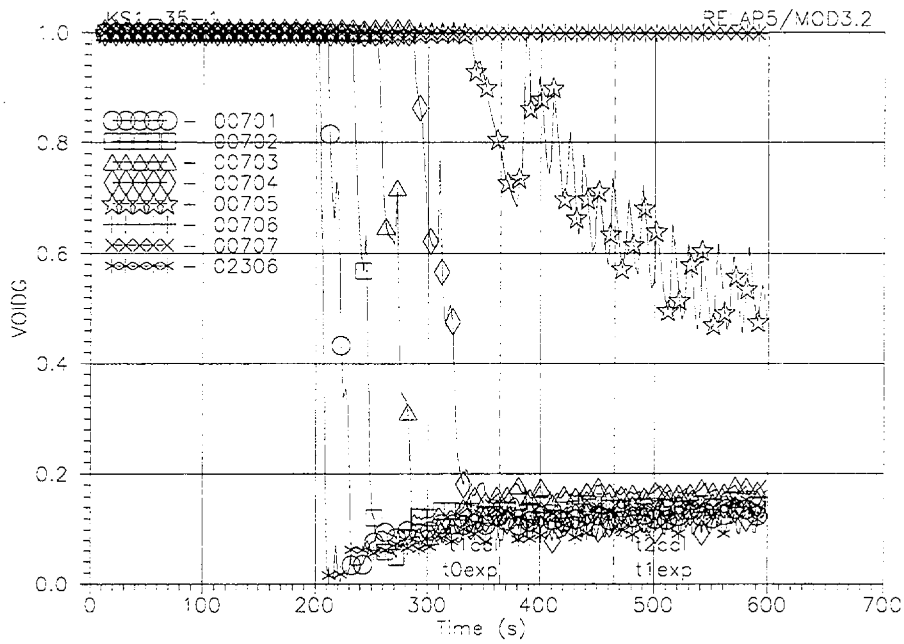
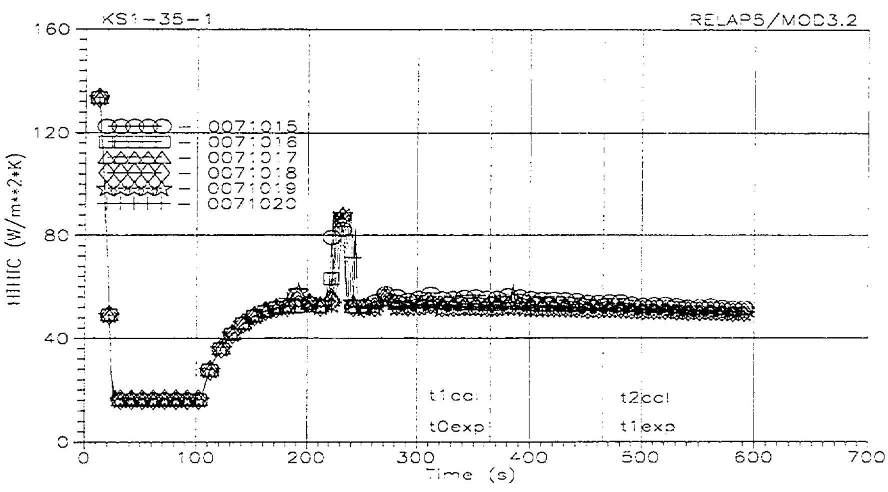
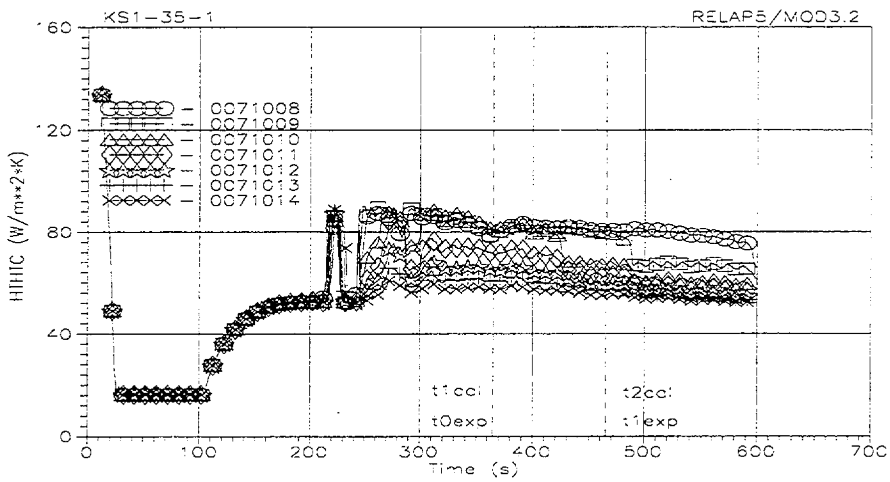


Fig. B-5. RELAP5/MOD3.2-calculated void fractions histories in the bottom part of FA channel (tcal=0- 600 s).





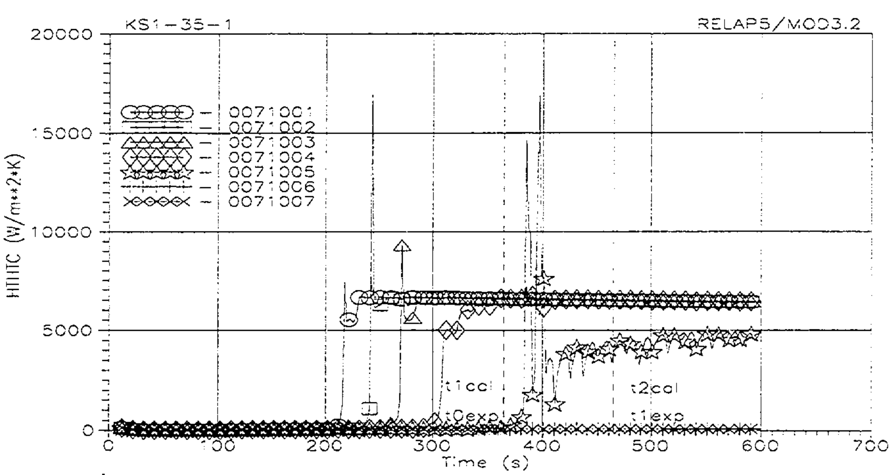


Fig. B-6. Behavior of RELAP5/MOD3.2-calculated Hw1(t) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper, middle and bottom parts of FA model (tcal=0-600 s).

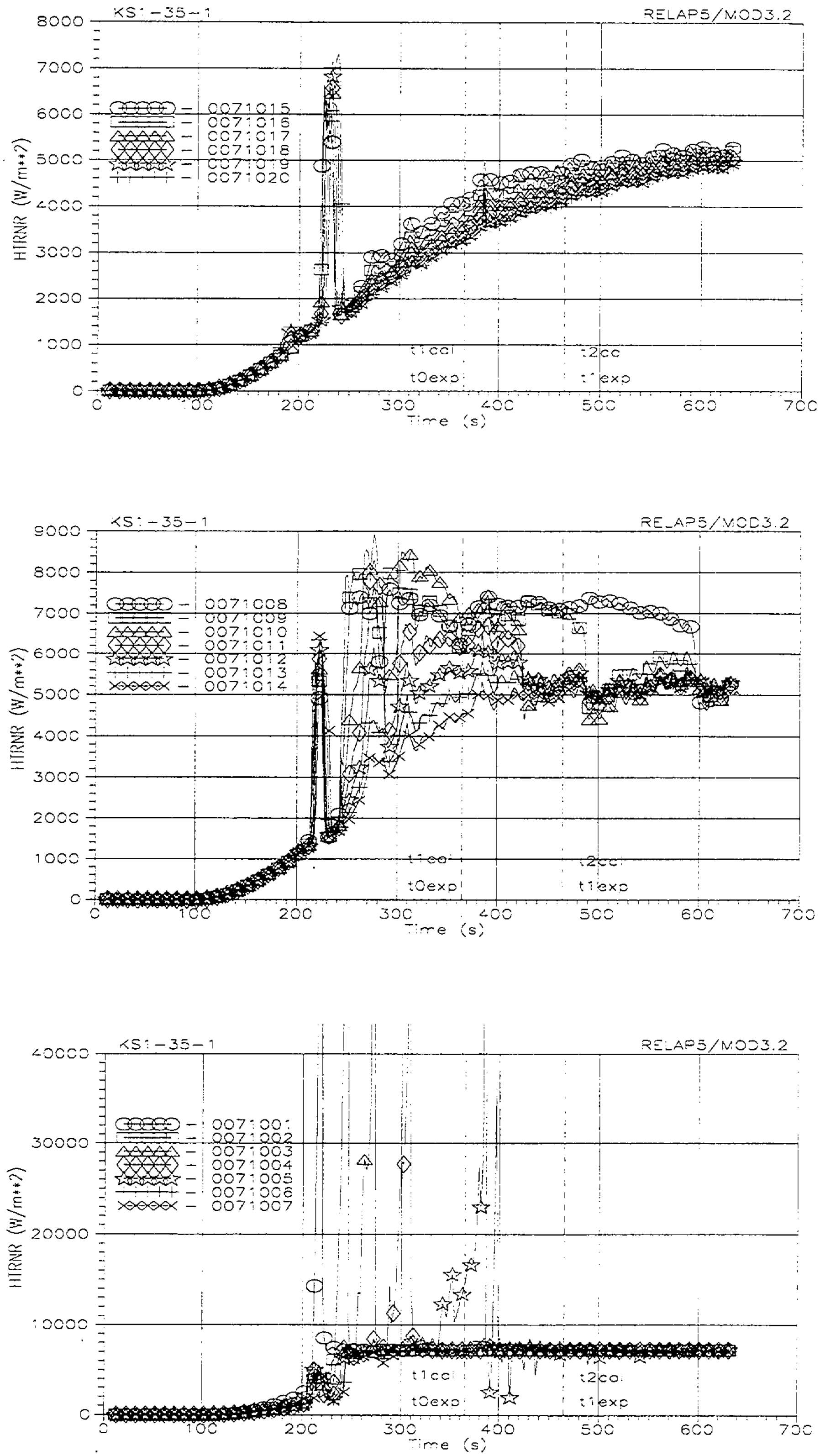


Fig. B-7. Behavior of RELAP5/MOD3.2-calculated qw1(t) specific heat flux from outer surfaces of the rod simulators to coolant in the upper, middle and bottom parts of FA model (tcal=0-600 s).

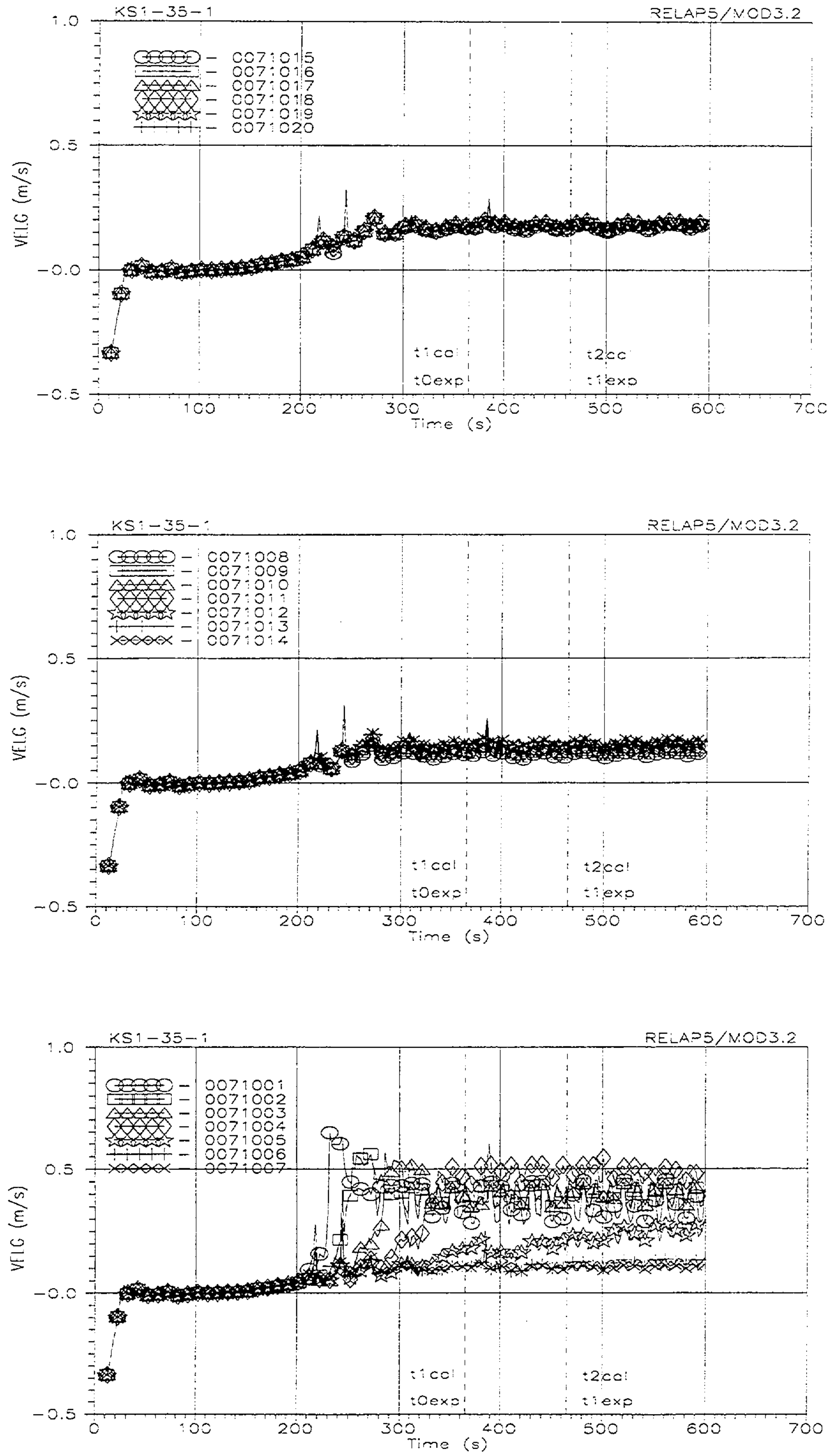


Fig. B-8. RELAP5/MOD3.2-calculated Vg(t) junction vapor velocities histories in the upper, middle and bottom parts of FA channel (tcal=0-600 s).

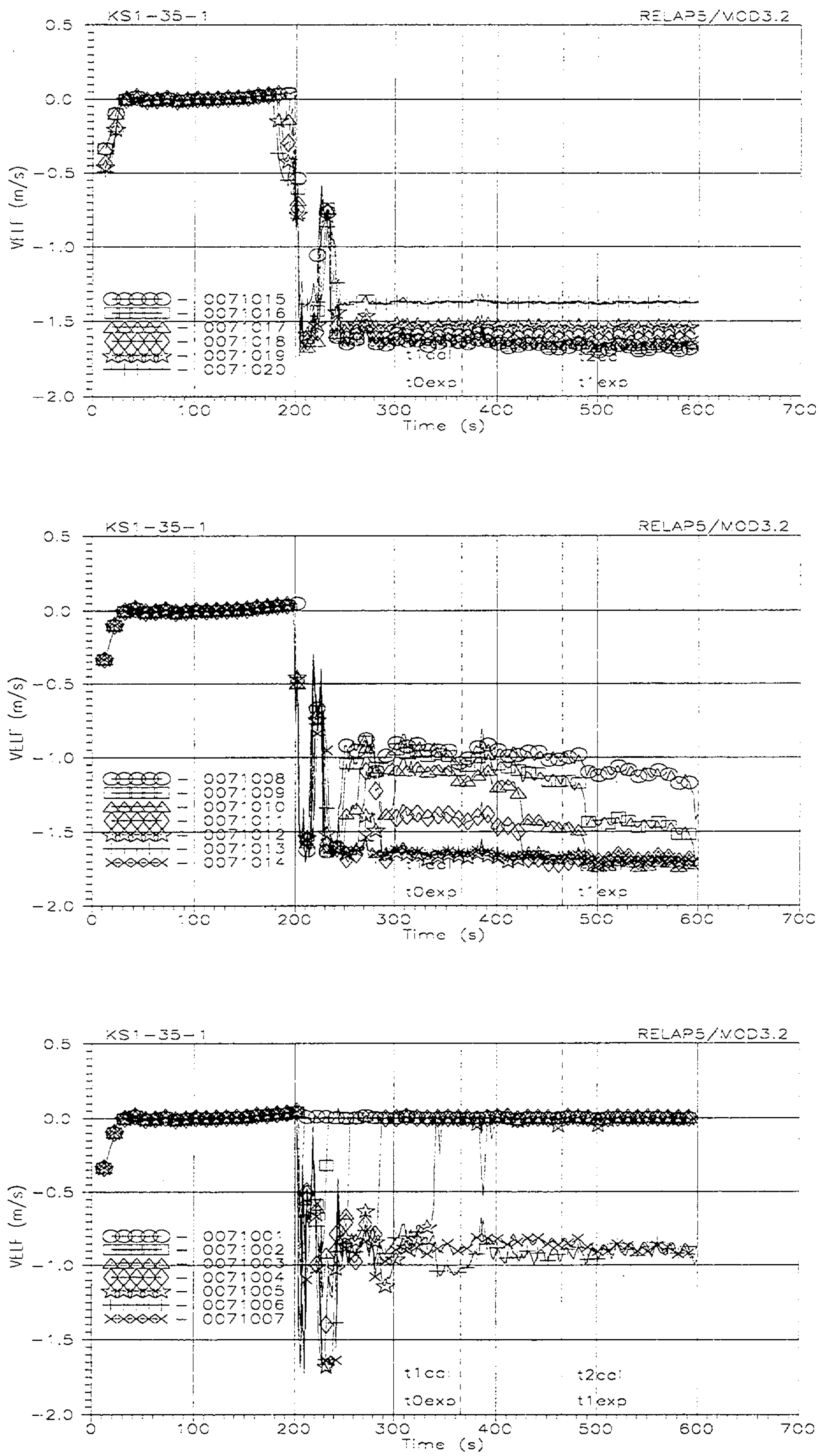


Fig. B-9. RELAP5/MOD3.2-calculated $V_L(t)$ junction liquid velocities histories in the upper, middle and bottom parts of FA channel (tcal=0-600 s).

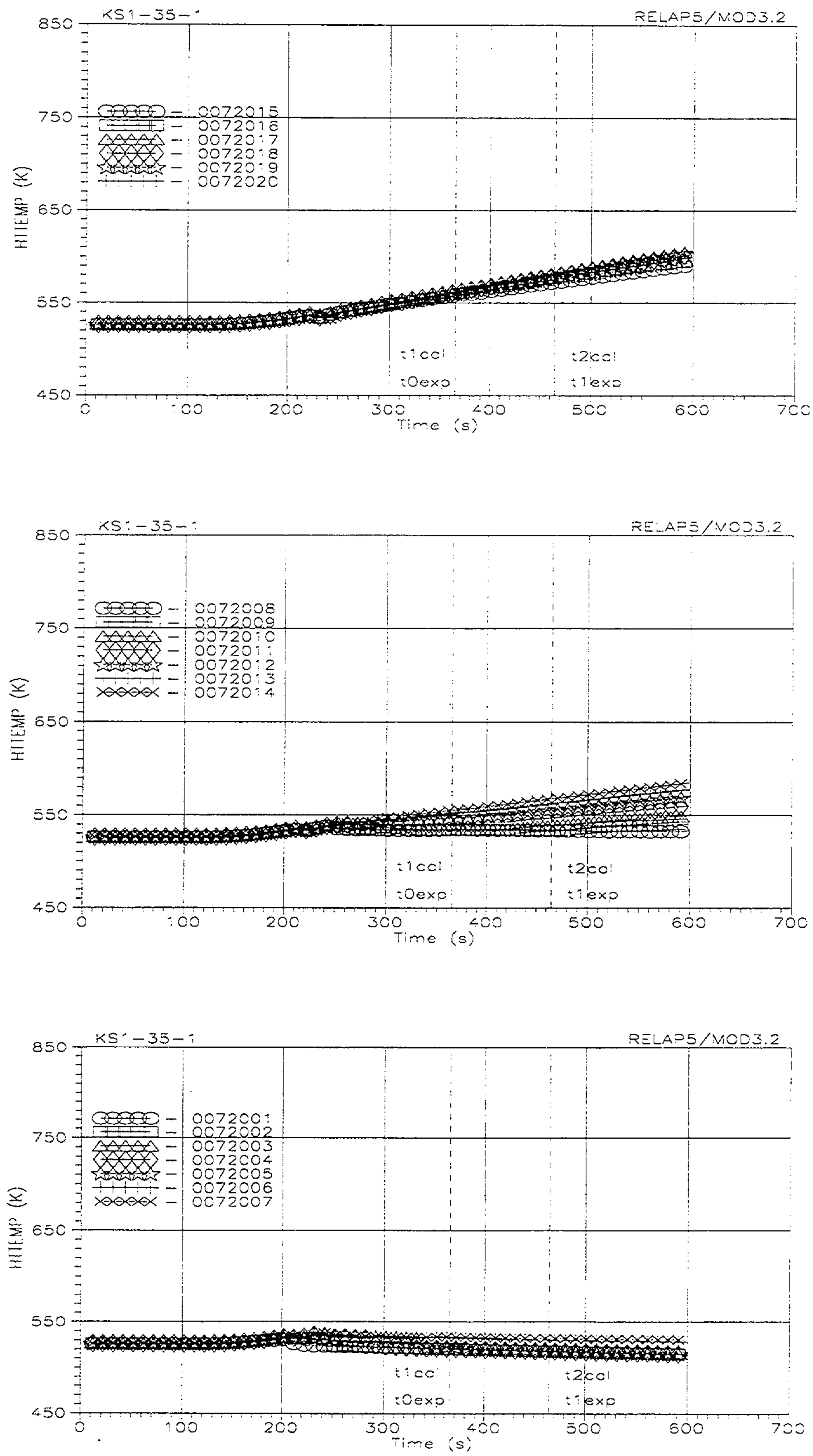


Fig. B-10. RELAP5/MOD3.2-calculated Ti(t) insulator inside wall temperatures histories in the upper, middle and bottom parts of the FA model (tcal=0-600 s).

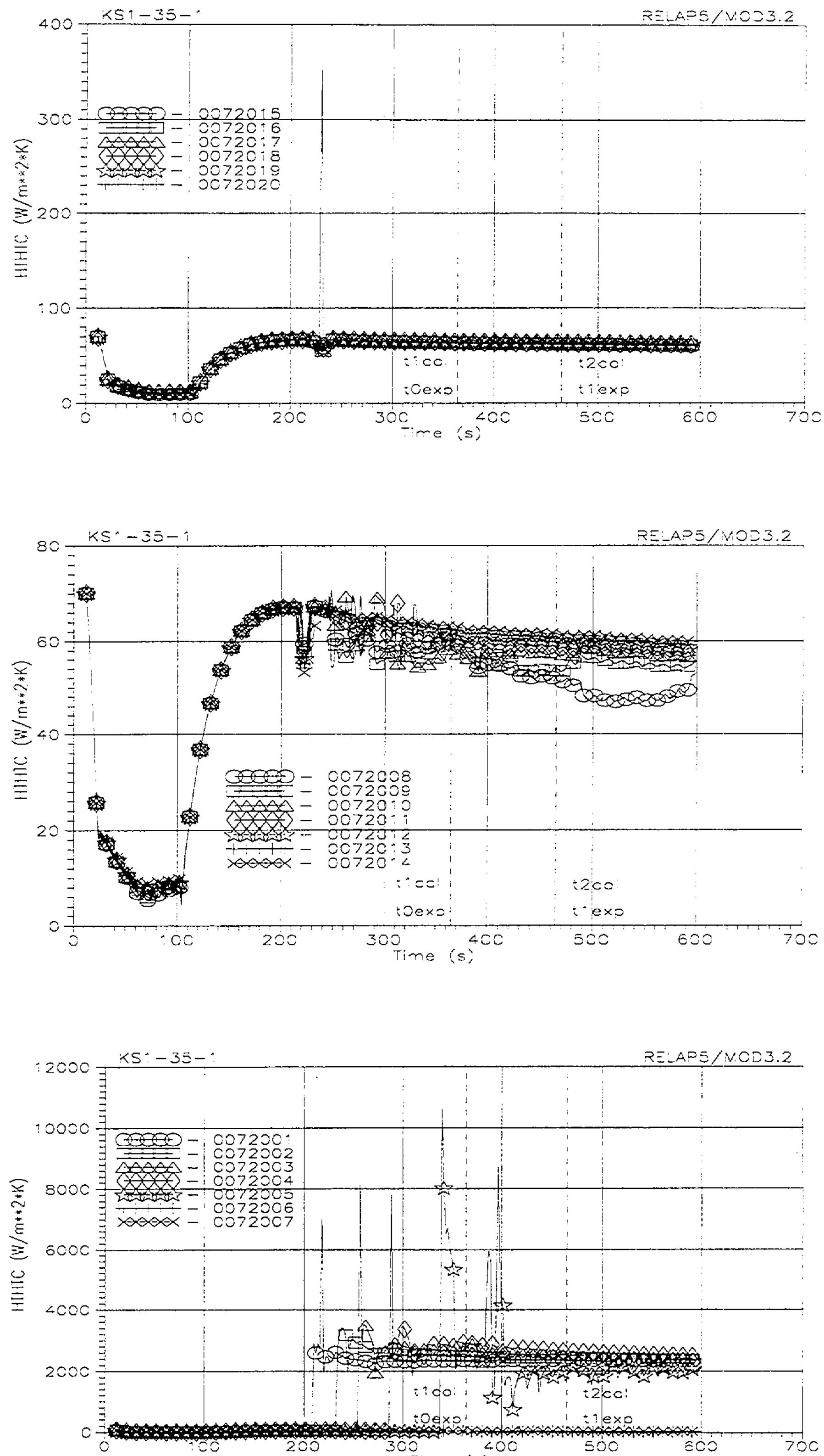


Fig. B-11. Behavior of RELAP5/MOD3.2-calculated Hw2(t) coefficient of heat transfer from coolant to the insulator in the upper, middle and bottom parts of FA model (tcal=0-600 s).

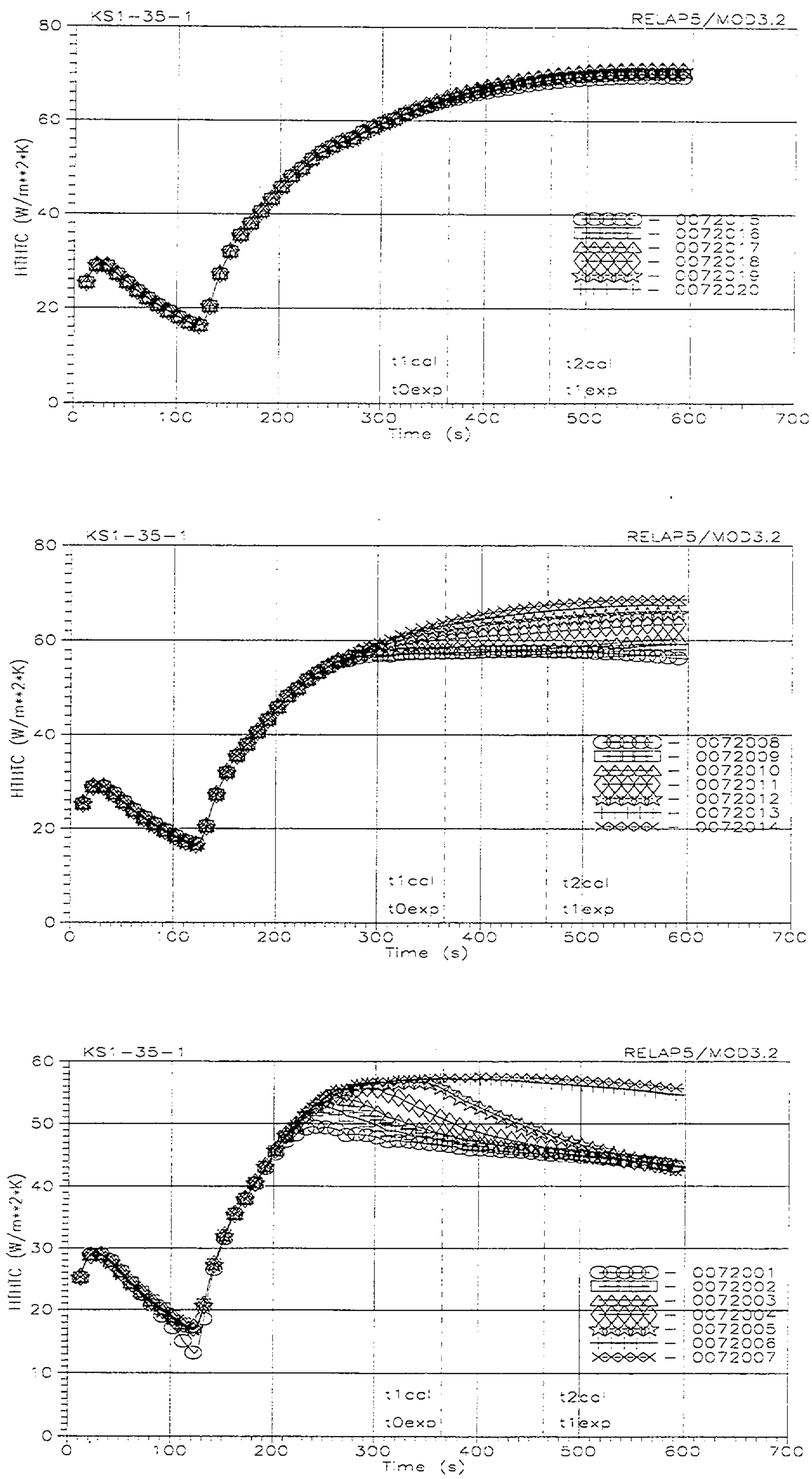


Fig. B-12. Behavior of RELAP5/MOD3.2-calculated Hw3(t) coefficient of heat transfer from outer surface of steel shroud to coolant on the height of Core model annular gap (tcal=0-600 s).

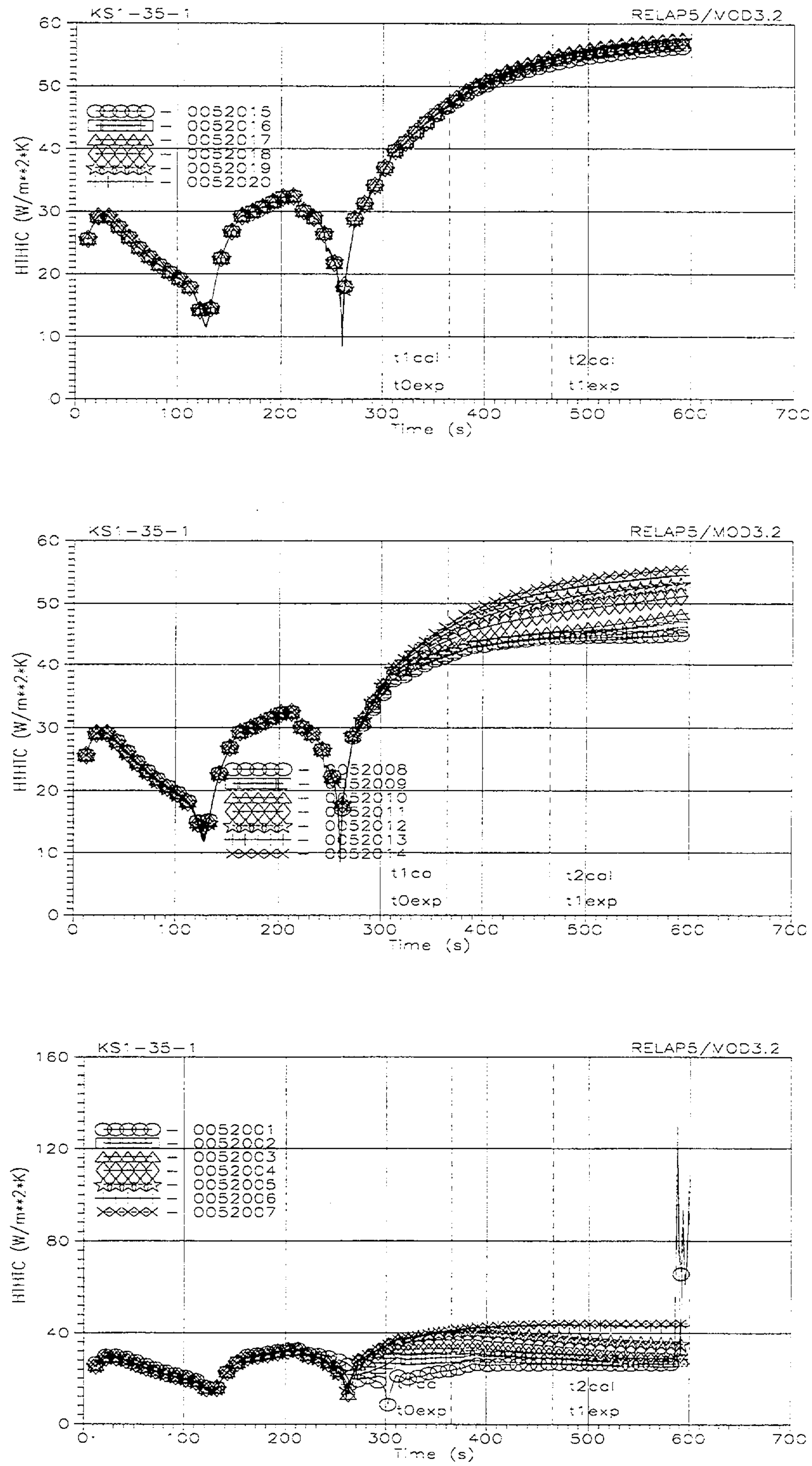


Fig. B-13. Behavior of RELAP5/MOD3.2-calculated Hw4(t) coefficient of heat transfer from coolant to inner surface of pressure vessel on the height of Core model annular gap (tcal=0-600 s).

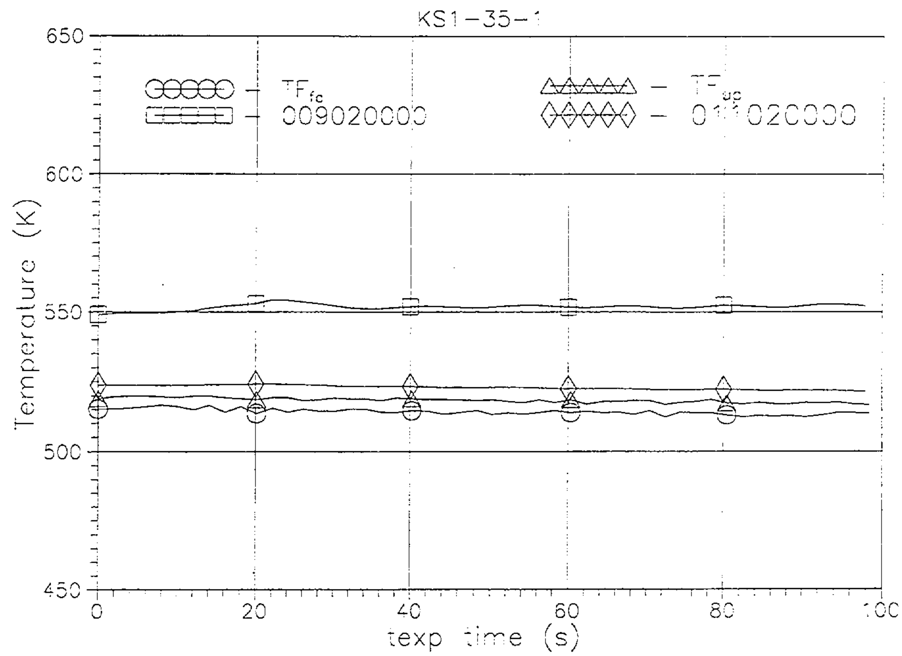


Fig. B-14. Comparison of measured and RELAP5/MOD3.2-calculated TFfa(t) FA model outlet and TFup(t) UP model inlet coolant temperatures histories (texp=0-100 s).

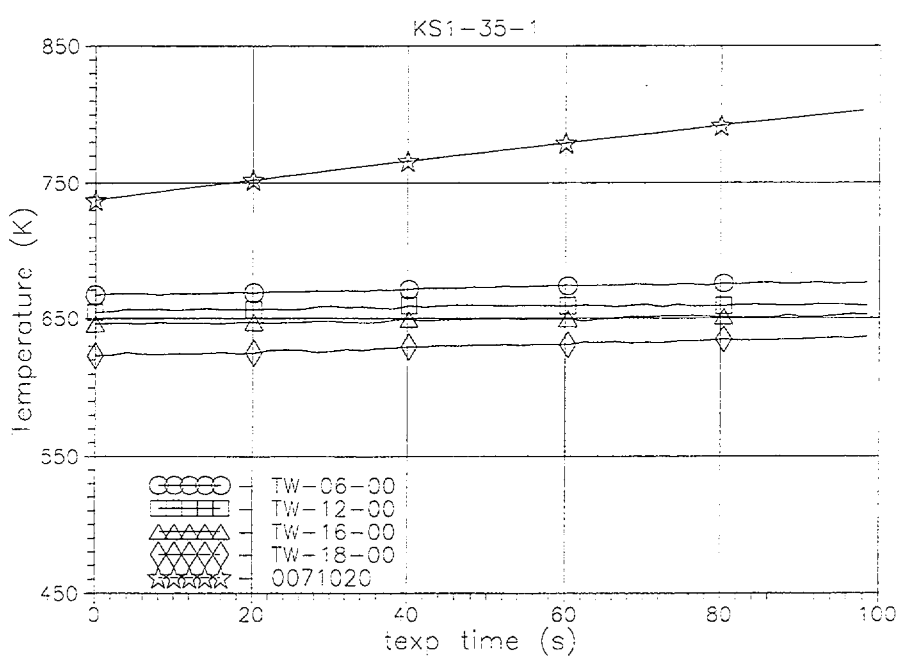


Fig. B-15. Comparison of measured TW06-00(t), TW12-00(t), TW16-00(t), TW18-00(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories at the top of FA model (texp=0-100 s).

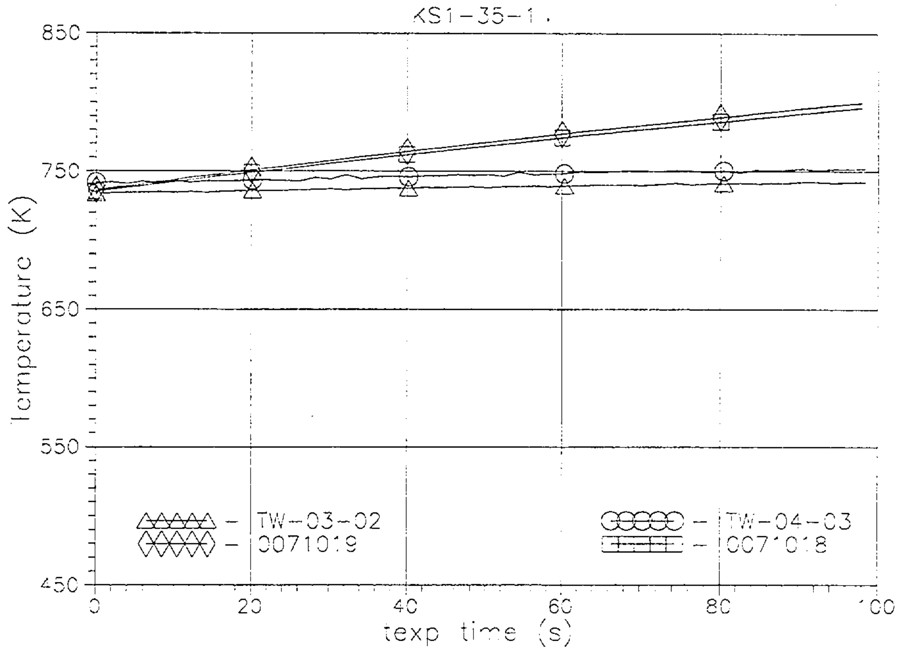


Fig. B-16. Comparison of measured TW03-02(t), TW04-03(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the upper part of FA model (texp=0-100 s).

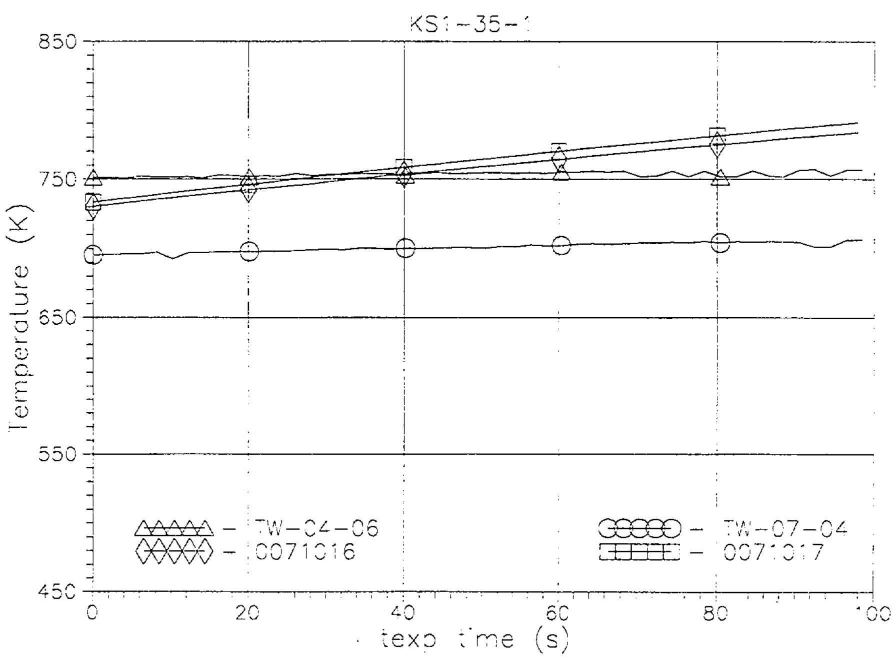


Fig. B-17. Comparison of measured TW07-04(t), TW04-06(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the upper part of FA model (texp=0-100 s).

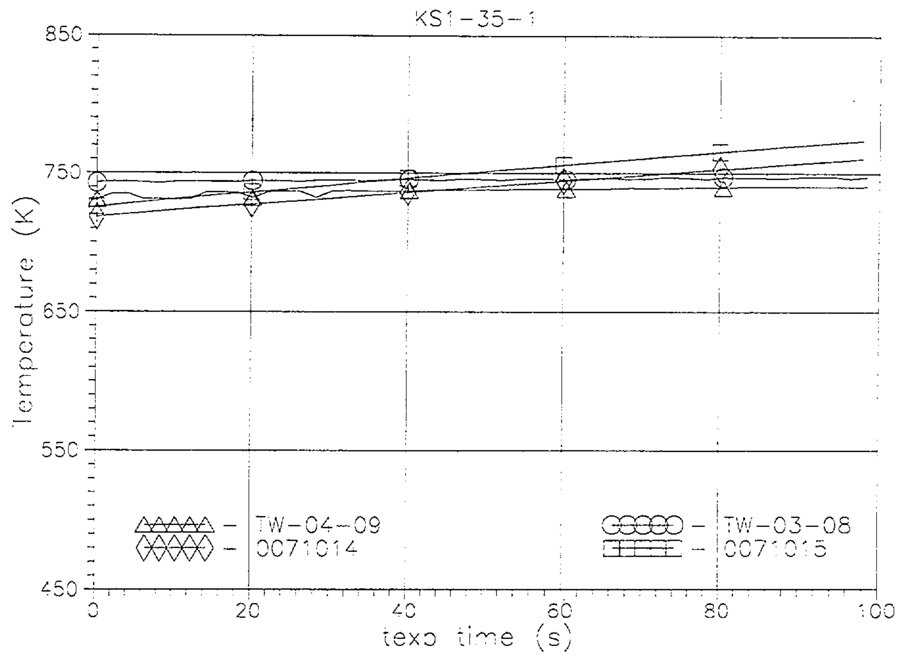


Fig. B-18. Comparison of measured TW03-08(t), TW04-09 (t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the upper part of FA model (texp=0-100 s).

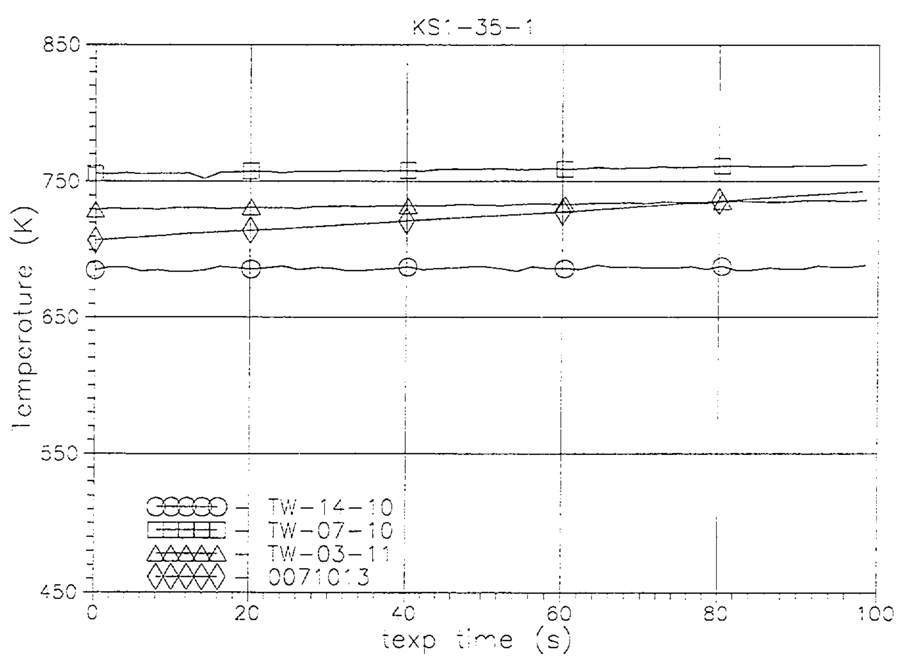


Fig. B-19. Comparison of measured TW14-10(t), TW07-10(t), TW03-11(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the middle part of FA model (texp=0-100 s).

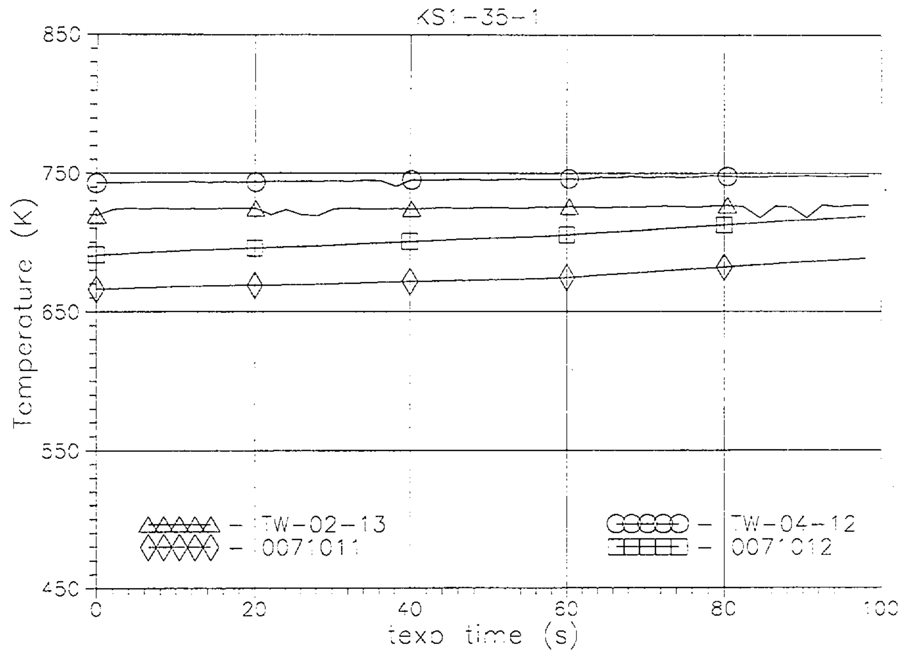


Fig. B-20. Comparison of measured TW04-12(t),TW02-13(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the middle part of FA model (texp=0-100 s).

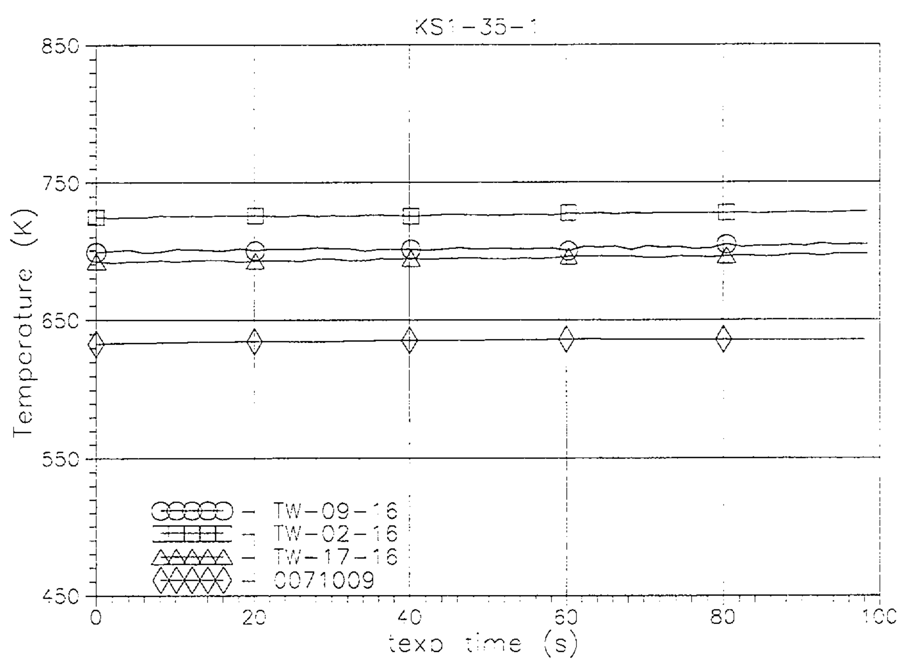


Fig. B-21. Comparison of measured TW09-16(t), TW02-16(t), TW17-16(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the middle part of FA model (texp=0-100 s).

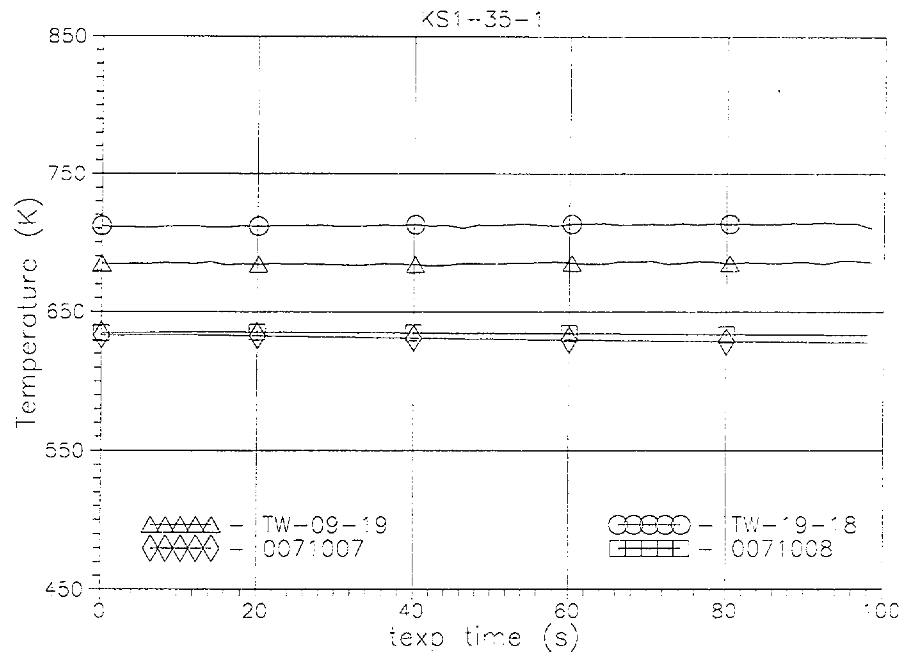


Fig. B-22. Comparison of measured TW19-18(t), TW09-19(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the bottom part of FA model (texp=0-100 s).

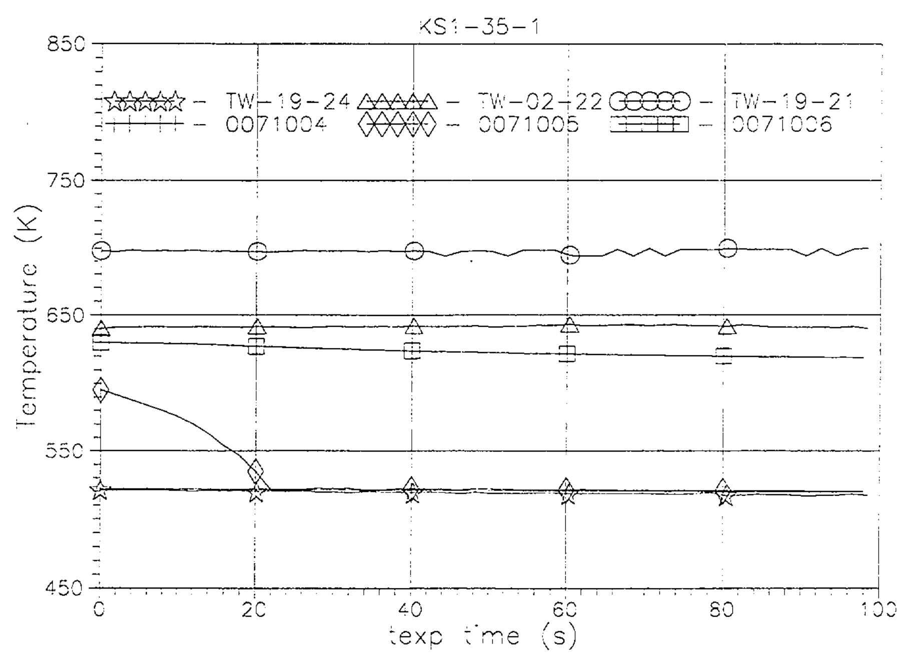


Fig. B-23. Comparison of measured TW19-21(t), TW02-22(t), TW19-24(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the bottom part of FA model (texp=0-100 s).

APPENDIX- C

SENSITIVITY STUDIES

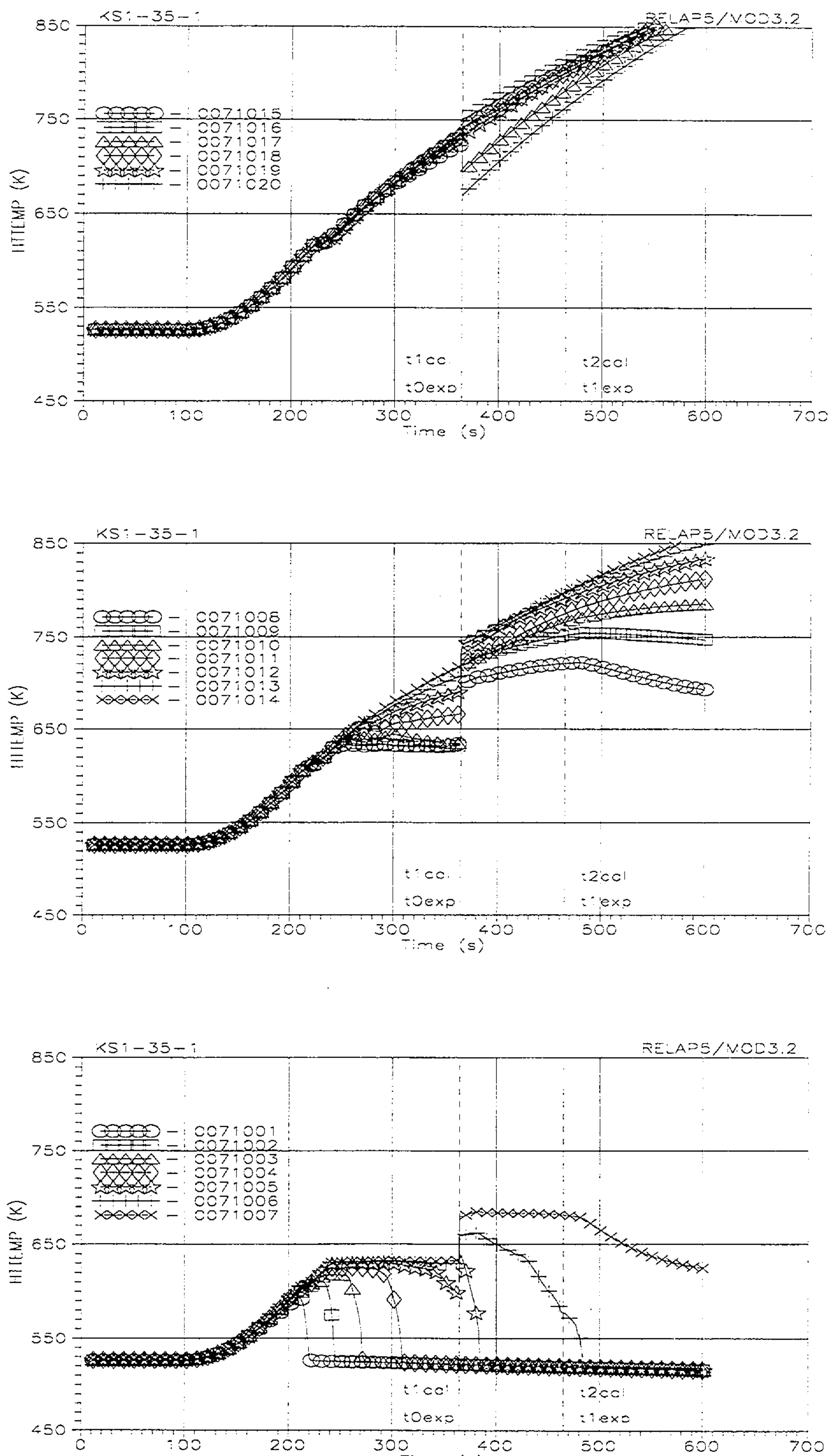


Fig. C-1. RELAP5/MOD3.2-calculated TW(t) heated tube inside wall temperatures histories in the upper, middle and bottom parts of the FA model (tcal=0-600 s). Maximum time step =0.01 s. Restart time t=365 s.

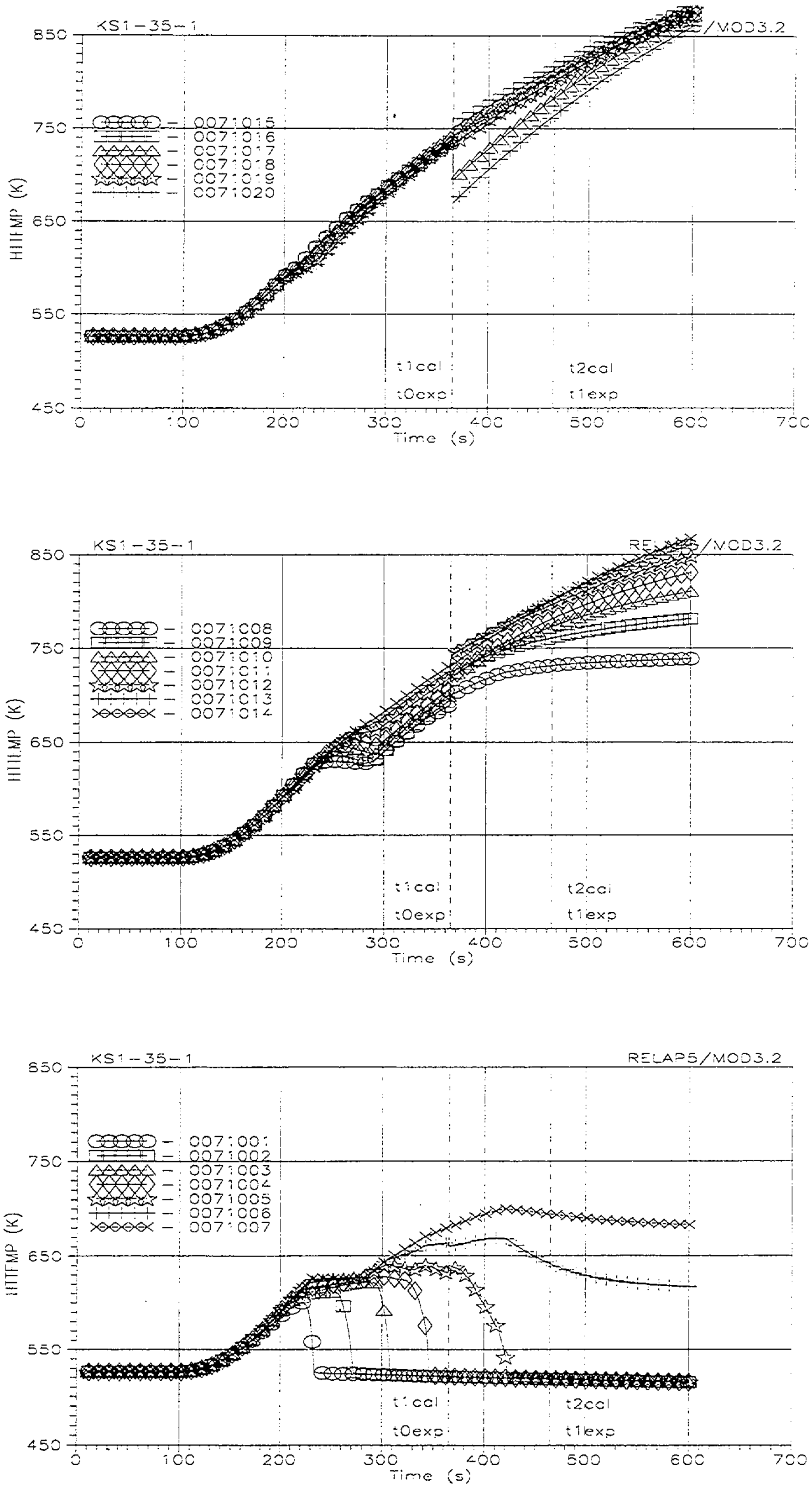


Fig. C-2. RELAP5/MOD3.2-calculated TW(t) heated tube inside wall temperatures histories in the upper, middle and bottom parts of the FA model (tcal=0-600 s). Maximum time step =0.2 s. Restart time t=365 s.

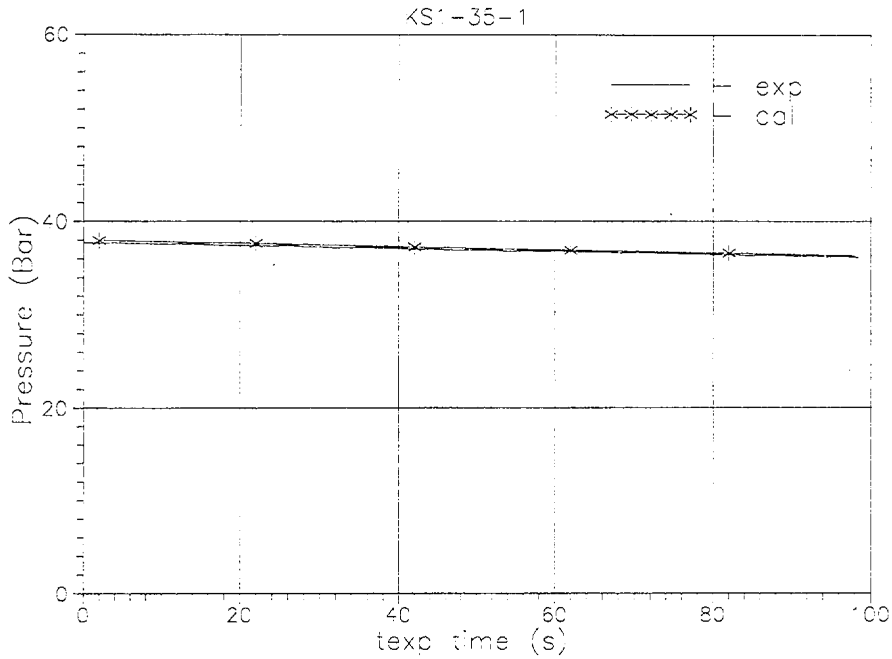


Fig. C-3. Comparison of measured Pout(t)exp and RELAP5/MOD3.2-calculated Pout(t)cal pressure at Core model outlet (texp=0-100 s).

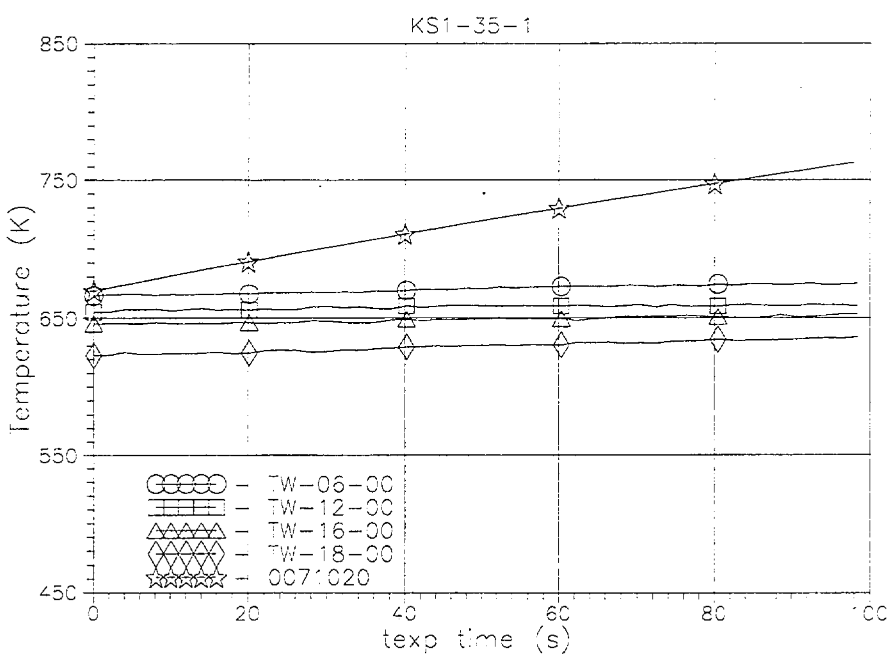


Fig. C-4. Comparison of measured TW06-00(t), TW12-00(t), TW16-00(t), TW18-00(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories at the top of FA model (texp=0-100 s).

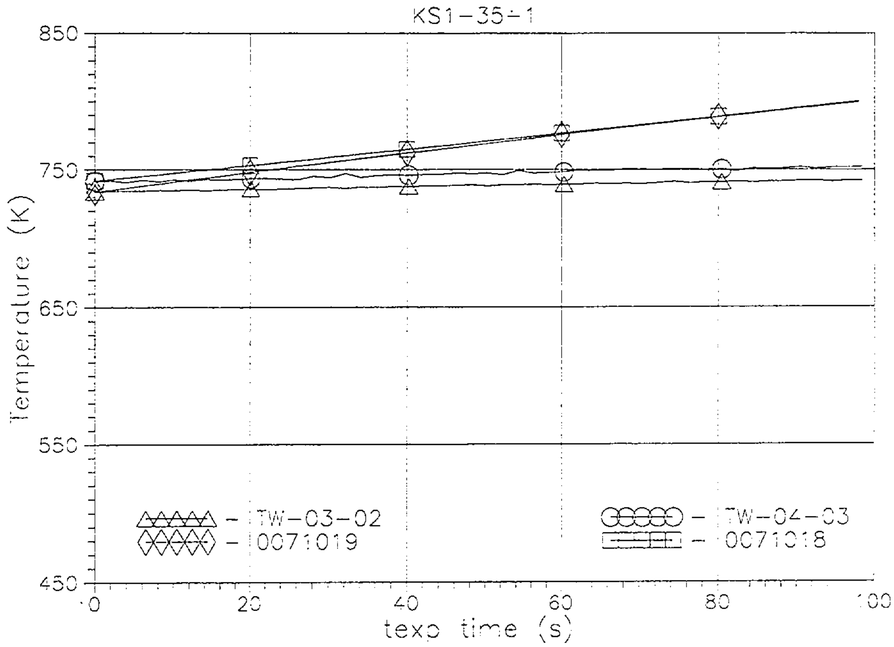


Fig. C-5. Comparison of measured TW03-02(t), TW04-03(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the upper part of FA model (texp=0-100 s)

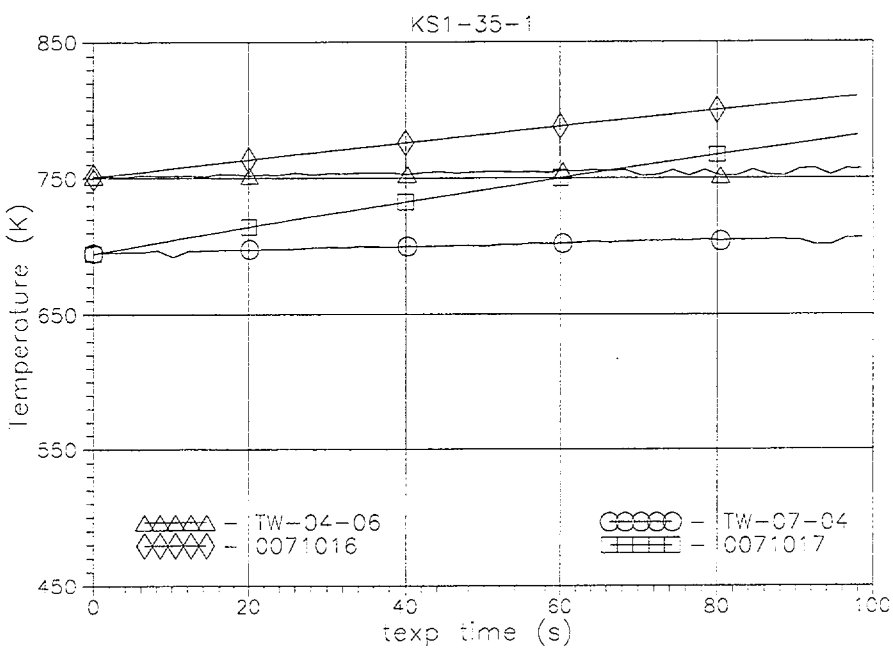


Fig. C-6. Comparison of measured TW07-04(t), TW04-06(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the upper part of FA model (texp=0-100 s)

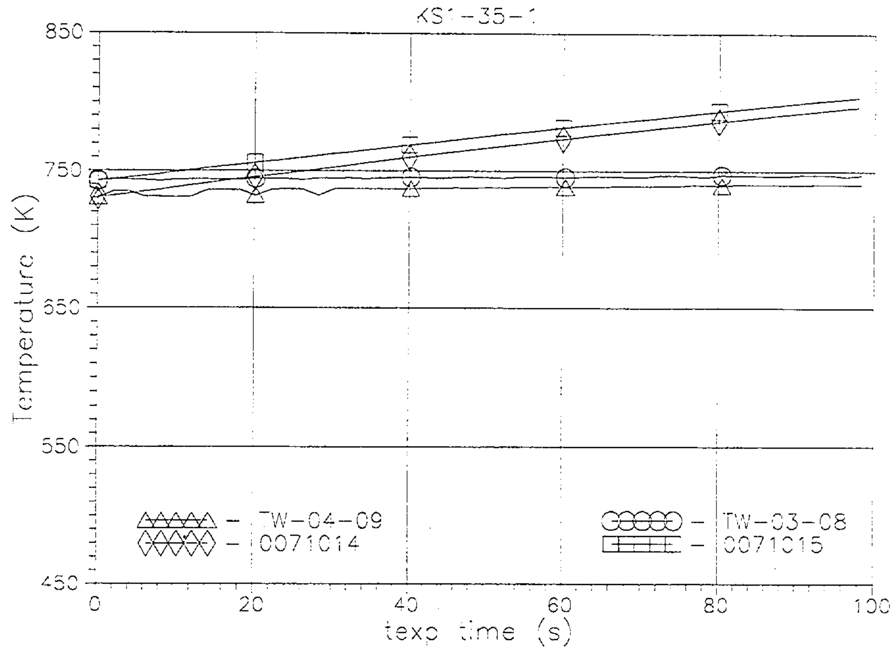


Fig. C-7. Comparison of measured TW03-08(t), TW04-09(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the upper part of FA model (texp=0-100 s)

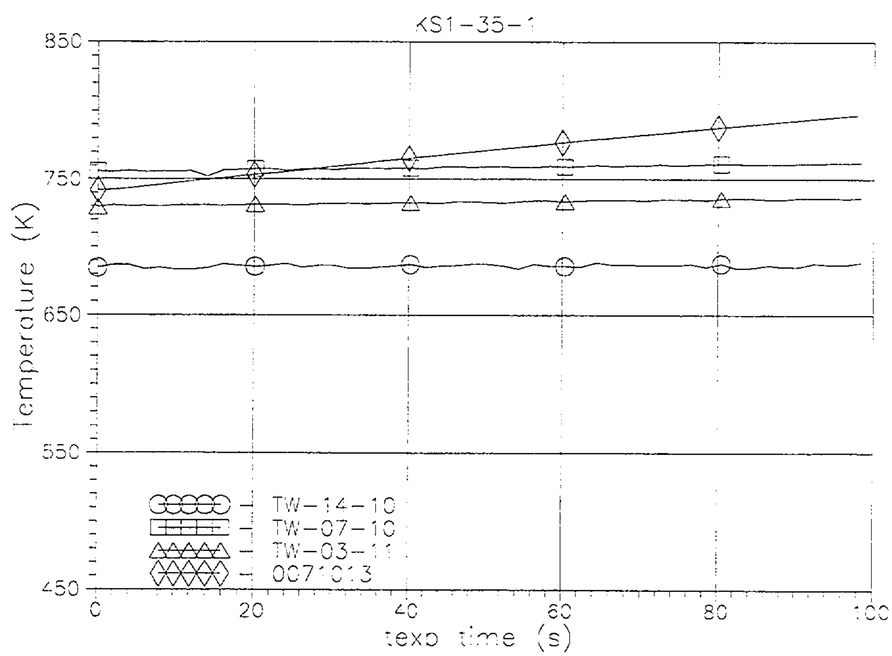


Fig. C-8. Comparison of measured TW14-10(t), TW07-10(t), TW03-11(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the middle part of FA model (texp=0-100 s)

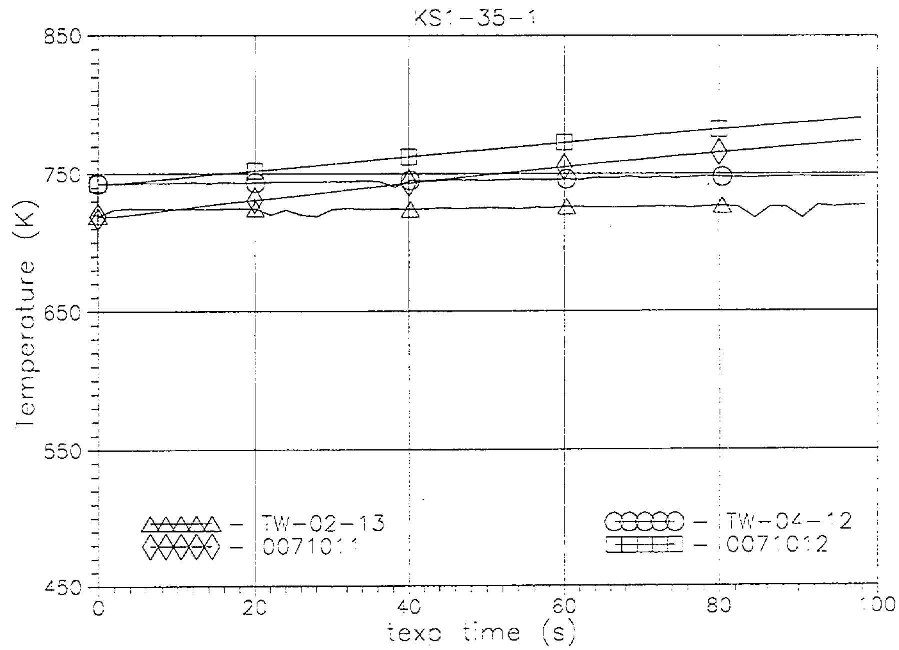


Fig. C-9. Comparison of measured TW04-12(t), TW02-13(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the middle part of FA model (texp=0-100 s)

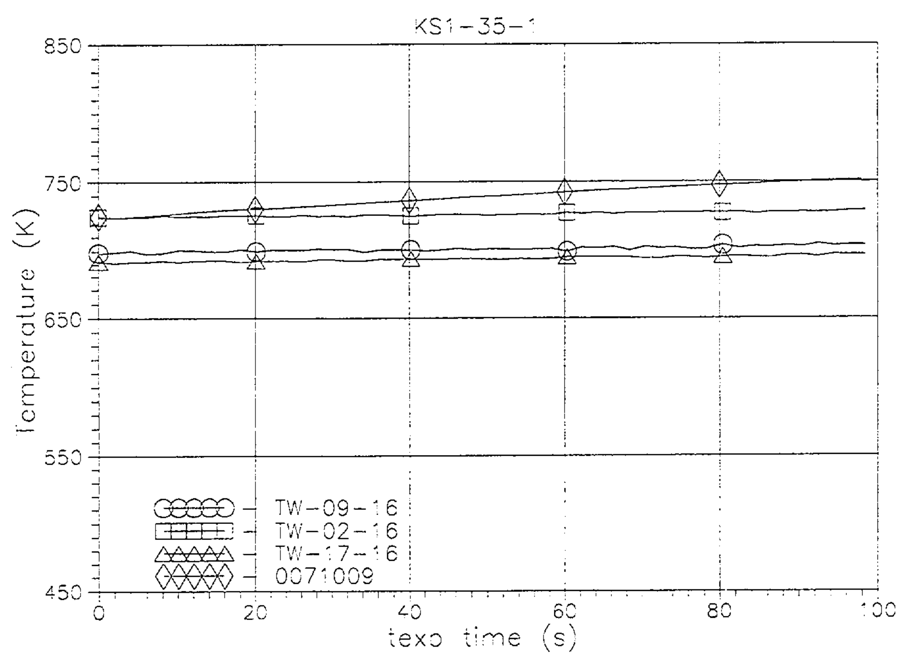


Fig. C-10. Comparison of measured TW09-16(t), TW02-16(t), TW17-16(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the middle part of FA model (texp=0-100 s)

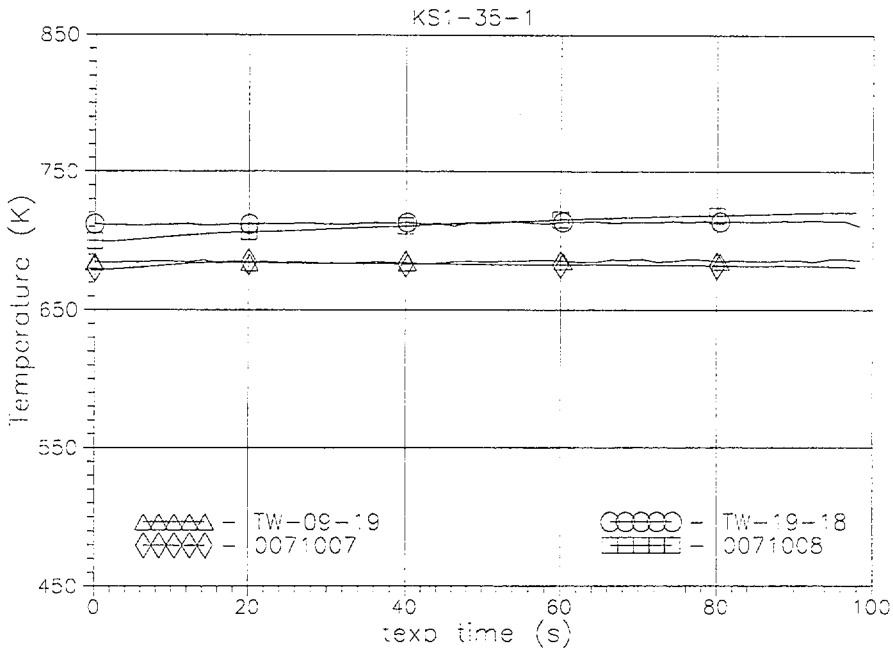


Fig. C-11. Comparison of measured TW19-18(t), TW09-19(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the bottom part of FA model (texp=0-100 s)

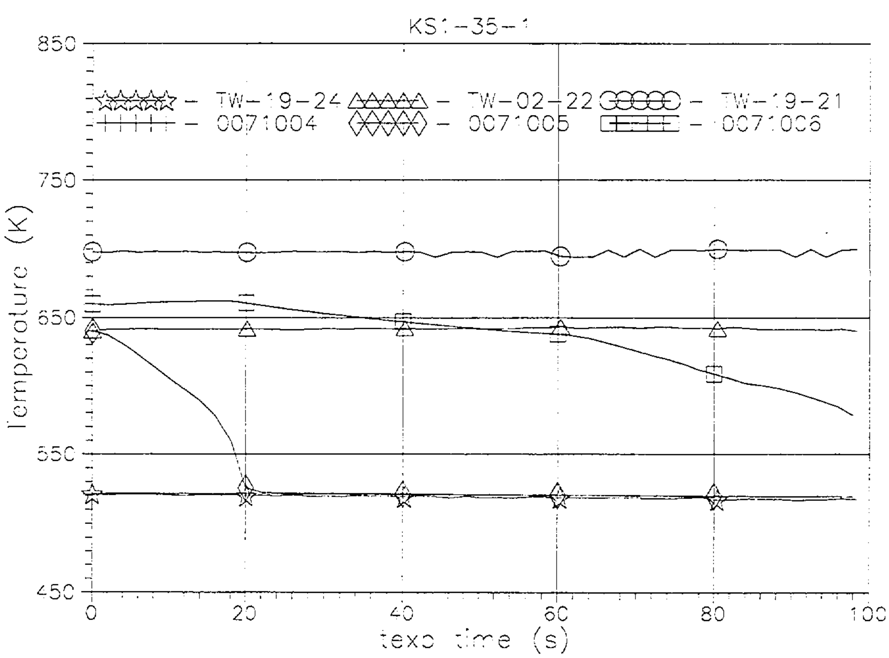


Fig. C-12. Comparison of measured TW19-21(t), TW02-22(t), TW19-24(t) and RELAP5/MOD3.2-calculated heated tube inside wall temperatures histories in the bottom part of FA model (texp=0-100 s)

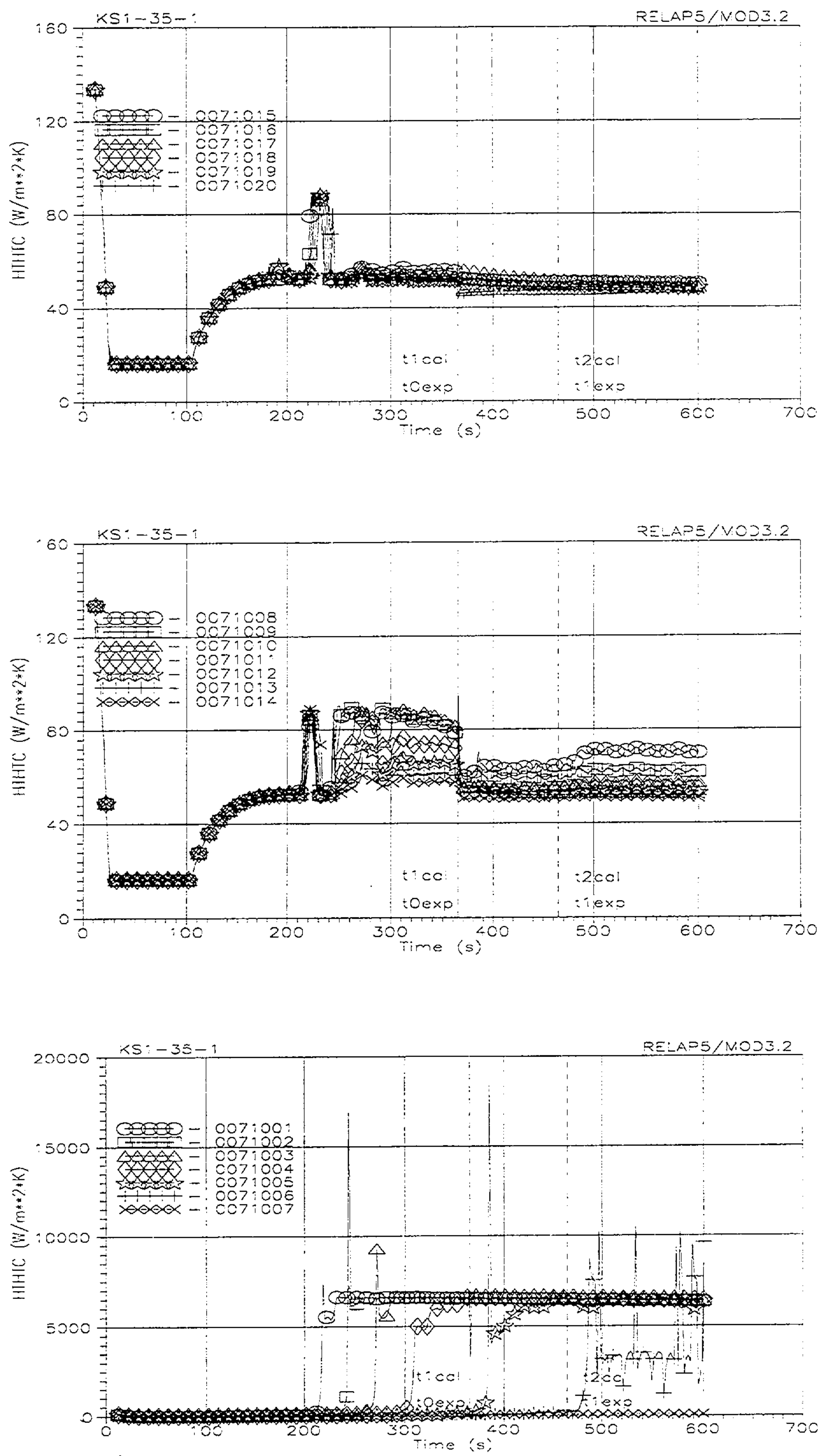


Fig. C-13. Behavior of RELAP5/MOD3.2-calculated Hw1(t) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper, middle and bottom parts of FA model (tcal=0-600 s),dtmax=0.01 s Restart t=365 s.

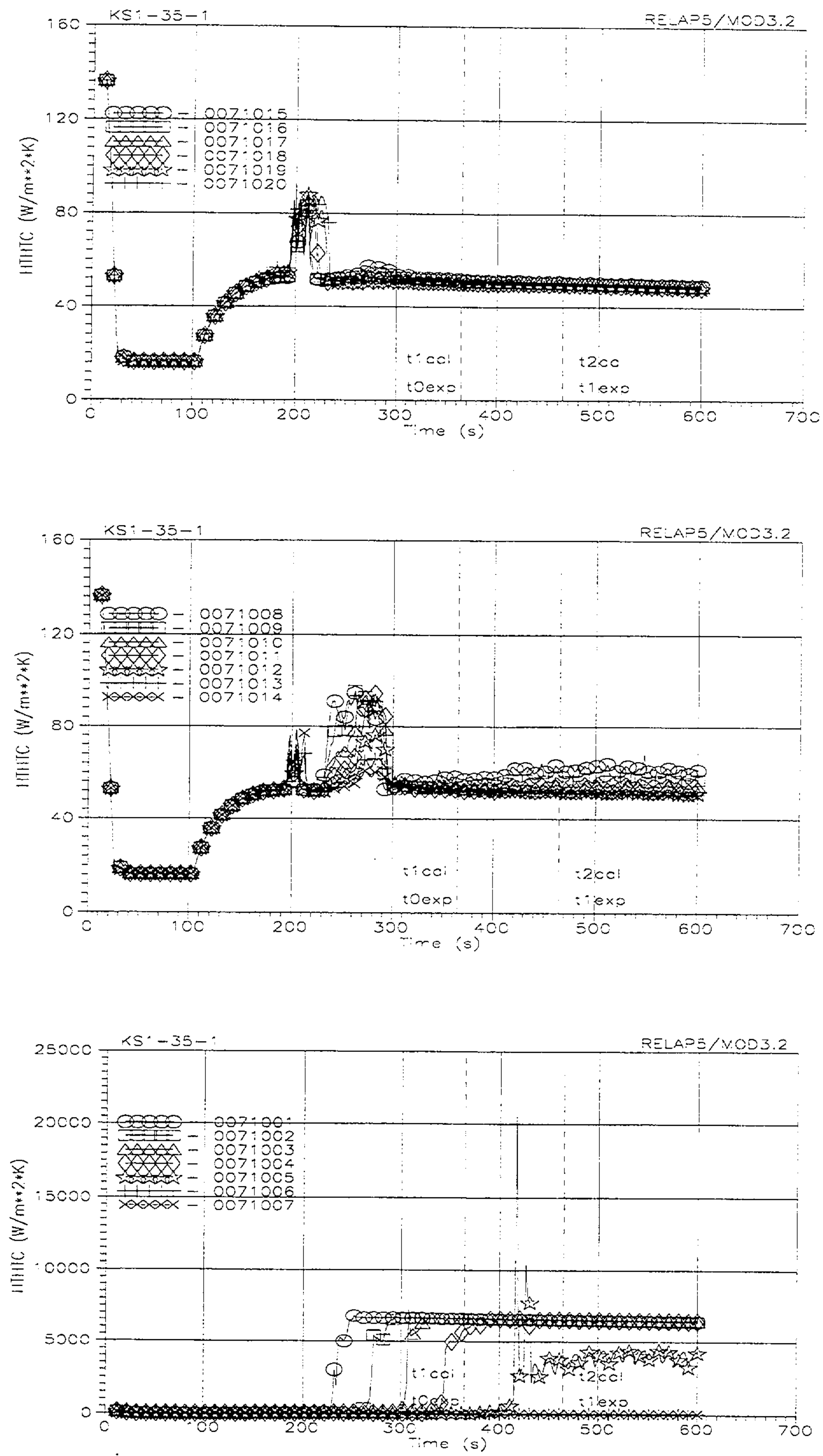


Fig. C-14. Behavior of RELAP5/MOD3.2-calculated Hw1(t) coefficient of heat transfer from outer surfaces of rod simulators to coolant in the upper, middle and bottom parts of FA model (tcal=0-600 s)),dtmax=0.2 s Restart t=365 s.

APPENDIX- D

BASE CASE INPUT DECK

Steady state base case input deck listing of KS-1 test 35-1

```
=ksl 35 01 test
*
*Input Deck for KS1-VVER-1000 Tests
*
**********************************************************
**********************************************************
*Assesment of RELAP5/MOD3.2 against KS1 test 35-01
**********************************************************
**********************************************************
0000100 new stdy-st
*0000101 inp-chk
0000102 si si
0000104 cmpress
0000110 air
**********************************************************
*         Time Steps Control Cards
**********************************************************
*crdno time min_dt max_dt ssdtt minor major restart
0000201 10. 1.0-6 0.005 15003 200 10000 10000
0000202 1000. 1.0-6 0.100 15003 100 10000 10000
**********************************************************
*                   HYDRODYNAMIC COMPONENTS
**********************************************************
*
* LOWER WATER COMMUNICATION LINE, components no v.1,sj2
*
0010000 water pipe *component no v.1
0010001 69
0010101 3.32-3 22 * water pipe dh=0.065 m
0010102 3.14-4 32 * water pipe dh=0.020 m
0010103 3.32-3 69 * water pipe dh=0.065 m
*
0010201 3.32-3 09 * water pipe dh=0.065 m
0010202 1.13-4 10 * water pipe dh=0.065 m
0010203 3.32-3 21 * water pipe dh=0.065 m
0010204 3.14-4 31 * water pipe dh=0.020 m
0010205 3.32-3 43 * water pipe dh=0.065 m
0010206 1.13-4 44 * water pipe dh=0.065 m
0010207 3.32-3 68 * water pipe dh=0.065 m
*
0010301 0.425 4, 0.4 8, 0.355 18, 0.4 22,
0010302 0.7 32
0010303 0.4 35, 0.355 45, 0.355 65, 0.375 69
*
0010601 -1.0 4, -90.0 8, 0.0 18, 90.0 22,
0010602 -3.3 32
0010603 -90.0 35, 0.0 45, 90.0 65, 1.0 69
*
0010801 5.0-5 0.065 22
0010802 5.0-5 0.020 32
0010803 5.0-5 0.065 69
*
0010901 0.0 0.0 3, 0.5 0.5 4, 0.0 0.0 7, 0.5 0.5 8
0010902 0.0 0.0 17, 0.5 0.5 18, 0.0 0.0 21
0010903 0.5 0.5 22, 0.0 0.0 31, 0.5 0.5 32, 0.0 0.0 35
0010904 0.5 0.5 36, 0.0 0.0 45, 0.5 0.5 46, 0.0 0.0 65
0010905 0.5 0.5 66, 0.0 0.0 68
*
*crdno tlpvbfe
0011001 0010000 69
*crdno fvcahs
0011101 001000 68
*
*crdno
*0011201 102 4.20+6 1.0 0.0 0.0 0.0 6
*0011202 102 4.20+6 0.0 0.0 0.0 0.0 7
0011203 103 4.20+6 516.0 0.0 0.0 0.0 69
*0011204 102 4.20+6 0.0 0.0 0.0 0.0 51
*0011205 102 4.20+6 1.0 0.0 0.0 0.0 69
0011300 1
0011301 0.0 0.0 0.0 68
*---------------------------------------------------------
*
0020000 sj2 sngljun
*crdno from to area floss rloss fvcahs
0020101 001010000 021020003 3.32-3 0.85 0.45 001100
0020201 0 0.0 0.0 0.0
*---------------------------------------------------------
*
* LOWER PLENUM MODEL, components no v.21,sj22,v.23
*
0210000 lowplenm annulus * component no v.21
0210001 5
0210101 0.044 1,0.0574 4, 0.02243 5
0210301 0.09 1,0.08 2,0.05 5
0210601 90.0 5
0210801 5.0-5 0.14 1, 5.0-5 0.22 4, 5.0-6 0.102 5
0210901 0.0 0.0 4
*crdno tlpvbfe
0211001 0010000 5
*crdno fvcahs
0211101 001000 4
*
0211201 102 4.20+6 0.0 0.0 0.0 0.0 1
0211202 102 4.20+6 0.0 0.0 0.0 0.0 2
0211203 102 4.20+6 0.8 0.0 0.0 0.0 5
0211300 1
0211301 0.0 0.0 0.0 4
0211401 0.14 0.0 1.0 1.0 1
0211402 0.22 0.0 1.0 1.0 3
0211403 0.102 0.0 1.0 1.0 4
*---------------------------------------------------------
*
0220000 sj22 sngljun
*crdno from to area floss rloss fvcahs
0220101 021010002 023030001 2.14-3 0.0 0.0 101100
0220110 0.013 0.0 1.0 1.0
0220201 0 0.0 0.0 0.0
*---------------------------------------------------------
*
0230000 lowplenm pipe * component no v.23
0230001 6
0230102 0.00973 5, 3.09-3 6
0230301 0.06 1, 0.09 2,0.08 3, 0.05 6
0230601 90.0 6
0230802 5.0-5 0.0429 5, 5.0-6 9.73-3 6
0230901 0.0 0.0 5
*
*crdno tlpvbfe
0231001 0010100 6
*crdno fvcahs
0231101 001000 5
*
0231201 102 4.20+6 0.0 0.0 0.0 0.0 1
0231202 102 4.20+6 0.0 0.0 0.0 0.0 4
0231203 102 4.20+6 0.8 0.0 0.0 0.0 6
0231300 1
0231301 0.0 0.0 0.0 5
*0231401 0.0429 0.0 1.0 1.0 2
0231402 9.73-3 0.0 1.0 1.0 5
*---------------------------------------------------------
*
*CORE MODEL, components no sj24,v.5,sj25,v.7,sj8
*
0240000 sj24 sngljun *outside annulus inlet
*crdno from to area floss rloss fvcahs
0240101 021050002 005010001 0.0 0.5 0.5 001100
0240201 0 0.0 0.0 0.0
*---------------------------------------------------------
*
0050000 outside annulus *component no v.5
0050001 20
0050101 0.02243 20
```

```
0050301 0.125 20
0050601 90. 20
0050801 5.0-5 0.0255 20
0050901 0.0 0.0 19
*
*crdno tlpvbfe
0051001 0010000 20
*crdno fvcahs
0051101 001000 19
*
*0051201 103 4.20+6 489.0 0.0 0.0 0.0 2
*0051201 102 4.20+6 1.0 0.0 0.0 0.0 1
0051202 102 4.20+6 1.0 0.0 0.0 0.0 20
0051300 1
0051301 0.0 0.0 0.0 19
*-----------------------------------------------------
*
0250000 sj25 sngljun *core pipe inlet
*crdno from to area floss rloss fvcahs
0250101 023060002 007010001 0.0 0.15 0.15 001100
0250201 0 0.0 0.0 0.0
*-----------------------------------------------------
*
0070000 core pipe * component no v.7, bundle
0070001 21
0070101 1.8065-3 20
0070102 3.09055-3 21
*
0070301 0.125 20
0070302 0.120 21
*
0070601 90. 21
*
0070801 1.0-5 9.75-3 20
0070802 1.0-5 16.07-3 21
*
0070901 0.0 0.0 1
0070902 0.26 0.26 2
0070903 0.0 0.0 3
0070904 0.26 0.26 4
0070905 0.0 0.0 5
0070906 0.26 0.26 6
0070907 0.0 0.0 7
0070908 0.26 0.26 8
0070909 0.0 0.0 9
0070910 0.26 0.26 10
0070911 0.0 0.0 11
0070912 0.26 0.26 12
0070913 0.0 0.0 13
0070914 0.26 0.26 14
0070915 0.0 0.0 15
0070916 0.26 0.26 16
0070917 0.0 0.0 17
0070918 0.26 0.26 18
0070919 0.0 0.0 19
0070920 0.4 0.4 20
*
*crdno tlpvbfe
0071001 0010100 21
*crdno fvcahs
0071101 001000 20
*
*0071201 102 4.20+6 0.0 0.0 0.0 0.0 1
0071202 102 4.20+6 1.0 0.0 0.0 0.0 21
0071300 1
0071301 0.0 0.0 0.0 20
0071401 9.75-3 0.0 1.000 1.00 20
*-----------------------------------------------------
*
0080000 sj8 sngljun *core channal outlet
*crdno from to area floss rloss fvcahs
0080101 007210002 009020003 0.0 1.3 0.7 001100
0080110 16.07-3 0.0 1.0 1.0
0080201 0 0.0 0.0 0.0
*-----------------------------------------------------*
*
*UPPER PLENUM MODEL, components no v.9,sj10,v.11
*
0090000 outchanl annulus * component no v.9
0090001 3
0090101 81.0-3 1
0090102 65.0-3 3
0090301 0.1 1,0.05 2,0.1 3
0090601 90.0 3
0090801 5.0-5 0.0 3
0090901 0.0 0.0 2
*
*crdno tlpvbfe
0091001 0010000 3
*crdno fvcahs
0091101 001000 2
*
0091201 102 4.20+6 0.0 0.0 0.0 0.0 1
0091202 102 4.20+6 1.0 0.0 0.0 0.0 3
*
0091300 1
0091301 0.0 0.0 0.0 2
*-----------------------------------------------------
*
0100000 sj10 sngljun
*crdno from to area floss rloss fvcahs
0100101 009020004 011010001 0.0 0.35 0.85 001100
0100201 0 0.0 0.0 0.0
*-----------------------------------------------------
*
0110000 upplenm pipe *component no v.11,upper plenum dh=0.102 m
0110001 11
0110101 8.17-3 11
0110301 0.42 1, 0.50 2, 0.6 3, 0.70 4,
0110302 1.0 10, 0.29 11
0110601 0.0 1, 90.0 11
0110801 5.0-5 0.102 11
0110901 1.15 1.15 1
0110902 0.0 0.0 10
*
*crdno tlpvbfe
0111001 0010000 11
*crdno fvcahs
0111101 001000 10
*
0111201 102 4.20+6 1.0 0.0 0.0 0.0 11
0111300 1
0111301 0.0 0.0 0.0 10
*-----------------------------------------------------
*
*HOT LEG MODEL and STEAM GENERATOR TUBES
SIMULATOR,components no sj12,v.14
*
0120000 sj12 sngljun
*crdno from to area floss rloss fvcahs
0120101 011100002 014000000 0.0 0.85 1.0 001100
0120201 0 0.0 0.0 0.0
*-----------------------------------------------------
*
0140000 hotleg pipe *component no v.14, hot leg and sg tubes simulator
0140001 14
0140101 0.0033183 14
0140301 1.0 1, 1.85 5, 1.0 7, 2.0 14
*0140301 1.0 1, 1.85 5, 1.5 6, 2.0 14
*
0140601 1.0 7, 1.0 14
*
0140801 5.0-5 0.065 14
*
0140901 0.5 0.5 1
0140902 0.0 0.0 4
```

```
0140903 0.5 0.5 5
0140904 0.0 0.0 13
*
*crdno tlpvbfe
0141001 0010000 14
*crdno fvcahs
0141101 001000 13
*
0141201 102 4.20+6 1.0 0.0 0.0 0.0 14
0141300 1
0141301 0.0 0.0 0.0 13
*-----------------------------------------------------
*
0150000 sj15 sngljun
*crdno from to area floss rloss fvcahs
*0150101 106010000 016000000 0.0 0.0 0.0 001100
0150101 014010000 016000000 0.0 0.0 0.0 001100
0150201 0 0.0 0.0 0.0
*------------------------------------------------------------
*
0160000 pressure tmdpvol
*crdno area lenght volume h.ang v.ang elev rgh dhyd pvbfe
0160101 0.2525 3.2 0.0 0.0 0.0 0.0 5.0-5 0.0 00000
0160200 2
0160201 0.0 4.20+6 1.0
*------------------------------------------------------------
*
*DOWNCOMER MODEL, components no sj101,v.102,sj103,v.104
*
1010000 sj101 sngljun
*crdno from to area floss rloss fvcahs
1010101 001010001 102010001 3.49-4 0.5 0.5 001100
1010201 0 0.0 0.0 0.0
*----------------------------------------------------
*
1020000 downcom1 pipe *component no v.102 dh=0.080 m
1020001 32
1020101 0.0050265 32
1020301 0.25 30, 0.2 31, 0.23 32
1020601 90. 32
1020801 5.0-5 0.08 32
1020901 0.0 0.0 31
*
*crdno tlpvbfe
1021001 0010000 32
*crdno fvcahs
1021101 001000 31
*
*1021201 103 4.20+6 516.0 0.0 0.0 0.0 1
1021201 102 4.20+6 0.5 0.0 0.0 0.0 1
*1021202 102 4.20+6 0.8 0.0 0.0 0.0 2
1021203 102 4.20+6 1.0 0.0 0.0 0.0 32
1021300 1
1021301 0.0 0.0 0.0 31
*------------------------------------------------
*
1030000 sj103 sngljun
*crdno from to area floss rloss fvcahs
1030101 102310003 104010001 0.0 0.5 0.5 001100
1030201 0 0.0 0.0 0.0
*------------------------------------------------
*
1040000 downcom2 pipe *component v.104 dh=0.073 m
1040001 11
1040101 0.0041854 4
1040102 0.00721 8, 0.00488 9, 0.0076 11
*
1040301 0.38 1, 0.35 2, 0.8 3, 0.7925 4,
1040302 0.9 5, 1.25 7, 1.29 8,
1040303 1.07 9, 0.928856013 10, 0.29 11
*
1040601 0.0 1, 45.0 2, 90.0 11
*
1040801 5.0-5 0.073 4
1040802 5.0-5 0.067 8,5.0-5 0.0299 9,5.0-5 0.05288 11
*
1040901 0.07 0.07 2
1040902 0.00 0.00 3
1040903 0.52 0.20 4
1040904 0.00 0.00 7
1040905 0.16 0.24 8
1040906 0.24 0.16 9
1040907 0.00 0.00 10
*
*crdno tlpvbfe
1041001 0010000 11
*crdno fvcahs
1041101 001000 10
*
*1041201 103 4.20+6 489.0 0.0 0.0 0.0 03
*1041202 102 4.20+6 1.0 0.0 0.0 0.0 04
1041203 102 4.20+6 1.0 0.0 0.0 0.0 11
*
1041300 1
1041301 0.0 0.0 0.0 10
*-------------------------------------------------------
*
1050000 sj105 sngljun
*crdno from to area floss rloss fvcahs
1050101 104100002 106010001 0.0 0.5 0.5 001100
1050201 0 0.0 0.0 0.0
*-------------------------------------------------------
*
*Cold leg model and steam generator tubes simulator,component no 106
1060000 cold pipe
1060001 6
1060101 0.0033183 6
1060301 1.39 5, 1.5 6
1060601 1.0 6
*1060601 0.3716971 6
1060801 5.0-5 0.065 6
*
1060901 0.0 0.0 4
1060902 0.5 0.5 5
*
*crdno tlpvbfe
1061001 0010000 6
*crdno fvcahs
1061101 001000 5
*
1061201 102 4.20+6 1.0 0.0 0.0 0.0 6
1061300 1
1061301 0.0 0.0 0.0 5
*-------------------------------------------------------
*
1070000 sj107 sngljun
*crdno from to area floss rloss fvcahs
1070101 106010000 014070003 0.0 0.1 0.1 001100
1070201 0 0.0 0.0 0.0
*-------------------------------------------------------
*
*HEAT STRUCTURE
*
10011000 22 3 2 0 0.0325
10011100 0 1
10011101 1 0.035 1 0.0375
10011201 1 2
10011301 0.0 2
10011401 516.2 3
10011501 001010000 10000 1 1 0.425 4
10011502 001050000 10000 1 1 0.4 8
10011503 001090000 10000 1 1 0.355 18
10011504 001190000 10000 1 1 0.4 22
10011601 -3 0 3004 1 0.425 4
10011602 -3 0 3004 1 0.4 8
10011603 -3 0 3004 1 0.355 18
```

```
10011604 -3 0 3004 1 0.4 22
10011701 0 0.0 0.0 0.0 22
10011801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 22
*
10012000 10 3 2 0 0.01
10012100 0 1
10012101 1 0.0125 1 0.015
10012201 1 2
10012301 0.0 2
10012401 516.0 3
10012501 001230000 10000 1 1 0.7 10
10012601 -3 0 3005 1 0.7 10
10012701 0 0.0 0.0 0.0 10
10012801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 10
*
10013000 37 3 2 0 0.0325
10013100 0 1
10013101 1 0.035 1 0.0375
10013201 1 2
10013301 0.0 2
10013400 0
10013401 516.2 3
10013501 001330000 10000 1 1 0.4 3
10013502 001360000 10000 1 1 0.355 13
10013503 001460000 10000 1 1 0.355 33
10013505 001500000 10000 1 1 0.375 37
10013601 -3 0 3004 1 0.4 3
10013602 -3 0 3004 1 0.355 13
10013603 -3 0 3004 1 0.355 33
10013605 -3 0 3004 1 0.375 37
10013701 0 0.0 0.0 0.0 37
10013801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 37
*
10212000 5 3 2 0 0.25
10212100 0 1
10212101 1 0.3 1 0.35
10212201 1 2
10212301 0.0 2
10212401 516.2 3
10212501 021010000 00000 1 1 0.09 1
10212502 021020000 00000 1 1 0.08 2
10212503 021030000 00000 1 1 0.05 3
10212504 021040000 10000 1 1 0.05 5
10212601 -3 0 3006 1 0.09 1
10212602 -3 0 3006 1 0.08 2
10212603 -3 0 3006 1 0.05 3
10212604 -3 0 3006 1 0.05 5
10212701 0 0.0 0.0 0.0 5
10212801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 5
*
10211000 5 3 2 0 0.11
10211100 0 1
10211101 1 0.12 1 0.13
10211201 1 2
10211301 0.0 2
10211401 526.4 3
10211501 023020000 00000 1 1 0.09 1
10211502 023030000 00000 1 1 0.08 2
10211503 023040000 00000 1 1 0.05 3
10211504 023050000 10000 1 1 0.05 5
10211601 021010000 00000 1 1 0.09 1
10211602 021020000 00000 1 1 0.08 2
10211603 021030000 00000 1 1 0.05 3
10211604 021040000 10000 1 1 0.05 5
10211701 0 0.0 0.0 0.0 5
10211801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 5
10211901 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 5
*
10071000 20 7 2 0 0.00297
10071100 0 1
10071101 1 0.00325 1 0.0035 1 0.00375 1 0.004 1 0.00425 1 0.0045
10071201 1 6
10071301 1. 6
10071401 526.4 7
10071501 0 0 0 1 2.375 20
10071601 007010000 10000 110 1 2.375 20
10071701 001 0.05 0.0 0.0 20
10071900 1
10071901 0.01346 0.0625 2.4375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 1
10071902 0.01346 0.1875 2.3125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 2
10071903 0.01346 0.3125 2.1875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 3
10071904 0.01346 0.4375 2.0625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 4
10071905 0.01346 0.5625 1.9375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 5
10071906 0.01346 0.6875 1.8125 0.0 0.0 0.0 0.0 1.0 0:125 1.42 1.0 6
10071907 0.01346 0.8125 1.6875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 7
10071908 0.01346 0.9375 1.5625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 8
10071909 0.01346 1.0625 1.4375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 9
10071910 0.01346 1.1875 1.0125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 10
10071911 0.01346 1.3125 1.1875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 11
10071912 0.01346 1.4375 1.0625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 12
10071913 0.01346 1.5625 0.9375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 13
10071914 0.01346 1.6875 0.8125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 14
10071915 0.01346 1.8125 0.6875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 15
10071916 0.01346 1.9375 0.5625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 16
10071917 0.01346 2.0625 0.4375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 17
10071918 0.01346 2.1875 0.3125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 18
10071919 0.01346 2.3125 0.1875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 19
10071920 0.01346 2.4375 0.0625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 20
*
10072000 20 14 2 0 0.031
10072100 0 1
10072101 1 0.032 1 0.033 1 0.034 1 0.035 1 0.036 1 0.037
10072102 1 0.038 1 0.039 1 0.040
10072103 1 0.041125 1 0.04225 1 0.043375 1 0.0445
10072201 2 9 1 13
10072301 0.0 13
10072401 526.4 14
10072501 007010000 10000 1 1 0.125 20
10072601 005010000 10000 1 1 0.125 20
10072701 0 0.0 0.0 0.0 20
10072801 0.0586 15.0 15.0 0.0 0.0 0.0 0.0 1.0 20
10072901 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 20
*
10052000 20 3 2 0 0.0955
10052100 0 1
10052101 1 0.1045 1 0.1095
10052201 1 2
10052301 0.0 2
10052401 526.4 3
10052501 005010000 10000 1 1 0.125 20
10052601 -3 0 3006 1 0.125 20
10052701 0 0.0 0.0 0.0 20
10052801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 20
*
10091000 1 2 2 0 0.037
10091100 0 1
10091101 1 0.043
10091201 1 1
10091301 0.0 1
10091401 526.4 2
10091501 007210000 10000 1 1 0.1 1
10091601 009010000 10000 1 1 0.1 1
10091701 0 0.0 0.0 0.0 1
10091801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 1
10091901 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 1
*
10092000 3 3 2 0 0.15
10092100 0 1
10092101 1 0.161 1 0.172
10092201 1 2
10092301 0.0 2
10092401 526.4 3
10092501 009010000 10000 1 1 0.10 1
10092502 009020000 10000 1 1 0.05 2
10092503 009030000 10000 1 1 0.10 3
10092601 -3 0 3006 1 0.10 1
```

```
10092602 -3 0 3006 1 0.05 2
10092603 -3 0 3006 1 0.10 3
10092701 0 0.0 0.0 0.0 3
10092801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 3
*
10111000 11 3 2 0 0.061
10111100 0 1
10111101 1 0.067 1 0.073
10111201 1 2
10111301 0.0 2
10111401 526.4 3
10111501 011010000 0 1 1 0.42 1
10111502 011020000 0 1 1 0.3 2
10111503 011030000 0 1 1 0.51 3
10111504 011030000 0 1 1 0.74734 4
10111505 011040000 10000 1 1 1.00 10
10111506 011110000 10000 1 1 0.29 11
10111601 -3 0 3008 1 0.42 1
10111602 -3 0 3008 1 0.3 2
10111603 -3 0 3008 1 0.51 3
10111604 -3 0 3008 1 0.74734 4
10111605 -3 0 3008 1 1.0 10
10111606 -3 0 3008 1 0.29 11
10111701 0 0.0 0.0 0.0 11
10111801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 11
*
10141000 14 3 2 0 0.0325
10141100 0 1
10141101 1 0.035 1 0.0375
10141201 1 2
10141301 0.0 2
10141401 526.4 3
10141501 014010000 10000 1 1 1.0 1
10141502 014020000 10000 1 1 1.85 5
10141503 014040000 10000 1 1 1.0 7
10141504 014070000 10000 1 1 2.0 14
10141601 -3 0 3004 1 1.0 1
10141602 -3 0 3004 1 1.85 5
10141603 -3 0 3009 1 1.0 7
10141604 -3 0 3004 1 2.0 14
10141701 0 0.0 0.0 0.0 14
10141801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 14
*
11022000 32 4 2 0 0.04
11022100 0 1
11022101 1 0.0475 1 0.055
11022102 1 0.0625
11022201 2 1 2 2 1 3
11022301 0.0 3
11022401 526.4 4
11022501 102010000 10000 1 1 0.25 30
11022502 102020000 10000 1 1 0.2 31
11022503 102050000 10000 1 1 0.23 32
11022601 -3 0 3007 1 0.25 30
11022602 -3 0 3007 1 0.2 31
11022603 -3 0 3007 1 0.23 32
11022701 0 0.0 0.0 0.0 32
11022801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 32
*
11041000 4 3 2 0 0.0365
11041100 0 1
11041101 1 0.0405 1 0.0445
11041201 1 2
11041301 0.0 2
11041401 526.4 3
11041501 104010000 0 1 1 0.38 1
11041502 104020000 0 1 1 0.35 2
11041503 104030000 10000 1 1 0.8 3
11041504 104030000 10000 1 1 0.7713 4
11041601 -3 0 3008 1 0.38 1
11041602 -3 0 3008 1 0.35 2
11041603 -3 0 3008 1 0.8 3
11041604 -3 0 3008 1 0.7713 4
11041701 0 0.0 0.0 0.0 4
11041801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 4
*
11042000 7 3 2 0 0.051
11042100 0 1
11042101 1 0.054 1 0.057
11042201 1 2
11042301 0.0 2
11042401 526.4 3
11042501 104050000 0 1 1 0.9 1
11042502 104060000 10000 1 1 1.25 3
11042503 104080000 0 1 1 1.297 4
11042504 104090000 0 1 1 1.07 5
11042505 104100000 0 1 1 0.795 6
11042506 104110000 0 1 1 0.29 7
11042601 -3 0 3008 1 0.9 1
11042602 -3 0 3008 1 1.25 3
11042603 -3 0 3008 1 1.297 4
11042604 -3 0 3008 1 1.07 5
11042605 -3 0 3008 1 0.795 6
11042606 -3 0 3008 1 0.29 7
11042701 0 0.0 0.0 0.0 7
11042801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 7
*
11061000 6 3 2 0 0.0325
11061100 0 1
11061101 1 0.035 1 0.0375
11061201 1 2
11061301 0.0 2
11061401 526.4 3
11061501 106010000 10000 1 1 1.39 5
11061502 106030000 0 1 1 1.5 6
11061601 -3 0 3004 1 1.39 5
11061602 -3 0 3009 1 1.5 6
11061701 0 0.0 0.0 0.0 6
11061801 0.0 15.0 15.0 0.0 0.0 0.0 0.0 1.0 6
*general tables
***matereal
20100100 tbl/fctn 1 1
20100101 295.0 15.
20100102 400.0 16.
20100103 500.0 18.
20100104 600.0 20.
20100105 700.0 21.
20100106 800.0 23.
20100107 900.0 25.
20100108 1000.0 26.
20100109 1100.0 28.
20100110 1200.0 29.
20100151 295.0 3.686+6
20100152 400.0 3.686+6
20100153 500.0 3.801+6
20100154 600.0 3.874+6
20100155 700.0 3.955+6
20100156 800.0 3.991+6
20100157 900.0 4.039+6
20100158 1000.0 4.043+6
20100159 1100.0 4.113+6
20100160 1200.0 4.115+6
*
20100200 tbl/fctn 1 1
20100201 295.0 2.25
20100202 400.0 1.8
20100203 500.0 1.65
20100204 600.0 1.5
20100205 700.0 1.35
20100206 800.0 1.2
20100207 900.0 1.112
20100251 295.0 2.128+6
20100252 400.0 2.408+6
20100253 500.0 2.604+6
20100254 600.0 2.772+6
20100255 700.0 2.940+6
```

20100256 800.0 3.080+6
20100257 900.0 3.220+6
*
20100300 s-steel
**heat source
20200100 power 0 1. 1000.
20200101 000.00 0.0
20200102 100.00 0.0
20200103 200.00 9.52
*
**out temperature
20200300 temp 0 1.0 1.0 0.0
20200301 0.0 300.0
*diam 75
20200400 htc-t 0 1.0 2.3
20200401 000.0 0.0
20200402 100.0 0.0
20200403 200.0 3.0
*diam 28
20200500 htc-t 0 1.0 4.6
20200501 000.0 0.0
20200502 100.0 0.0
20200503 200.0 2.9
*diam can 1
20200600 htc-t 0 1.0 2.0
20200601 000.0 0.0
20200602 100.0 0.0
20200603 200.0 3.0
*diam can 2
20200700 htc-t 0 1.0 2.4
20200701 000.0 0.0
20200702 100.0 0.0
20200703 200.0 3.0
*diam vks 1 2
20200800 htc-t 0 1.0 2.3
20200801 000.0 0.0
20200802 100.0 0.0
20200803 200.0 3.0
*diam 75 (top)
20200900 htc-t 0 1.0 4.3
20200901 000.0 0.0
20200902 100.0 0.0
20200903 200.0 3.00
.*end of data set

Input deck 1
Base case transient restart input deck listing of KS-1 test 35-1
Maximum time step 0.01, restart time 0.0 s
=
0000100 restart transnt
*0000101 inp-chk
0000102 si si
0000103 970 cmpress
0000202 365. 1.0-6 0.001 15003 200 100000 1000000
0000203 600. 1.0-6 0.001 15003 200 1000000 1000000
*
0150000 autleg delete
*
0160000 cmpnstr delete
*
.end data set

Input deck 2
Time step sensitivty restart input deck listing of KS-1 test
Maximum time step 0.2s, restart time 0.0 s
=
0000100 restart transnt
*0000101 inp-chk
0000102 si si
0000103 970 cmpress
0000202 365. 1.0-6 0.2 15003 10 100000 1000000
0000203 600. 1.0-6 0.2 15003 10 1000000 1000000
*
0150000 autleg delete
*
0160000 cmpnstr delete
*
.end data set

Input deck 3
Sensitivty Tw(z)exp variation restart input deck listing of KS-1 test 35-1
Maximum time step dt=0.01s, restart time 365.0 s.
Using base case input deck, dT=0.01 s.
=
0000100 restart transnt
*0000101 inp-chk
0000102 si si
0000103 4483 cmpress
*
0000203 600. 1.0-6 0.01 15003 200 1000 10000
*
10071000 20 7 2 0 0.00297
10071100 0 1
10071101 1 0.00325 1 0.0035 1 0.00375 1 0.004 1 0.00425 1 0.0045
10071201 1 6
10071301 1. 6
*10071401 526.4 7
10071400 -1
10071401 521.0 521.0 521.0 521.0 521.0 521.0 521.0
10071402 521.0 521.0 521.0 521.0 521.0 521.0 521.0
10071403 521.0 521.0 521.0 521.0 521.0 521.0 521.0
10071404 521.0 521.0 521.0 521.0 521.0 521.0 521.0
10071405 640.0 640.0 640.0 640.0 640.0 640.0 640.0
10071406 660.0 660.0 660.0 660.0 660.0 660.0 660.0
10071407 680.0 680.0 680.0 680.0 680.0 680.0 680.0
10071408 700.0 700.0 700.0 700.0 700.0 700.0 700.0
10071409 725.0 725.0 725.0 725.0 725.0 725.0 725.0
10071410 719.0 719.0 719.0 719.0 719.0 719.0 719.0
10071411 719.0 719.0 719.0 719.0 719.0 719.0 719.0
10071412 743.0 743.0 743.0 743.0 743.0 743.0 743.0
10071413 742.0 742.0 742.0 742.0 742.0 742.0 742.0
10071414 731.0 731.0 731.0 731.0 731.0 731.0 731.0
10071415 743.0 743.0 743.0 743.0 743.0 743.0 743.0
10071416 751.0 751.0 751.0 751.0 751.0 751.0 751.0
10071417 695.0 695.0 695.0 695.0 695.0 695.0 695.0
10071418 742.0 742.0 742.0 742.0 742.0 742.0 742.0
10071419 734.0 734.0 734.0 734.0 734.0 734.0 734.0
10071420 670.0 670.0 670.0 670.0 670.0 670.0 670.0
10071501 0 0 0 1 2.375 20
10071601 007010000 10000 110 1 2.375 20
10071701 001 0.05 0.0 0.0 20
10071900 1
10071901 0.01346 0.0625 2.4375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 1
10071902 0.01346 0.1875 2.3125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 2
10071903 0.01346 0.3125 2.1875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 3
10071904 0.01346 0.4375 2.0625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 4
10071905 0.01346 0.5625 1.9375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 5
10071906 0.01346 0.6875 1.8125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 6
10071907 0.01346 0.8125 1.6875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 7
10071908 0.01346 0.9375 1.5625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 8
10071909 0.01346 1.0625 1.4375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 9
10071910 0.01346 1.1875 1.0125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 10
10071911 0.01346 1.3125 1.1875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 11
10071912 0.01346 1.4375 1.0625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 12
10071913 0.01346 1.5625 0.9375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 13
10071914 0.01346 1.6875 0.8125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 14
10071915 0.01346 1.8125 0.6875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 15
10071916 0.01346 1.9375 0.5625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 16
10071917 0.01346 2.0625 0.4375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 17
10071918 0.01346 2.1875 0.3125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 18
10071919 0.01346 2.3125 0.1875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 19
10071920 0.01346 2.4375 0.0625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 20

```
*
.end data set
```

Input deck 4
Sensitivty Tw(z)exp variation restart input deck listing of KS-1 test 35-1
Maximum time step dt=0.01s, restart time 365.0 s.
Using time step sensitivity case input deck, dT=0.2 s.

```
=
0000100 restart transnt
*0000101 inp-chk
0000102 si si
0000103 36500 cmpress
*
0000203 600. 1.0-6 0.01 15003 200 1000 10000
*
10071000 20 7 2 0 0.00297
10071100 0 1
10071101 1 0.00325 1 0.0035 1 0.00375 1 0.004 1 0.00425 1 0.0045
10071201 1 6
10071301 1. 6
*10071401 526.4 7
10071400 -1
10071401 521.0 521.0 521.0 521.0 521.0 521.0 521.0
10071402 521.0 521.0 521.0 521.0 521.0 521.0 521.0
10071403 521.0 521.0 521.0 521.0 521.0 521.0 521.0
10071404 521.0 521.0 521.0 521.0 521.0 521.0 521.0
10071405 640.0 640.0 640.0 640.0 640.0 640.0 640.0
10071406 660.0 660.0 660.0 660.0 660.0 660.0 660.0
10071407 680.0 680.0 680.0 680.0 680.0 680.0 680.0
10071408 700.0 700.0 700.0 700.0 700.0 700.0 700.0
10071409 725.0 725.0 725.0 725.0 725.0 725.0 725.0
10071410 719.0 719.0 719.0 719.0 719.0 719.0 719.0
10071411 719.0 719.0 719.0 719.0 719.0 719.0 719.0
10071412 743.0 743.0 743.0 743.0 743.0 743.0 743.0
10071413 742.0 742.0 742.0 742.0 742.0 742.0 742.0
10071414 731.0 731.0 731.0 731.0 731.0 731.0 731.0
10071415 743.0 743.0 743.0 743.0 743.0 743.0 743.0
10071416 751.0 751.0 751.0 751.0 751.0 751.0 751.0
10071417 695.0 695.0 695.0 695.0 695.0 695.0 695.0
10071418 742.0 742.0 742.0 742.0 742.0 742.0 742.0
10071419 734.0 734.0 734.0 734.0 734.0 734.0 734.0
10071420 670.0 670.0 670.0 670.0 670.0 670.0 670.0
10071501 0 0 0 1 2.375 20
10071601 007010000 10000 110 1 2.375 20
10071701 001 0.05 0.0 0.0 20
10071900 1
10071901 0.01346 0.0625 2.4375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 1
10071902 0.01346 0.1875 2.3125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 2
10071903 0.01346 0.3125 2.1875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 3
10071904 0.01346 0.4375 2.0625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 4
10071905 0.01346 0.5625 1.9375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 5
10071906 0.01346 0.6875 1.8125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 6
10071907 0.01346 0.8125 1.6875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 7
10071908 0.01346 0.9375 1.5625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 8
10071909 0.01346 1.0625 1.4375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 9
10071910 0.01346 1.1875 1.0125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 10
10071911 0.01346 1.3125 1.1875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 11
10071912 0.01346 1.4375 1.0625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 12
10071913 0.01346 1.5625 0.9375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 13
10071914 0.01346 1.6875 0.8125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 14
10071915 0.01346 1.8125 0.6875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 15
10071916 0.01346 1.9375 0.5625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 16
10071917 0.01346 2.0625 0.4375 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 17
10071918 0.01346 2.1875 0.3125 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 18
10071919 0.01346 2.3125 0.1875 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 19
10071920 0.01346 2.4375 0.0625 0.0 0.0 0.0 0.0 1.0 0.125 1.42 1.0 20

*
.end data set
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11. ABSTRACT *(200 words or less)*

This report has been prepared as a part of the Agreement on Research Participation and Technical Exchange under the International code application and Maintenance Program. KS-1 Test 35-1 data on the behavior of the heated rod temperatures in the partially uncovered VVER Core model were simulated with RELAP5/MOD3.2 to assess the code, especially its non-equilibrium (unequal phase temperatures) heat t transfer models for modeling phenomena in partially uncovered core under Small Break LOCA conditions. The test has been carried out at experimental section KS-1 of the test facility KS (RRC KI) in 1991. KS-1 experimental section (VVER Loop model) includes models of all main elements of VVER type reactor, loop hot leg model and cold leg simulator, and also horizontal SG tube bundle simulator with passive heat removal. Core model consists of 19 electrically heated rod simulators with diameter 9 mm and height 2.5m. Test 35-1 models thermal and hydraulic processes during reflux condenser mode in primary circuit with low mixture level in partially uncovered VVER core under conditions of small residual heat power, middle pressure and counter current flow in the core. First a study of the effect of the hydraulic nodalization to the code calculations was performed using different number of hydraulic volumes for Core model. after the choice of proper nodalization and maximum user-specified time step, base case calculations were done for the test. The differences between code predictions for behavior of rod simulator temperatures along the height of Core model and test data are described and analyzed. Sensitivity studies were carried out to investigate the effects of modeling on the behavior of the rod simulator temperatures along the height of Core model.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

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