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International Agreement Report

Post-Test Analysis of PIPER-ONE PO-IC-2 Experiment by RELAP5/MOD3 Codes

Prepared by
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ABSTRACT

RELAP5/MOD3.1 was applied to the PO-IC-2 experiment performed in PIPER-ONE facility, which has been modified to reproduce typical isolation condenser thermal-hydraulic conditions. RELAP5 is a well known code widely used at the University of Pisa during the past seven years. RELAP5/MOD3.1 was the latest version of the code made available by the Idaho National Engineering Laboratory at the time of the reported study. PIPER-ONE is an experimental facility simulating a General Electric BWR-6 with volume and height scaling ratios of 1/2200 and 1./1, respectively. In the frame of the present activity a once-through heat exchanger immersed in a pool of ambient temperature water, installed approximately 10 m above the core, was utilized to reproduce qualitatively the phenomenologies expected for the Isolation Condenser in the simplified BWR (SBWR). The PO-IC-2 experiment is the flood up of the PO-SD-8 and has been designed to solve some of the problems encountered in the analysis of the PO-SD-8 experiment. A very wide analysis is presented hereafter including the use of different code versions.

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1. INTRODUCTION

Innovative reactors, (essentially AP-600 and SBWR) are characterized by simplification in the design and by the presence of passive systems. Experimental and theoretical research are needed to qualify the new components introduced in the design and to characterize the new thermalhydraulic scenarios expected during accidents. Available system codes have to be validated in order to be used for evaluating the thermalhydraulic performances of the new systems, especially in case of long lasting transients evolving at low pressure /1/.

In the frame of the activities carried out at University of Pisa related to the analysis of thermalhydraulic situations of interest to the mentioned reactors (e.g. refs. /2/, and /3/), three series of experiments have been carried out utilizing the PIPER-ONE facility. They were aimed at the experimental investigation of the behaviour of systems simulating the main features of the Gravity Driven Cooling System (GDCS, first series of experiments, refs. /4/) and of the reactor pressure vessel Isolation Condenser (IC, second and third series of experiments, refs. /5/ to /7/ and ref. /8/, respectively). At the same time Relap5/mod2 /9/, and mod/3 /10/ codes have been extensively applied as best estimate tools to predict the transient scenarios of both SBWR and AP-600 reactors; (see also refs. /11/ and /12/).

PIPER-ONE is a General Electric BWR experimental simulator specifically designed in the early '80 to reproduce small break LOCAs transient scenarios (e.g. refs. /13/ - /15/). The volume scaling ratio is 1/2200, the height scaling ratio is 1/1 and the available core power is roughly 25% of the scaled full nominal power. The mentioned experiments were essentially devoted to a qualitative investigation of the thermalhydraulic conditions typical of the new components foreseen in the above reactors (essentially SBWR) and at setting up a data base suitable for code assessment. The distortions that characterize PIPER-ONE hardware in comparison with a scaled loop simulating SBWR, completely prevent a possible application of the measured data to reactor conditions: the core and downcomer heights, as well the distance between the Bottom of Active Fuel (BAF) and the Isolation Condenser top are important parameters not considered in the model.

The aforementioned applications to innovative reactors scenarios emphasized the codes inadequacies in producing reliable results when system pressure attains values below 0.5 MPa. Numerical deficiencies, limited ranges of validity of the utilized correlations and lack of user experience (i.e. difficulty to develop a suitable code use strategy) are retained mostly responsible of this situation.

The purposes of the activity described in the present document, that is the direct follow up of the post-test evaluation of the previous IC experiment PO-SD-8, ref. /7/, are essentially three:

a) to give an outline of test results obtained during the high pressure part of the test PO-IC-2 also related to the study of the Isolation Condenser performance;
b) to evaluate the capabilities of the latest version of Relap5/mod3 code (i.e. version 3.1) in reproducing the experimental scenario giving emphasis to the attempt of fixing the code limitations and the criteria for the optimal use of the code.
c) to demonstrate possible improvement in the latest code version with respect to the previous one especially in relation to condensation.

In order to achieve these objectives the original Relap5/mod2 nodalization of the PIPER-ONE apparatus /16/, also modified to perform pre-test and post-test calculations of the test PO-SD-8 (e.g. refs. /7/ and /17/), was completely revised. In particular, the number of nodes was roughly doubled also considering the available computer code capabilities. This nodalization was qualified by the calculation of the test PO-SD-8 and was used extensively for stability analysis in PIPER-ONE loop, ref. /18/.

Many sensitivity calculations were performed in the present context to identify some unknown boundary conditions (e.g. spatial distribution of heat losses to the environment) and to optimize the user choices like the countercurrent flow limiting option in the annular region of steam separator to predict liquid deentrainment from the mixture flowing out from the core.

2. DESCRIPTION OF THE EXPERIMENT

2.1 PIPER-ONE Facility

The PIPER-ONE apparatus is an integral test facility designed for reproducing the behaviour of BWRs in thermalhydraulic transient, dominated by gravity forces.

The ENEL BWR plant installed at Caorso (I) was formerly taken as the reference prototype in the design of the apparatus. The reactor is a General Electric BWR-4 plant, equipped with a Mark II containment, but it has some features of the latest GE design (e.g., 8x8 fuel rod assembly). The situation of nuclear energy in Italy, at the beginning of the experimental phase, led to a revision of the original experimental programme. The BWR-6 plant, equipped with 624 fuel bundles was assumed at reference for the first test carried-out on the PIPER-ONE facility, chosen by OECD-CSNI as ISP 21 /19/; then, the latter was used as a reference plant for all the LOCA tests, which had already been performed.

The simplified sketch of the apparatus is shown in Fig. 1; it includes the main loop, the ECCS simulators (LPCI/CS, HPCI/CS) and the systems simulating ADS, SRV and steam line, as well as the blow-down line.

Nine zones can be identified in the main loop: lower plenum, core, core bypass (outside the core), guide tube region, upper plenum, region of separators and dryers, steam dome, upper downcomer, lower downcomer and jet pump region. The correspondence between the circuit and the vessel of the actual plant is shown in Fig. 2.

The volume scaling factor is about 1/2200, while the core cell geometry and the piezometric heads acting on the lower core support plate are the same in the model and in the reference plant.

The heated bundle consists of 16 (4x4) indirectly heated electrical rods, whose height, pitch and diameter are the same as in the reference plant (Fig. 3). The maximum available power is 320 kW, corresponding to about 25% of scaled full of the reference BWR.

The one-dimensionality as well as the overall simplicity of the apparatus are highlighted in Fig. 1; this is the direct outcome of the main objective of the research. In fact, the primary circuit was designed in such a way to have as far as possible:

- one dimensional cylindrical volumes (nodes in codes calculations);
- connections between adjacent nodes clearly defined (geometric discontinuities, Venturi nozzles, orifices);
- lack of items (such as pumps and control systems) which can originate confusing situations in code calculations.

The instrumentation system has features consistent with the fundamental philosophy of the facility design:

- direct measurements of integral or mean quantities (overall heat and mass entering or exiting from the primary circuit, collapsed levels in the various zones, mean temperatures in the volumes and interfacing structures, mean density in a section, etc.);
- measurement of the various quantities (such as fluid and structure temperatures) in the middle of the volumes and at the junctions connecting the various zones.

Roughly 250 transducers are part of the instrumentation system: rod surface temperatures, absolute pressures, differential pressures, flowrates, density and temperatures of the fluid and of the structures are measured in different zones of the loop.

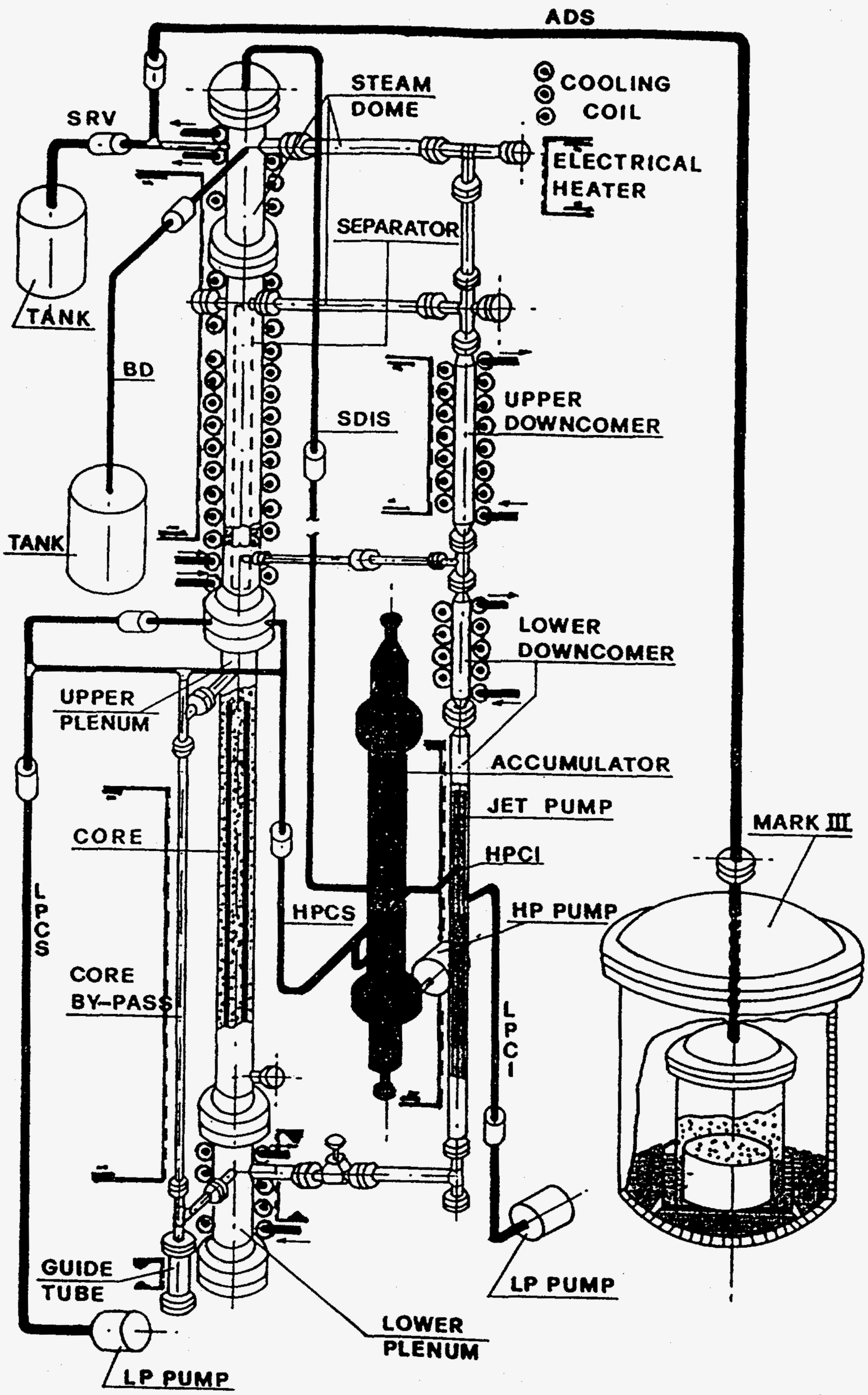


Fig. 1 - Sketch of PIPER-ONE facility

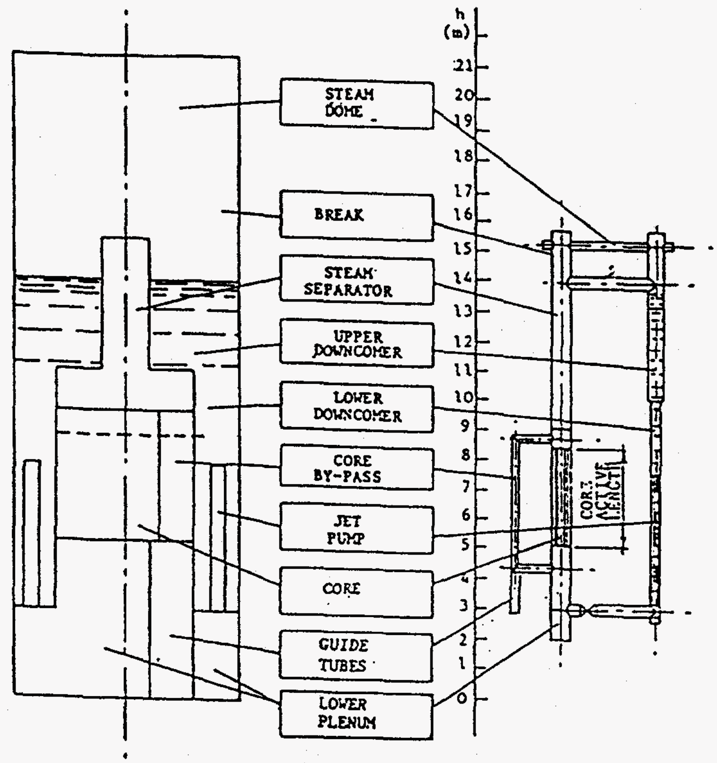


Fig. 2 - Comparison between main regions in PIPER-ONE and in BWR-6

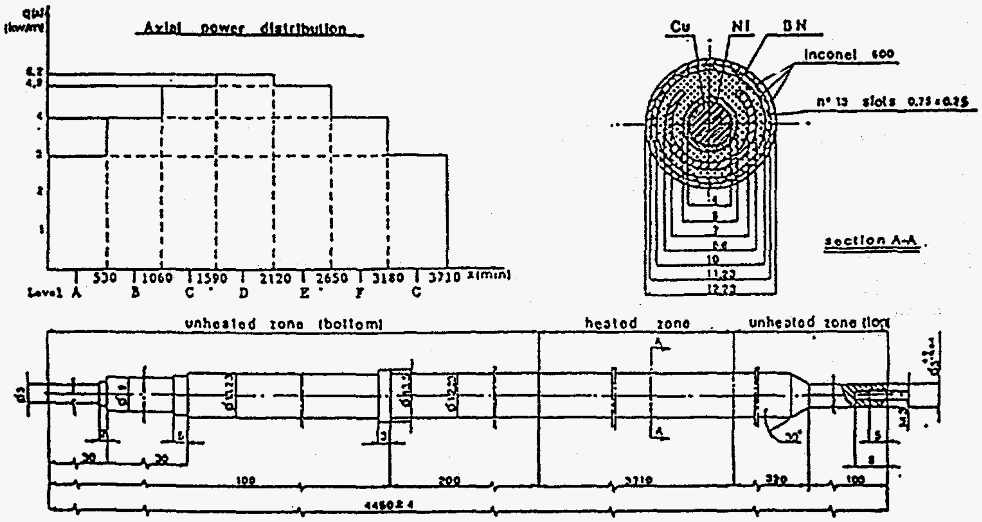


Fig. 3 - Details of the heating rod of PIPER-ONE

The data acquisition system can record 128 signals, with a frequency of up to 10 Hz for each signal. Particular care was taken to evaluate and maintain an adequate accuracy in measurements. The methodology developed (and adopted) includes:

- periodic calibration of all the transducers, in such a way to avoid or at least to reduce the systematic errors;
- control of the instrumentation system and of the related data acquisition system, before, during the preparation and at the end of each test. These checks reduce random errors and verify the correct operation of the measurement and data acquisition systems.

As already mentioned, the facility hardware was modified by inserting the loop, which can operate at the same pressure of the main circuit (Fig. 4).

The main component of Isolation Condenser loop is a heat exchanger consisting of a couple of flanges that support 12 pipes, 22 mm outer diameter and 0.4 m long; it is immersed in a tank of 1 m^3 volume, containing stagnant water, located at 4th floor of the PIPER-ONE service structure. The heat exchanger is connected at the top and at the bottom respectively with the steam dome and the lower plenum of the main loop. In order to enhance natural convection inside the pool, a sort of shroud has been installed that divides the pool into two parts; a hot one and a cold one, the former encompassing the IC as can be seen in Fig. 5.

The Isolation Condenser loop is instrumented with a turbine flow-meter (Fig. 4) and a differential pressure transducer on the hot side (PD-IC-2 in Fig. 5) and a series of almost 30 thermocouples in various position of the IC and of the pool as can be derived from Figs. 5 and 6.

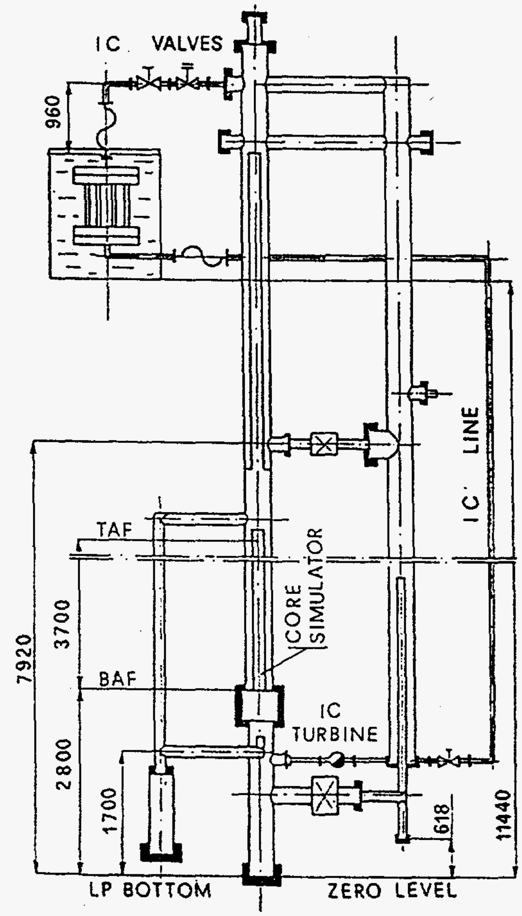
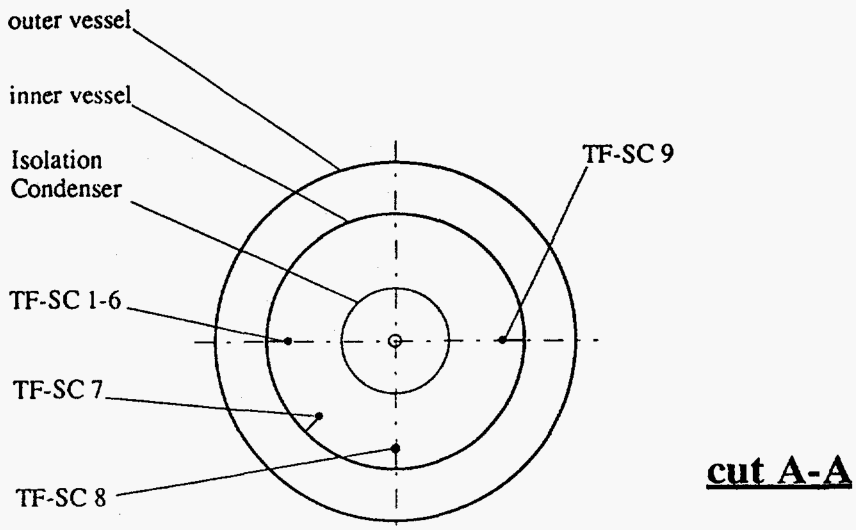


Fig. 4 - Connection between isolation condenser loop and PIPER-ONE loop

In particular, 5 thermocouples measure the primary side fluid temperature at the inlet (TF-IC-0), and outlet of the tubes bundle (TF-IC-4) and inside three different tubes (TF-IC-1 to 3); 7 thermocouples are installed on the outer surface of the tubes (TS-IC-1 to TS-IC-9, excluding the position 2 and 4); 2 thermocouples are installed on the inner surface of the tubes (TS-IC-2 and TS-IC-4); 14 thermocouples (TF-SC-1 to TF-SC-14) give a measure of the fluid temperature distribution in the pool. The distribution of thermocouple should give an idea of possible multidimensional phenomena in the pool and inside the IC. In addition, the instrumentation already available for measuring pressure, level and temperature in the different zones of PIPER-ONE apparatus is used.

Hardware restrictions preclude the possibility to have a system correctly scaled with respect to those provided for the new generation nuclear reactors, particularly the GE SBWR. This is evident from Table I, where relevant hardware data characterizing the Isolation Condenser loop installed in PIPER-ONE facility are compared with SBWR related data. In particular, Table I demonstrates that the heat transfer area of Isolation Condenser in PIPER-ONE is roughly five times larger than the ideal value. The distance between bottom of the active fuel and the Isolation Condenser and the height of the core itself are two of the most important parameters differentiating PIPER-ONE from SBWR. These essentially prevent any possibility of extrapolating PIPER-ONE experimental data to SBWR.



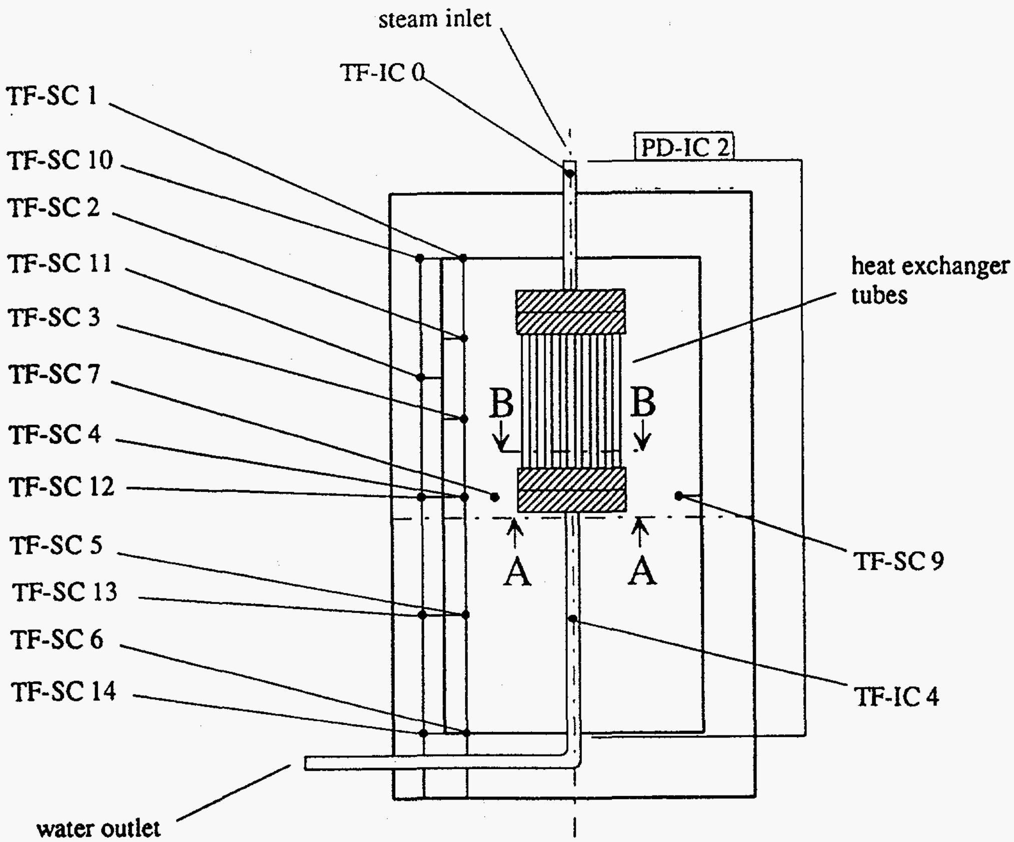


Fig. 5 - Sketch of isolation condenser pool with temperature measurement locations (part A)

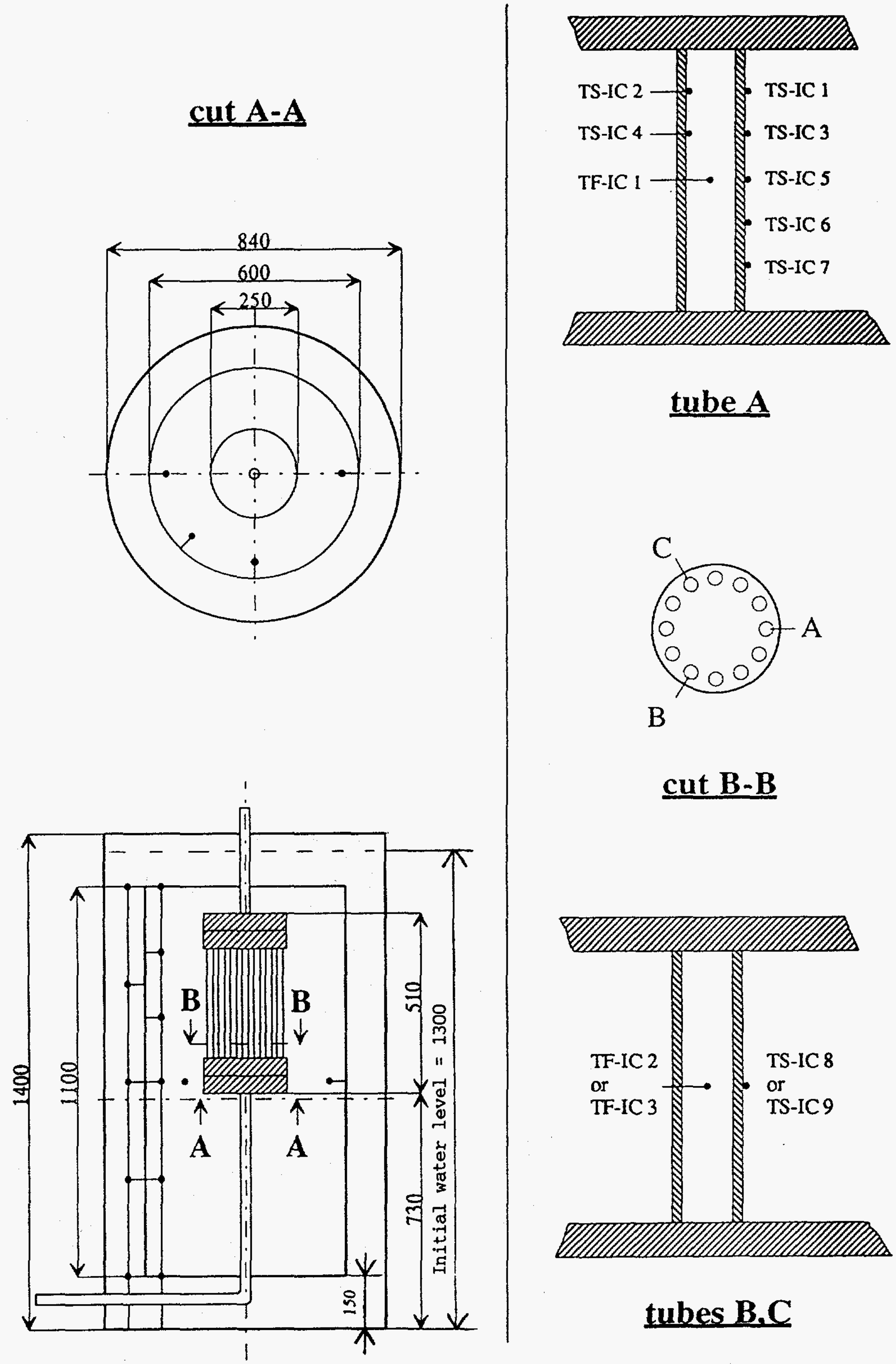


Fig. 6 - Sketch of isolation condenser pool with temperature measurement locations (part B)

	QUANTITY	UNIT	PIPER-ONE	SBWR (°)	RATIO (+) PIPER-ONE/SBWR	IDEAL (+) VALUE OF THE RATIO PIPER-ONE/SBWR
1	Primary system volume	m^3	0.199	595.	1/2990	1/2990
2	Core height	m	3.710	2.743	1.35/1	1/1
3	Maximum nominal core power	MW	0.320	2000.	1/6200	1/2990
4	Value of 3% core power	MW	0.041 (-)	60.	1/1463	1/2990
5	Ratio (3% core power) /primary system volume	MW/m^3	0.206	0.1	2.06/1	1/1
6	Isolation condenser heat transfer area (++)	m^2	0.301	184	1/610	1/2990
7	Isolation condenser heat transfer area over primary system volume	m^{-1}	1.512	0.31	4.9/1	1/1
8	Isolation condenser volume	m^3	0.0015	2.334	1/1556	1/2990
9	Isolation condenser volume over primary system volume	-	0.0075	0.0038	1.97/1	1/1
10	Isolation condenser heat transfer area over 3% core power	m^2/kW	7.341	3.066	2.39/1	1/1
11	Height of isolation condenser top related to bottom of active fuel	m	8.64	24.75	1/2.86	1/1
12	Diameter of a single tube	m	0.020	0.0508	1/2.54	1/1
13	Thickness of a single tube	m	0.0023	0.0023	1/1	1/1

(+) non-dimensional
(++) only tube bundles
(°) IC data have been taken from reference /21/
(-) related to BWR6

Tab. I - Comparison between isolation condenser related data in PIPER-ONE and in SBWR.

2.2 TEST PO-IC-2

2.2.1 Planning of the test

As already mentioned, test PO-IC-2 was the follow-up of the PIPER-ONE experiment PO-SD-8. Essentially, some discrepancies were found in the comparison measured-calculated trends in relation to variables representative of the IC behaviour; the lack of adequate local instrumentation in the IC prevented a complete characterization of the code-calculation adequacy. Furthermore, strong thermal stratification, as expected, took place in the cooling pool. The last two items led to the planning of the PO-IC-2 test as reported in ref. /8/.

Owing to the above, the instrumentation system was largely improved, now including the transducers discussed in the previous section A "shroud" was inserted into the pool to facilitate natural convection motion.

The original design of the PO-IC-2 experiment foresaw the same boundary and initial conditions as PO-SD-8 test; similar features were also foreseen for general test conduction (e.g. different core power levels, timings, etc.). Considering the presence of new devices installed in the PIPER-ONE facility (essentially active feedwater and steam line systems, ref. /18/), the initial part of the test should be addressed to characterizing PO behaviour in natural circulation. Unfortunately, the electrical power supply system suffered of heavy problems during the first attempt to carry out the experiment. Owing to this the maximum power was limited to less than 100 kW (i.e. 1/4 of the nominal value for the facility, roughly).

So, only two power steps were included in the final test design, at about 40 and 80 kW respectively, while primary circuit pressure was as specified, i.e. around 5. MPa (the same as in the experiment PO-SD-8). Relevant boundary and initial conditions are discussed in the following section.

2.2.2 Test execution

The execution of the PO-IC-2 test was essentially the same as test PO-SD-8; the "dynamic steady state", utilizing the active feedwater and steam line systems, was not performed and the usual "static steady steady" was achieved.

The primary circuit was pressurized at the specified value by single phase and two-phase natural circulation with heat sources consisting of the core simulator and the structures heating system; before the test beginning, the liquid was drained to obtain the required levels in the downcomer and core regions.

The "static steady state" was achieved at zero core power and with structures electrical heating power switched on to compensate the heat losses (around 20 kW). The isolation condenser line was closed and almost full of ambient temperature liquid (60 mm above the top of IC heat exchanger).

At the beginning of the test, core heating power was switched on and almost simultaneously (see below) the IC line was open. Two core power levels, as already mentioned, were considered.

2.2.3 Test results

The initial and boundary conditions for the PIPER-ONE experiment PO- IC-2 are given in Tabs. II to IV. The two parts of the test ("low" and "medium" power, respectively) were carried out subsequently and in this way are also considered in the code calculation; so, initial conditions are only related to the "low" power phase.

32 measurement points were recorded during the test; most of these, are related to the IC loop and the remaining ones to the primary circuit. The measurement error band is that typical of all PO tests, because the established procedure of instrumentation check has been followed for carrying at the test. As an example the temperature signals have an error band (2 σ) of ± 2K /19/.

PARAMETER	SIGN	UNIT	VALUE
LP pressure	PA-LP-1	MPa	5.1
LP fluid temperature	TF-LP-1	°C	262.5
Core level	LP-CC-1	m	11.9
Downcomer level	LP-LD-1	m	10.7
IC line fluid temperature	TF-IC-1	°C	17.5
IC pool fluid temperature	TF-SC-1	°C	17.5

Tab. II - PIPER-ONE test PO-IC-2: initial conditions

PARAMETER OR EVENT	TIME (s)
Test initiation	0.0
Power versus time	as in Tab. IV
IC top valve opens	4.0
IC bottom valve opens	32.0
IC top valve closes	508.0
IC top valve opens again	602.0
IC top and bottom valve close	1106.0
End of test	1184.0

Tab. III - PIPER-ONE test PO-IC-2: boundary conditions

TIME (°) (s)	POWER (kW)
0.0	0.0
5.0	41.60
438.0	41.60
440.7	0.0
586.1	0.0
588.0	70.47
590.0	73.30
1086.0	73.30
1088.0	0.0
1184.0	0.0

(°) from test start

Tab. IV - PIPER-ONE test PO-IC-2: power history

Primary circuit behaviour

Primary circuit pressure, lower plenum temperature, downcomer and core region levels are shown in Figs. 7 to 10, together with core power.

The IC was expected to remove almost 80 kW, ref. /7/; so the primary system pressure decrease until about 500 s (Fig. 7) is a foreseeable result considering that at the transient initiation (Tab. III) the IC line was opened and about 40 kW were supplied to the core simulator. In the second part of the transient, starting at about 600 s, the core power was very close to the IC removed power and primary circuit pressure was quite constant; a slight decrease of the pressure testifies that IC removed power is (slightly) larger than the power supplied to core simulator (73. kW).

The thermocouple producing the signal in Fig. 8, is installed in the zone of the lower plenum where the IC line is connected with the primary circuit: this explains the oscillations observable during the IC operation periods. In particular, oscillations amplitudes as large as 80 K have been measured as a consequence of cold liquid (coming from IC) mixing with hot liquid in the primary circuit.

Average cooling of the primary loop in the first phase of the experiment can also be deduced from observing core and downcomer regions levels in Figs. 9 and 10. In the second part of the experiment these levels remain quite constant. Unquantified dynamic effects are included in the level signal during the periods of IC operation; these are due to the natural circulation flowrate (0.5 - 0.7 kg/s) between core and downcomer.

IC system behaviour

The Isolation Condenser system behaviour has been characterized by the time trends reported in figures from 11 to 28.

The mass flowrate and the pressure drops across the IC are shown in Fig. 11. The mass flowrate signal, output of the turbine transducer, is not correct up to about 200 s. The pressure drop signal gives an idea of the filling and emptying of the IC tubes: starting from a situation with liquid level at the top of the component, a drop of the level up to about 2/3 of the tubes height can be observed in both the phases of the experiment. During the period of isolation of the line the internal side refills owing to abrupt steam condensation (this causes a shock wave that, among the other things, is the origin of problems in code calculations).

The axial tubes external surface temperatures (Fig. 12), show a large difference along the pipe high (around 50 K).

Other temperature differences can be observed in Figs. 13-17. A temperature jump of about 60 K roughly (the tubes thickness is 3 mm) is measured across the thickness in the upper part of the tubes (Fig. 13, see also Fig. 26); a larger temperature jump exists between the fluid and the external surface temperature (Fig. 14). Two-dimensional effects are indicated by Fig. 15, that shows the fluid temperature at the center of the two tubes: differences of the order of 20 K occur at the same elevation in two different tubes; moreover, the phenomenon repeats with the same characteristics in the two phases of the experiment. Radial disuniformities seem less important in the external surface (Fig. 16, see also Fig. 28); nevertheless, some additional analysis is needed to characterize the occurrence of multidimensional effects. Finally, fluid temperature variations between the inlet and the outlet of the IC can be drawn from Fig. 17; this shows that all the steam is condensed in the first half of IC, and the liquid outflowing from IC is highly subcooled (about 120 C).

Fluid temperatures inside the pool are shown in figures from 18 to 23. Essentially three aspects should be noted:

a) strong temperature stratification exists: the fluid temperature differences between top and bottom is of the order of 70 K (Fig. 18);

b) fluid temperatures are almost the same in the internal and the external sides of the shroud (Figs. from 20 to 23): this means that the shroud is not effective in enhancing natural circulation between the heated and the unheated part of the pool also due to the good heat conduction across the wall;
c) maximum fluid temperature in the pool is always below the saturation temperature; i.e. no bulk boiling condition was achieved during the test.

Elaborations of the discussed signals are given in Figs. 24 to 28.

It can be noted that saturated steam (or two-phase mixture) is present at the IC inlet (Fig. 24).

The IC removed power is larger than the core supplied power in the first phase of the experiment and roughly the same in the second period; this is confirmed by the primary pressure that decreases in the first period and remains almost constant in the second one. The IC removed power is obtained from

$$GIC \bullet (HGI - HFO)$$

where GIC is the IC flowrate, HGI is the steam saturation enthalpy at IC inlet (so it is assumed that only steam arrives from the primary circuit) and HFO is the liquid enthalpy at the IC outlet. Obviously the inadequacy of GIC in the first 200 s (see above) also reflects in the calculated IC power.

Temperature jumps are reported in Figs. 26 to 28.

Significant outcomes

Two main aspects can be emphasized from the analysis of the experimental data.

The former is connected with the constant value of the IC removed power, whatever is the electrical power supplied to the core simulator. This situation was already found in the previous experiment (test PO-SD-8, ref. /7/) albeit with a different primary circuit geometrical configuration and with different values (larger values) for core power. The phenomenon is a consequence of the about constant value of the IC flowrate. This occurs because the IC loop can be considered as one of the two parallel natural circulation flow paths for the two-phase mixture in the core region, the other one being the main loop with the downcomer. Actually, the overall flowrate across the core is the sum of flowrates crossing downcomer and IC. The driving heads are the pressure differentials between downcomer and core regions and between IC and core regions, respectively. Owing to geometry, the pressure drops across IC are higher than across the downcomer (ideally, with the same flowrate). As a consequence of this, increases of core power reflect as increases of mass flow across the downcomer.

The same conclusion can be reached considering that the pressure drop between the points connecting the IC to the primary loop are held nearly constant by the gravity head constituted by the liquid level in the downcomer that, at its time does not substantially change in the two periods of the experiment. As a final note, the overall gravity head in the IC line cannot change too much owing to the elevation of the IC component itself (the only zone where fluid density variations may occur assuming in any case complete condensation) that is less than 1/10 of the total axial length. Second order contributions to differences between the high and the low power periods as far as the overall IC removed power is concerned, come from:

- the progressive heating of the pool that in the high power period, may be compensated by the increase in the heat transfer coefficient on the outer part of the IC tubes;
- pressure variations in the primary circuit.

The latter aspect concerns the local behaviour of the heat transfer coefficient in the IC region. First of all it should be noted that the liquid level in the IC is almost the same during the two periods of the experiment (Fig. 11). Secondly, as already mentioned, temperature increases in the pool (of almost 70 K in the upper part, Fig. 18) have no or limited consequence upon the external surface tubes temperature (Fig. 12). Also the temperature jump between primary fluid and tubes external surface, remains almost constant as it results from Fig. 14. As a conclusion, notwithstanding variations of fluid conditions in the pool, the heat transfer phenomenon remains almost unchanged, when core power is varied.

An experimental verification of the link between IC and DC flowrates has been achieved recently, during the execution of another tests PO-IC-3, similar to PO-IC-2 but at low pressure (~ 0.5 MPa).

In the test PO-IC-3, after a period of quasi-steady conditions, a valve was open simulating a small break in lower DC. This lead to the stop in natural circulation between core and DC, due to the DC level lowering.

In this time period the IC flowrate increased.

It should be noted that both the above conclusions have been confirmed by code calculation results (see below) and seem directly applicable to nuclear power plant conditions: infact the described phenomena are not affected by the scale distortions of the PIPER-ONE apparatus.

Experimental errors

An extensive analysis for determining errors characterizing the experimental data was carried out in the occasion of the use of PIPER-ONE for the OECD/CSNI ISP 21, refs. /25/ to /27/. Details about methods for deriving measurement errors, can be found in ref. /28/.

The error concerned (i.e., error bands corresponding to two standard deviations) for the most relevant quantities, are as follows, ref. /28/:

- absolute pressure: ± 0.05 MPa;
- fluid temperature in primary loop: ± 2 K;
- core level: ± 0.1 m;
- downcomer level: ± 0.1 m;
- fluid temperature in the tank: ± 0.5 K;
- IC flowrate: ± 0.01 kg/s;
- core power: ± 1 KW (valid for the present test only);
- timing error (mainly for valves opening/closure): ± 2 s.

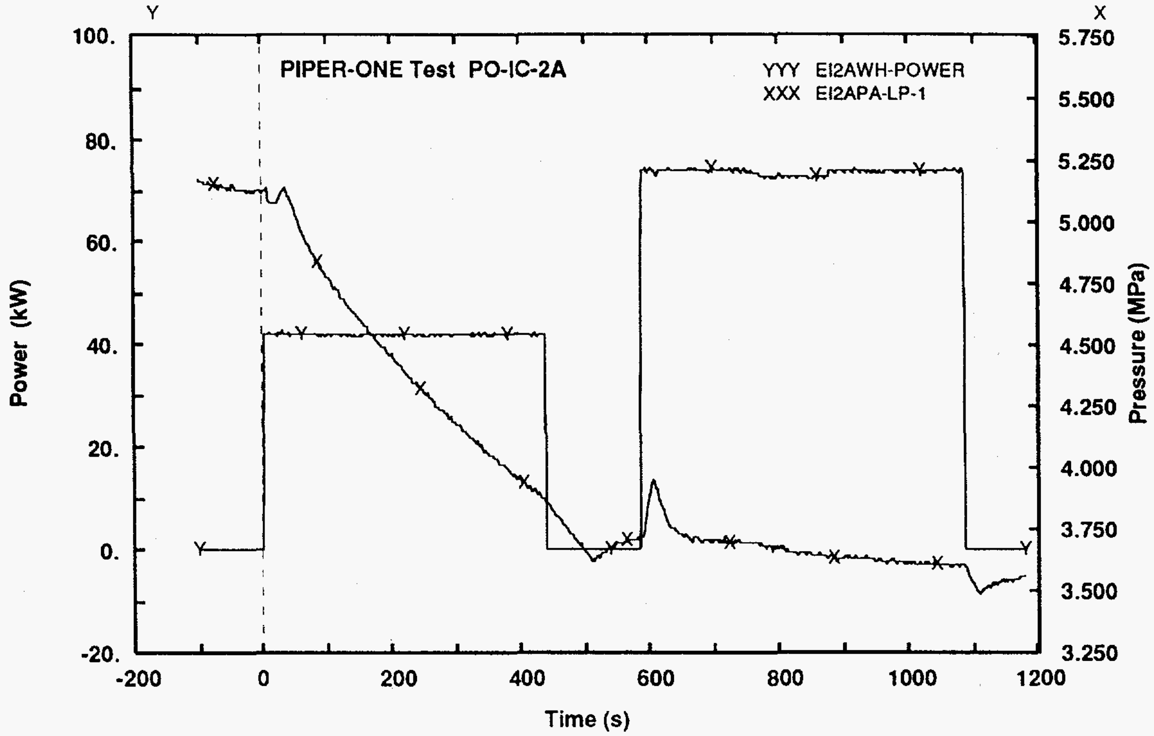


Fig. 7 - Core power and lower plenum pressure

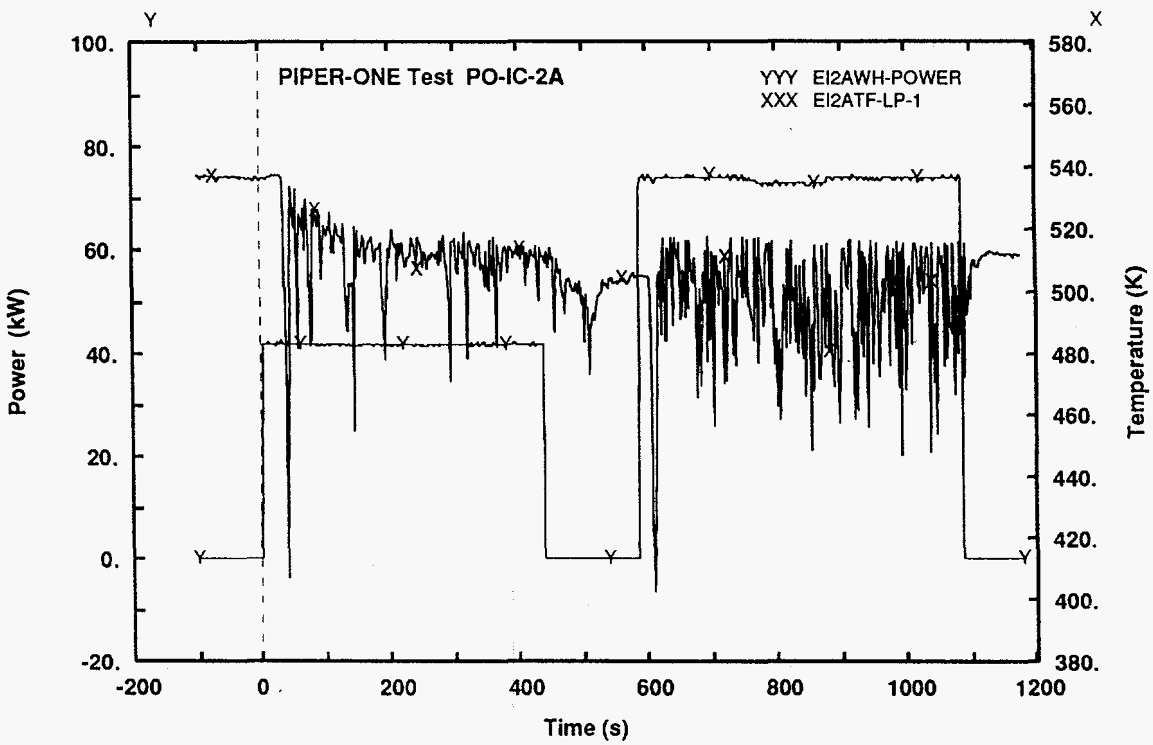


Fig. 8 - Core power and fluid temperature in lower plenum

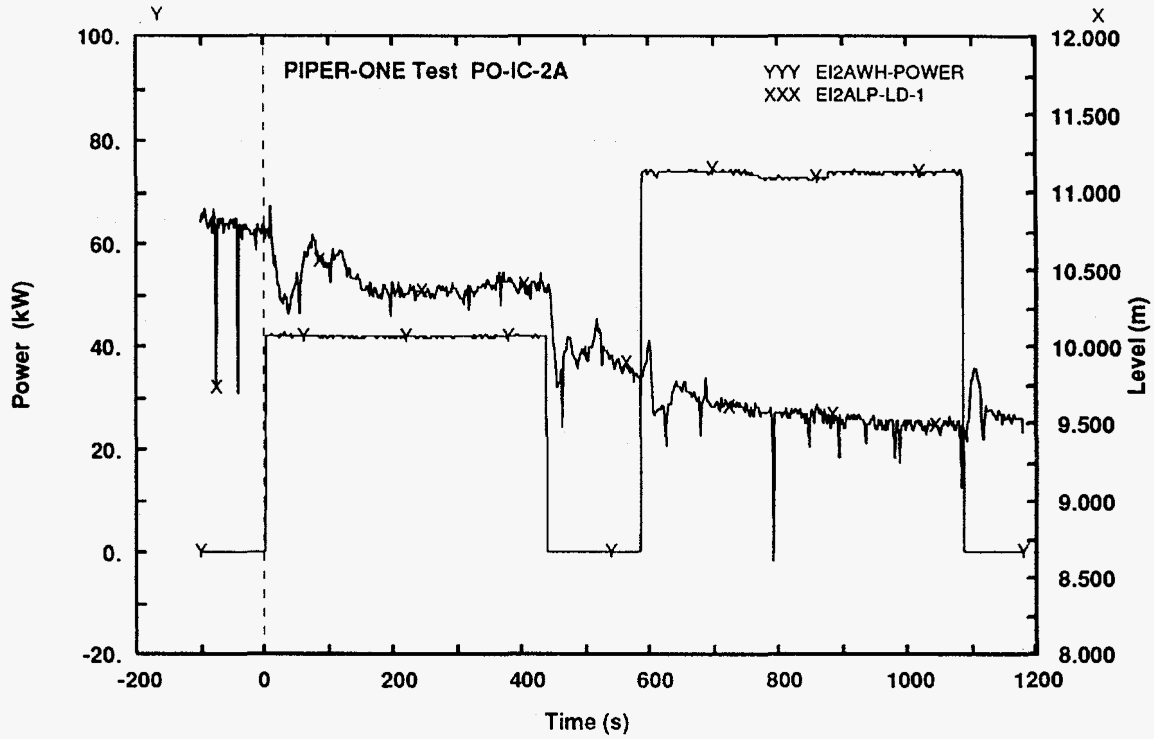


Fig. 9 - Core power and downcomer level

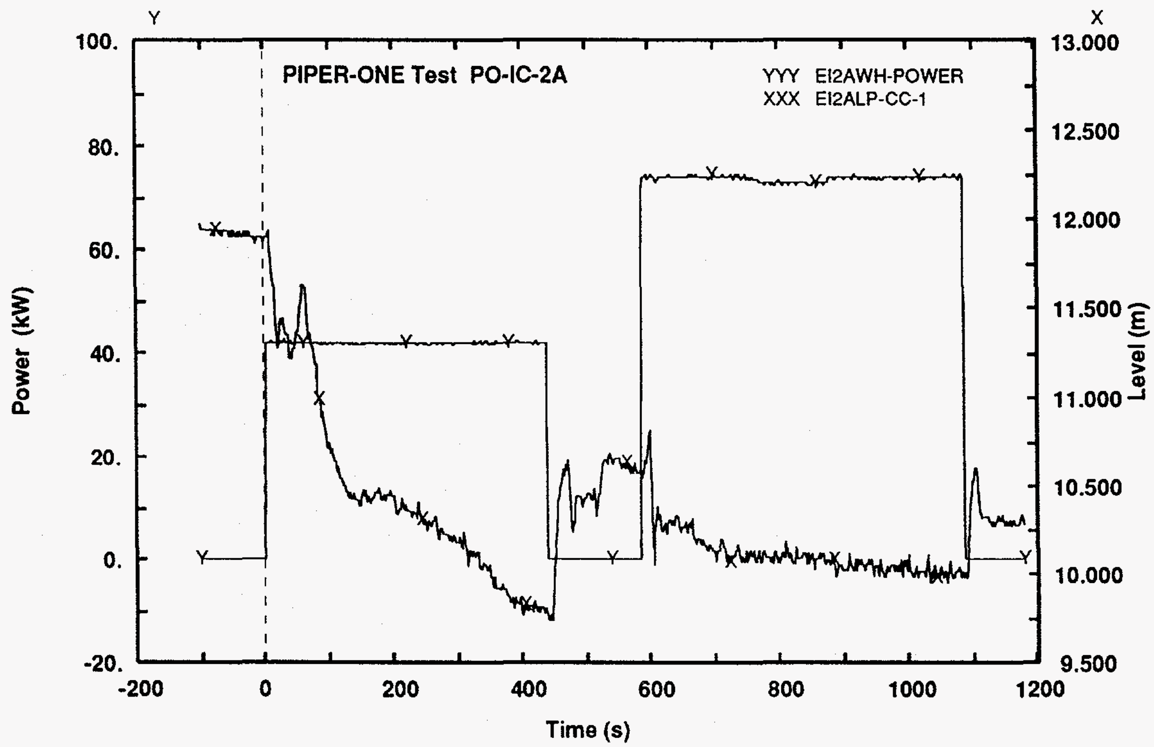


Fig. 10 - Core power and core level

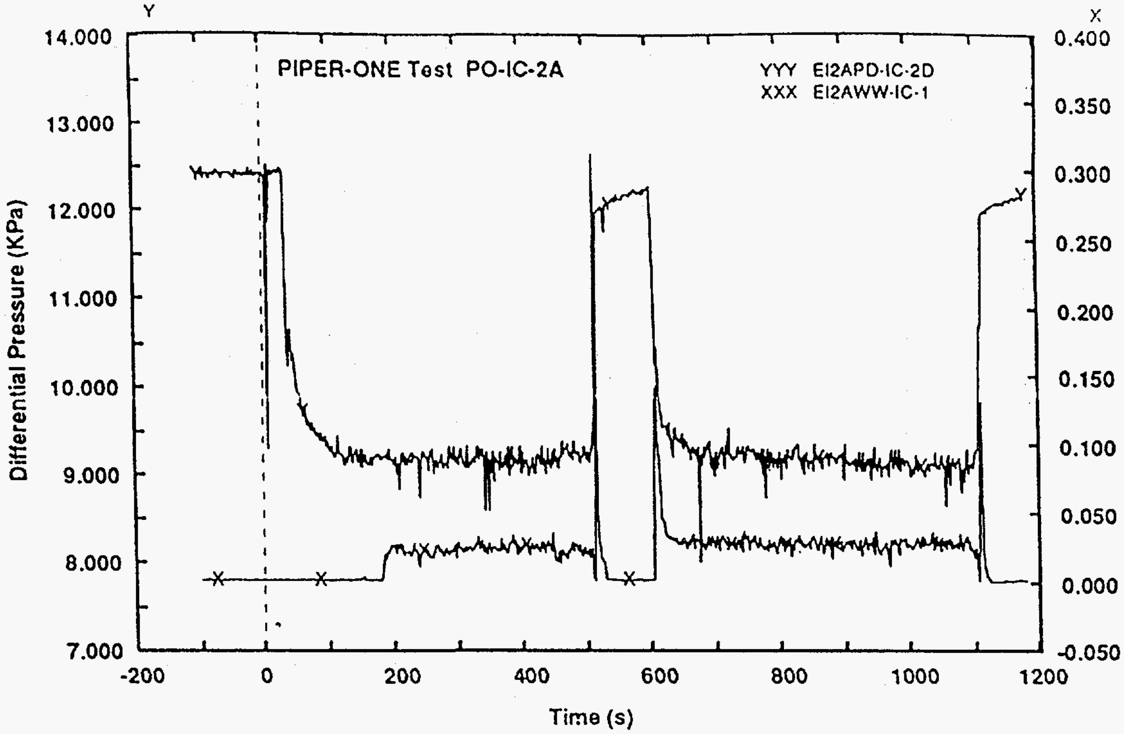


Fig. 11 - Pressure drop and flowrate across IC

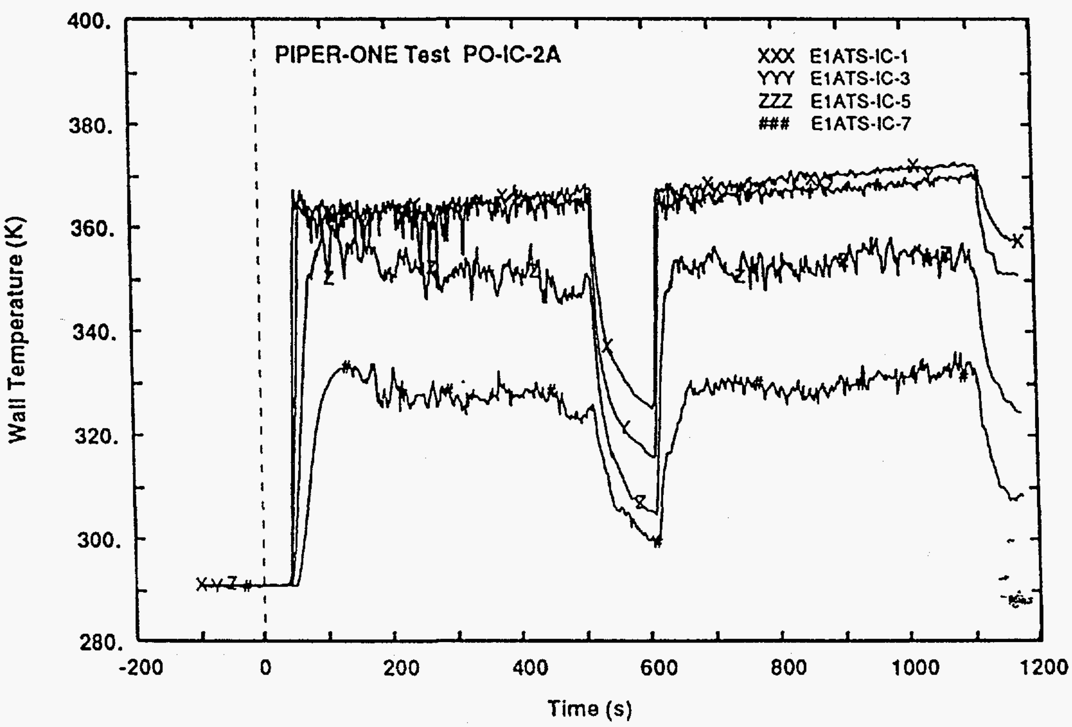


Fig. 12 - Tube "A" axial temperature distribution (external TC)

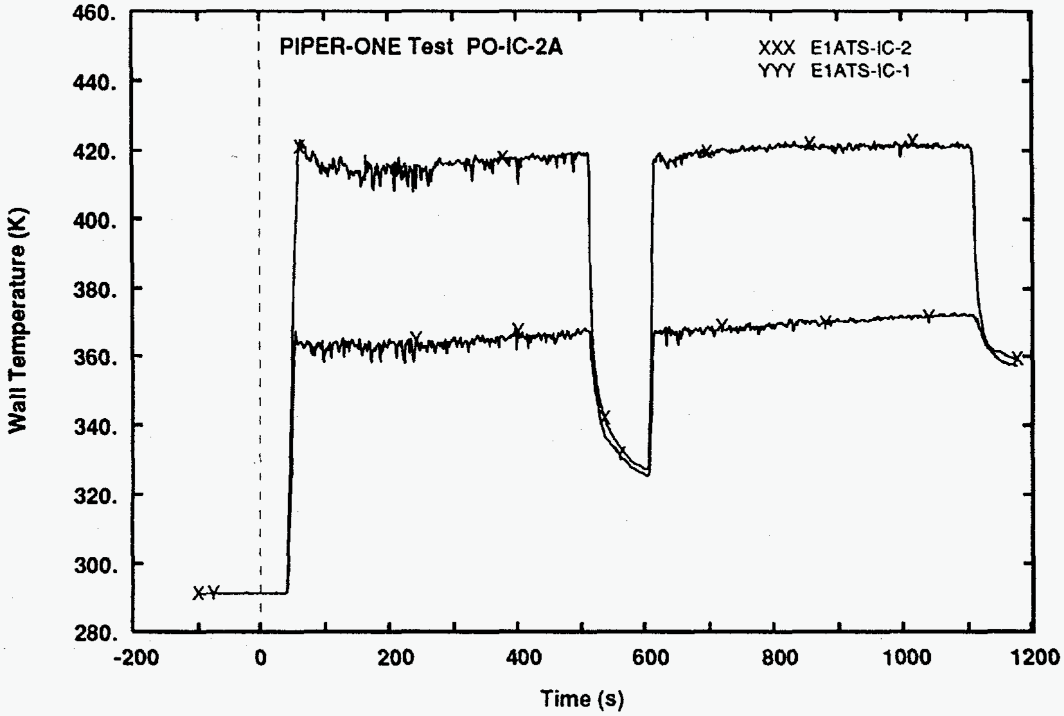


Fig. 13 - Tube "A" internal and external TC (upper elevation)

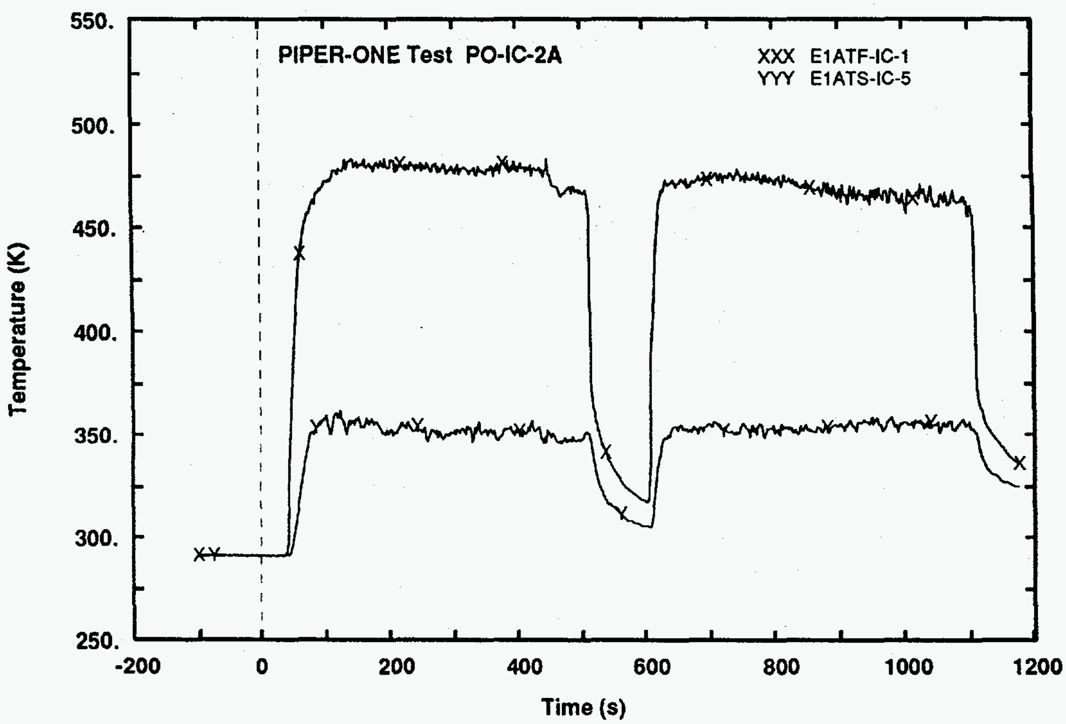


Fig. 14 - Tube "A" fluid temperature and external TC
(middle elevation)

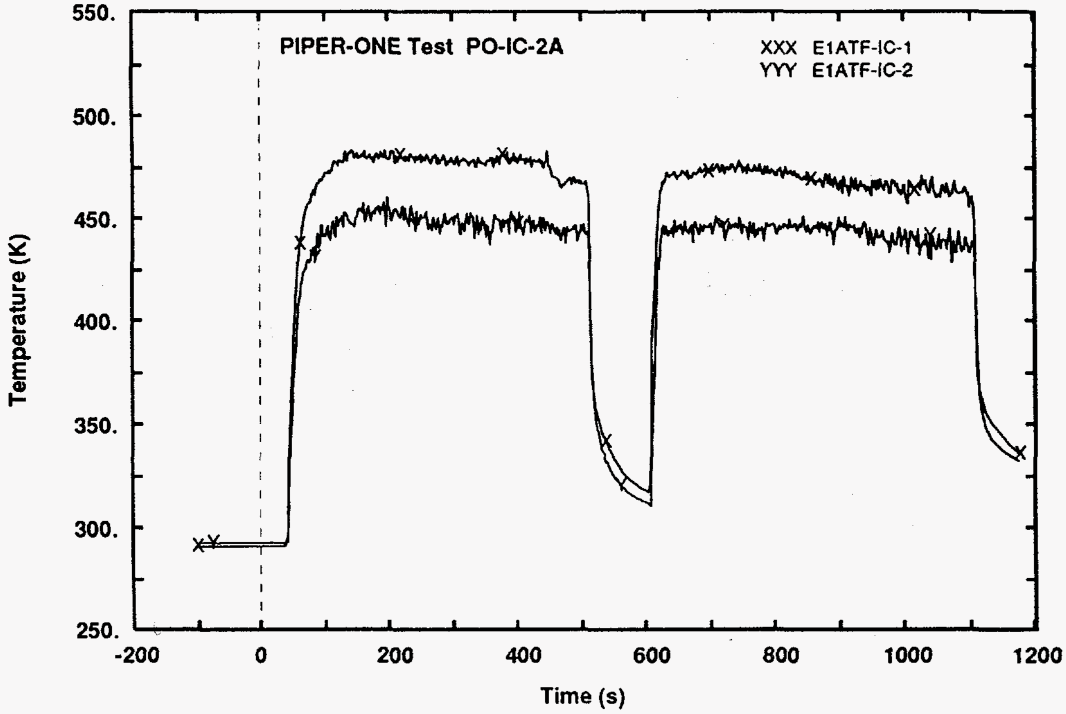


Fig. 15 - Tubes "A" and "B" fluid temperature (middle elevation)

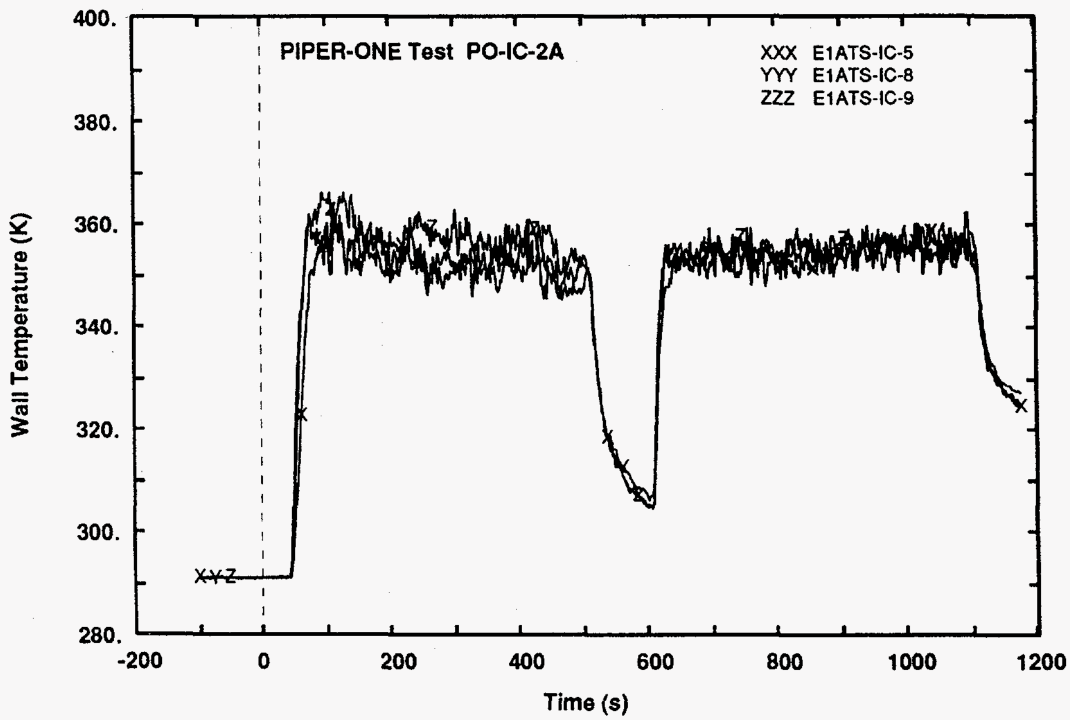


Fig. 16 - Tubes "A" "B" and "C" external TC (middle elevation)

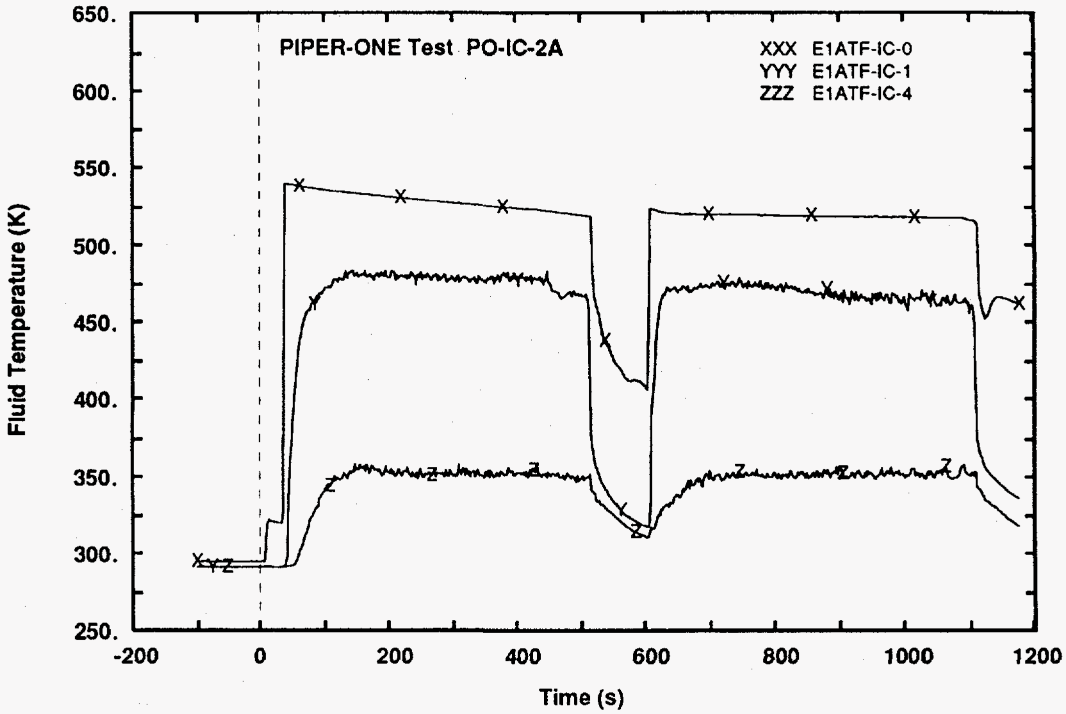


Fig. 17 - IC fluid temperatures (inlet, center and outlet)

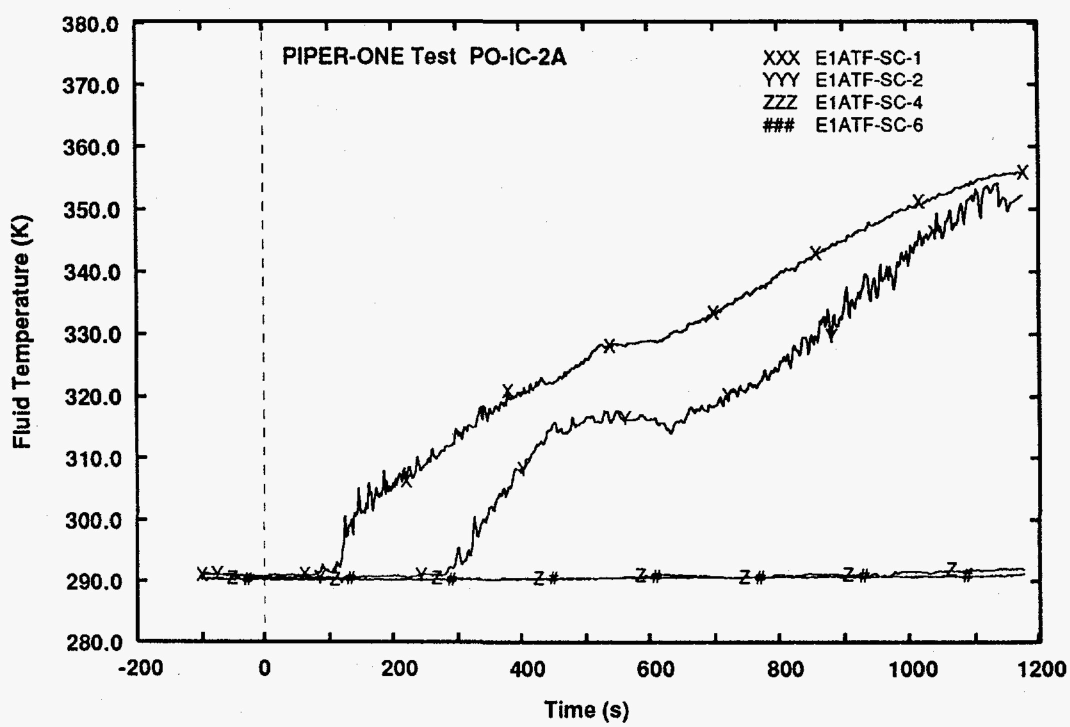


Fig. 18 -Pool internal axial fluid temperatures

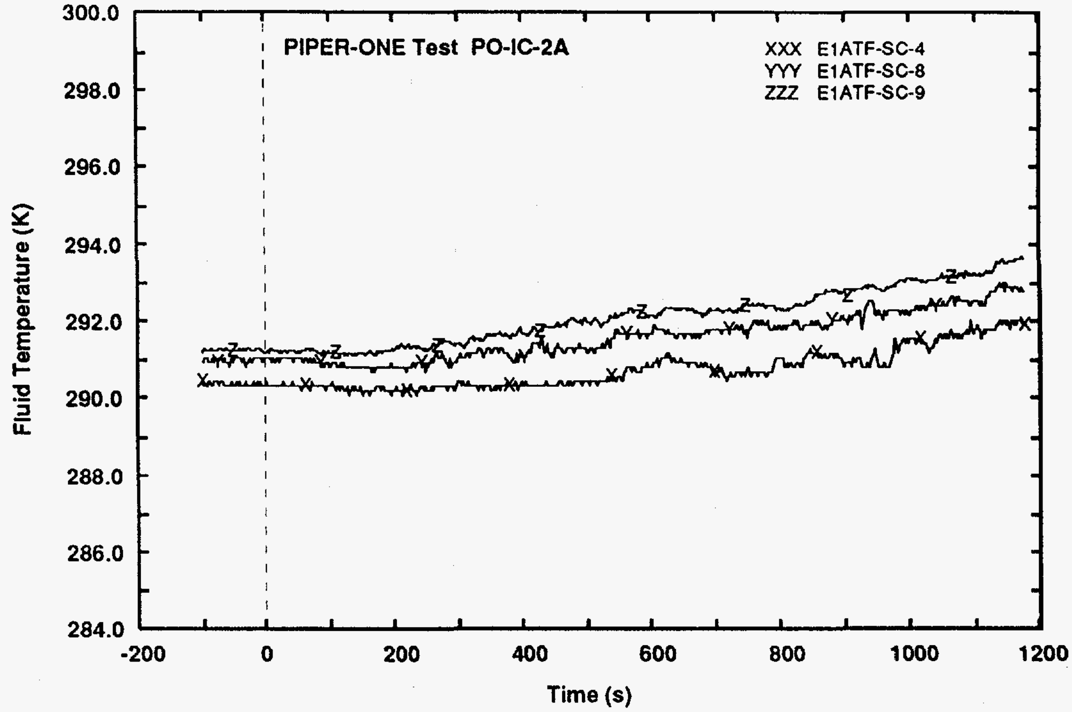


Fig. 19 - Pool internal temperatures in different azimutal positions

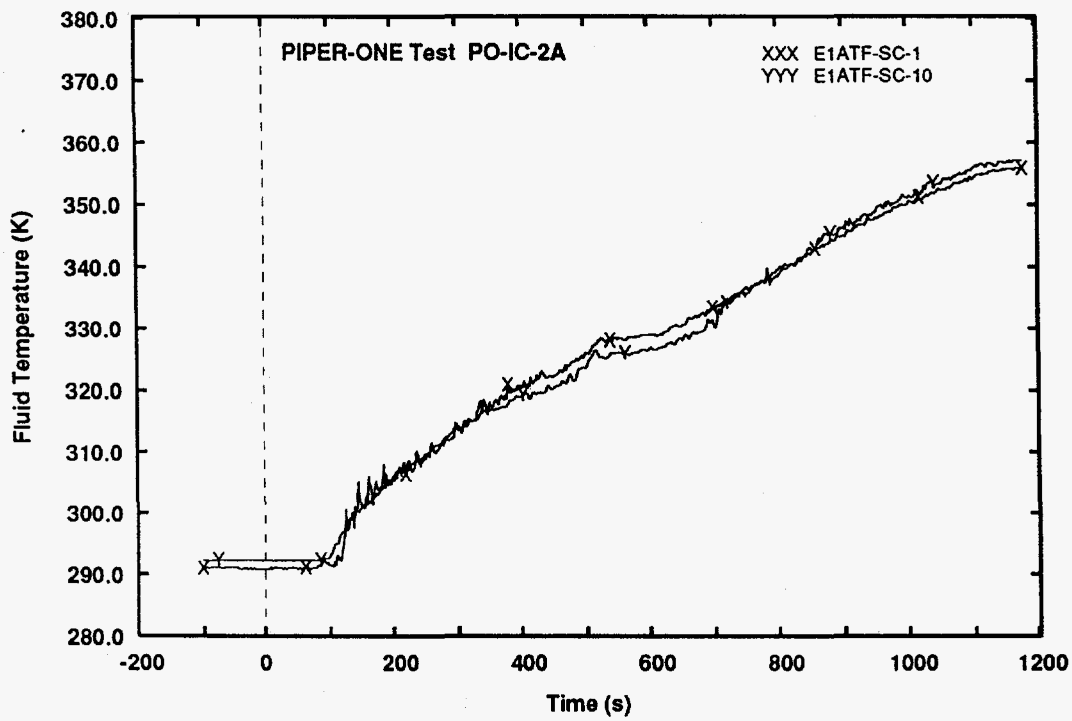


Fig. 20 - Pool temperatures, internal and external to shroud (upper elevation)

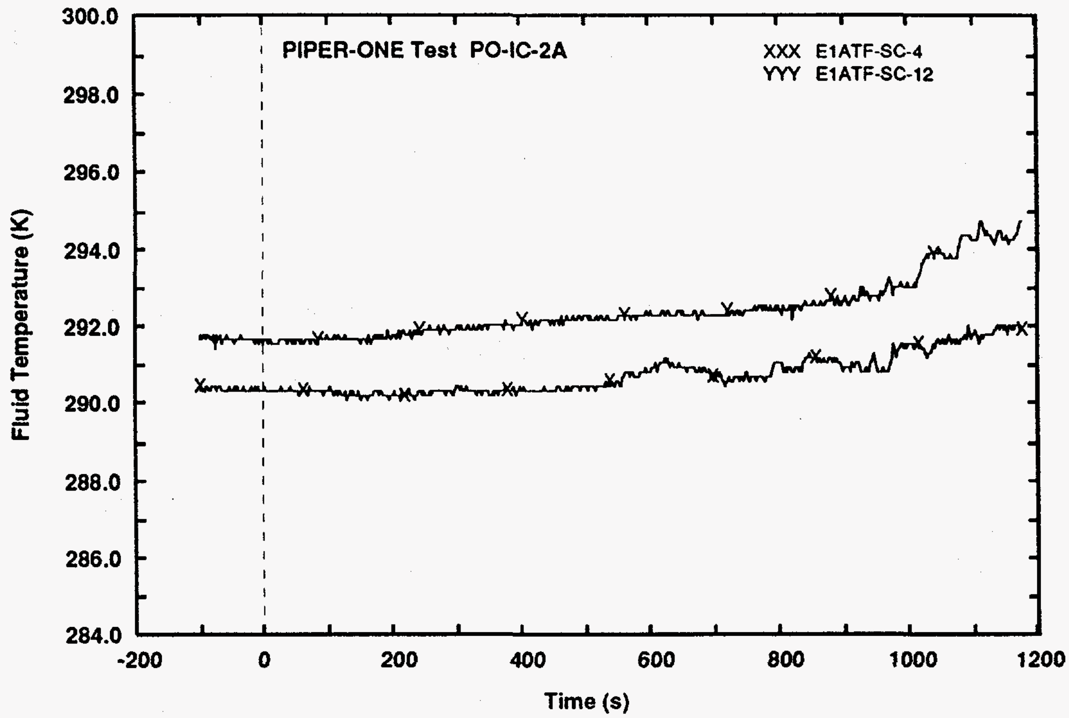


Fig. 21 - Pool temperatures, internal and external to shroud (middle elevation)

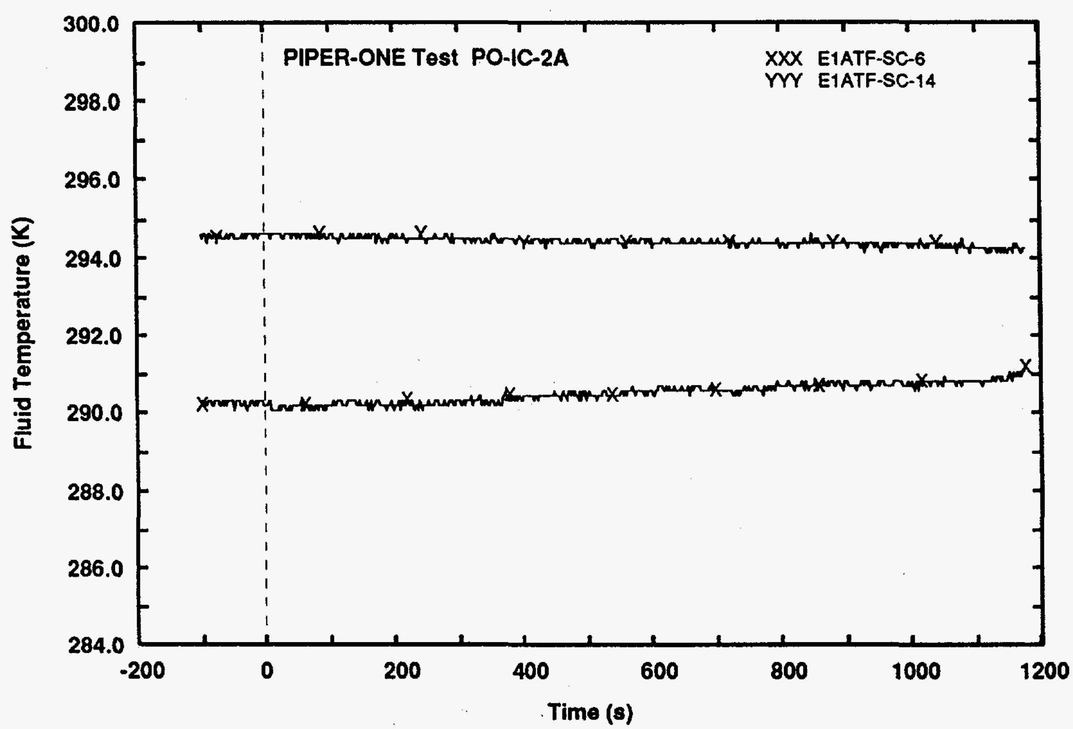


Fig. 22 - Pool temperatures, internal and external to shroud (lower elevation)

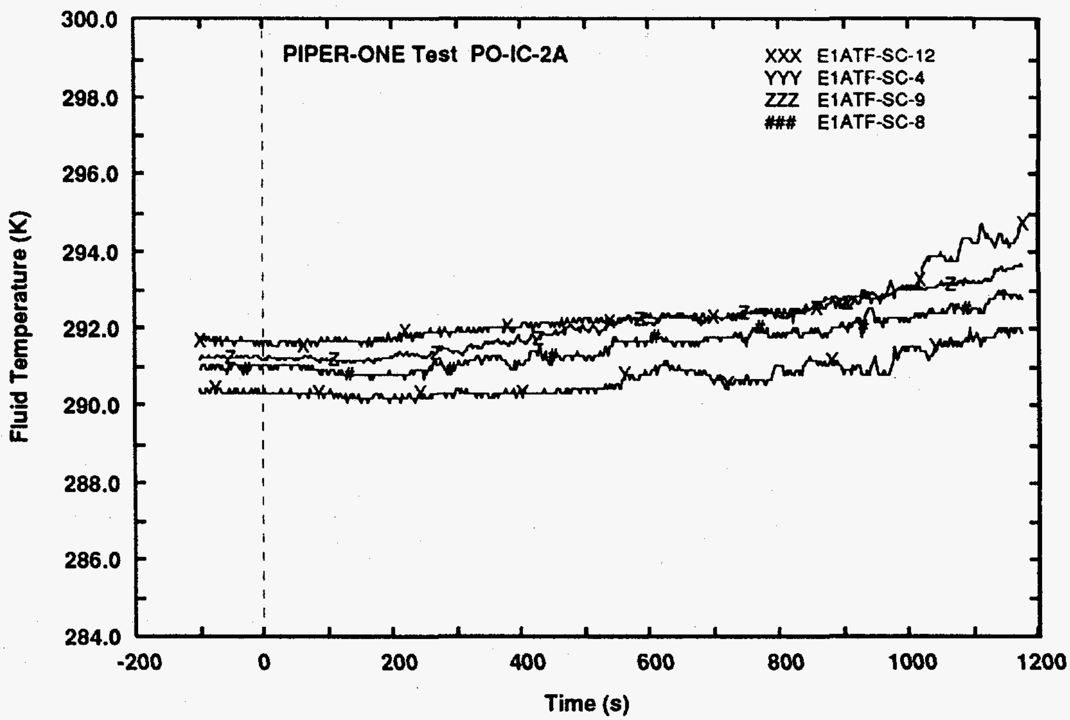


Fig. 23 - Pool temperatures (differential positions)

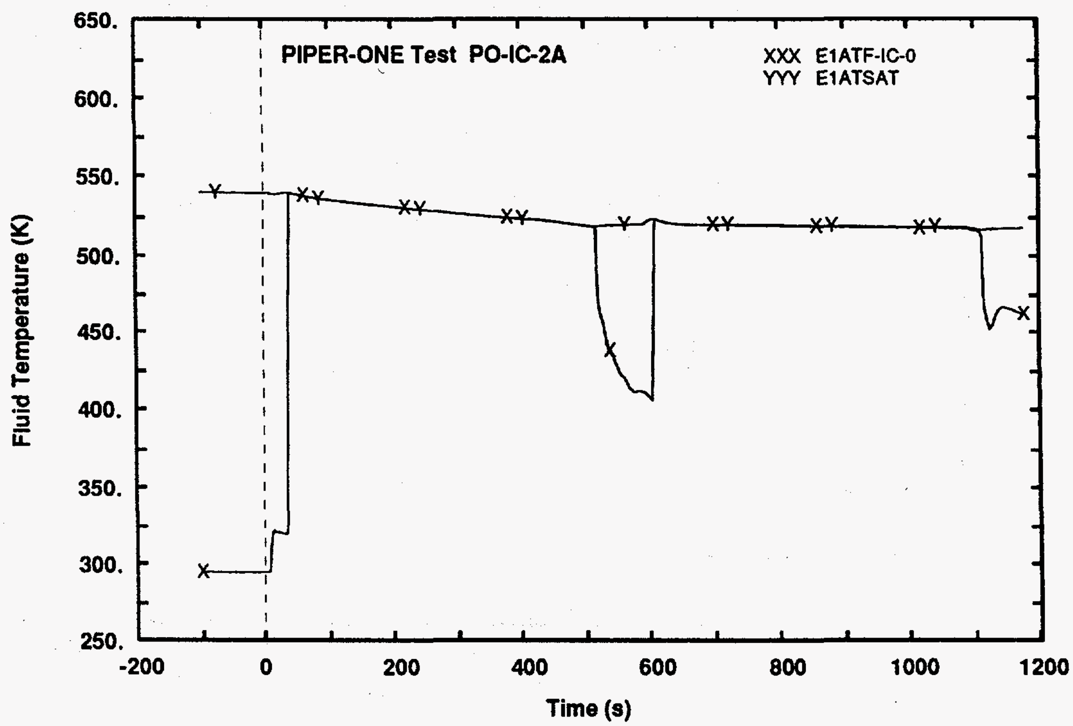


Fig. 24 - Temperature at IC inlet comparison with saturation temperature

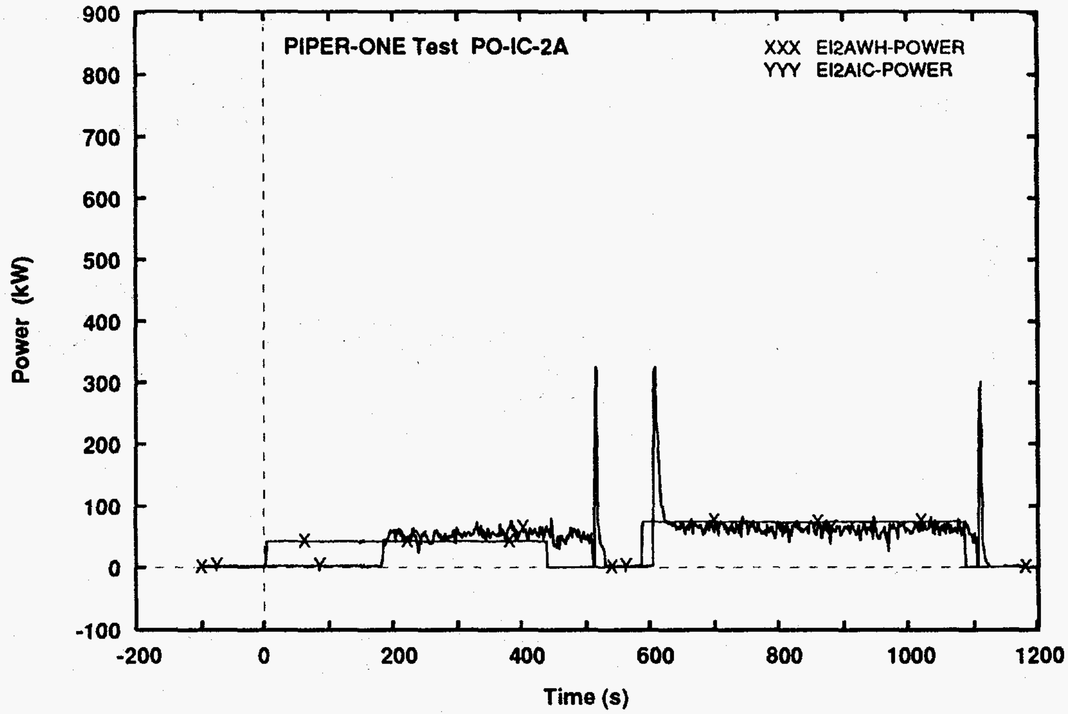


Fig. 25 - Rod power and thermal power across IC

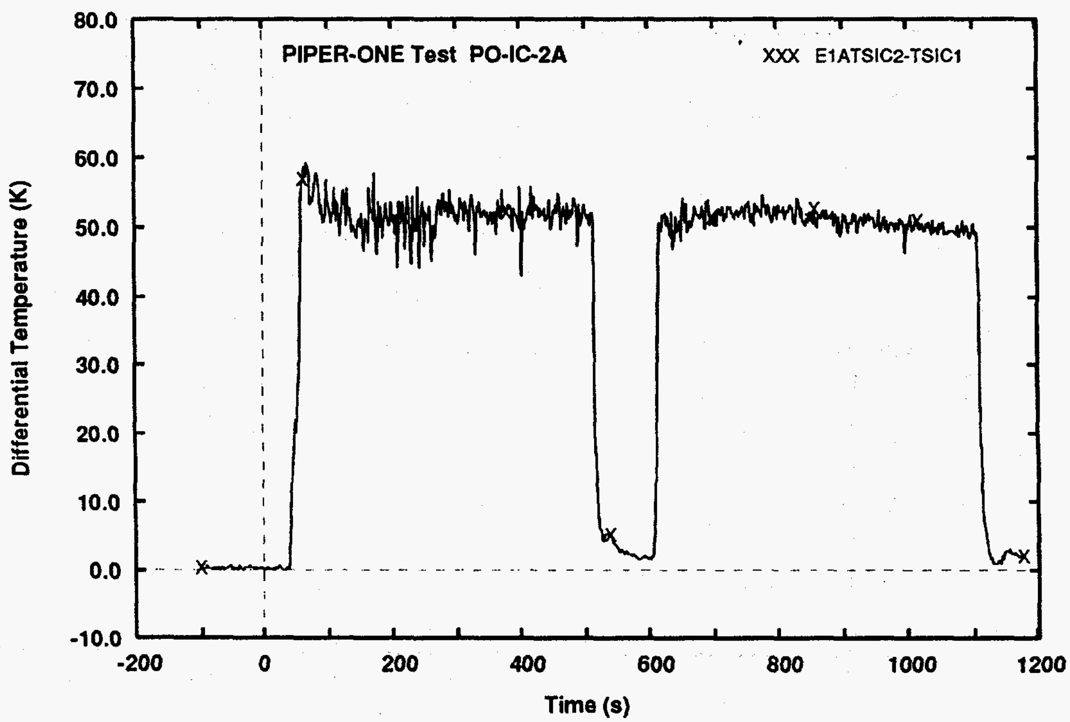


Fig. 26 - Temperature jump across the wall

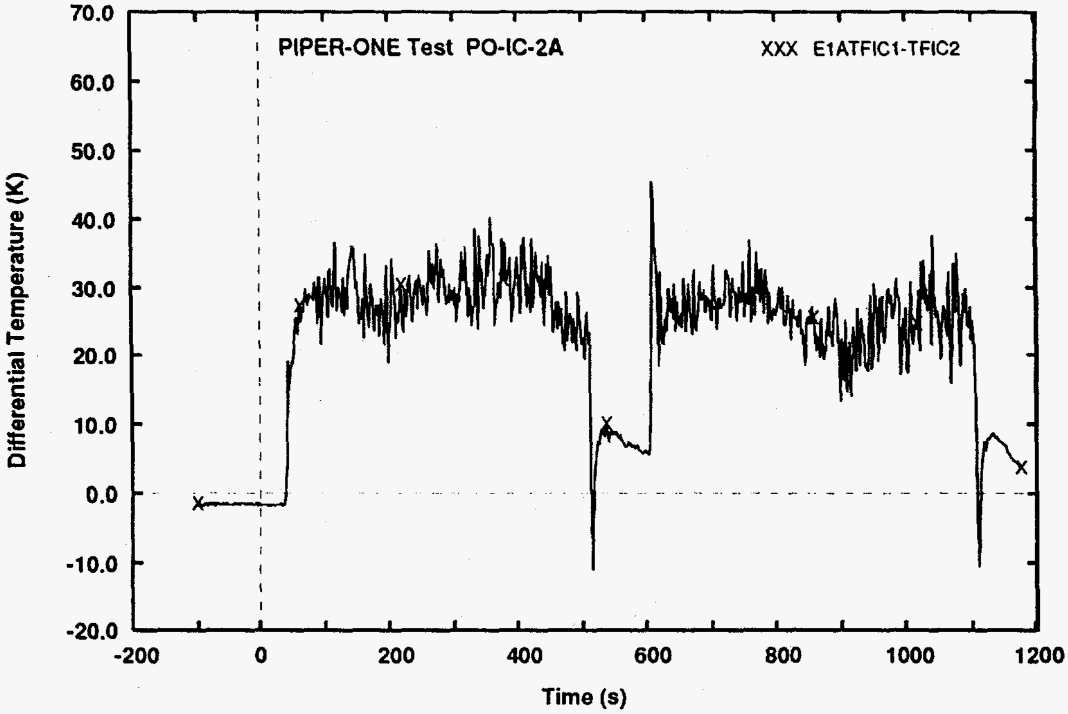


Fig. 27 - Fluid temperature disuniformity across tubes

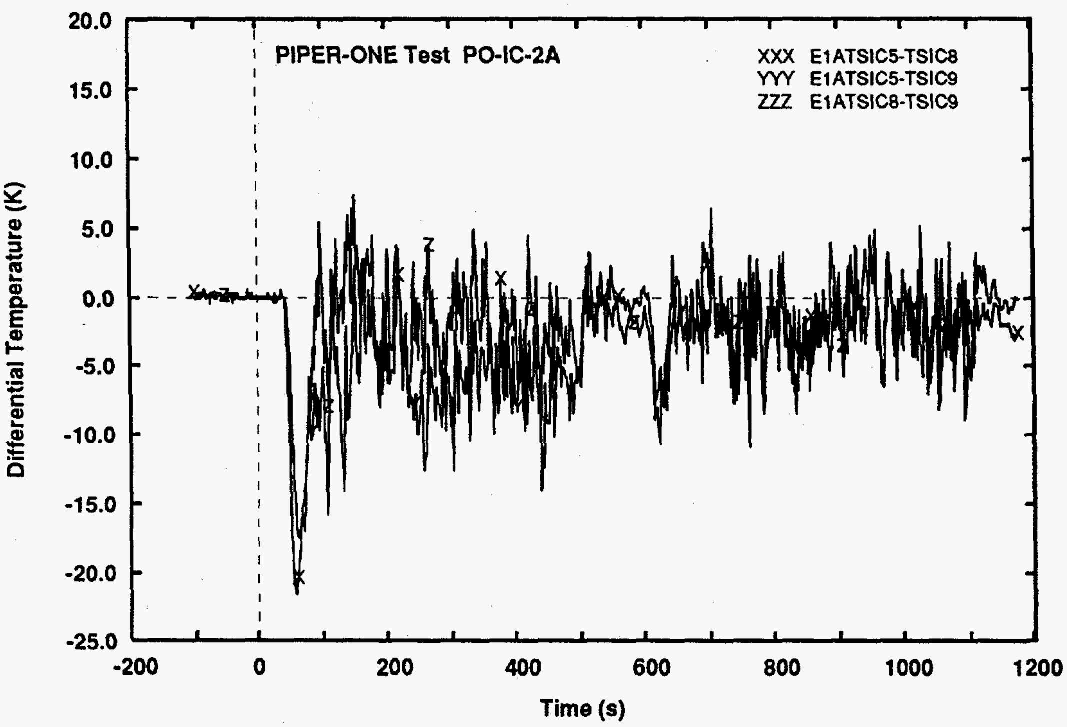


Fig. 28 - Surface temperature disuniformities

3. ADOPTED CODES AND NODALIZATION

3.1 The used codes

The standard version of the Relap5/mod3.1 has been adopted as reference code in the present study; none of the possible user selectable options has been activated when performing the reference calculation; necessary adjustments of initial and boundary conditions (see below), within the experimental uncertainty bands, have been done with this code version ("reference" code version) aiming at getting the "base calculation". The adopted standard version of Relap5/mod3.1 runs on an IBM RISC 6000.

Once the "base calculation" results have been obtained, previous code versions Relap5/mod2.5, Relap5/mod3 7J and Relap5/mod3 v80, running on Cray mainframe, IBM PC 486 and IBM RISC 6000 respectively, have been utilized, too.

3.2 Strategy of calculations and specific objectives

The overall strategy of the performed analysis aimed at assessing the capabilities of the reference code version and at identifying possible improvements with respect to previous code versions; sensitivity calculations considering variations in the nodalization have been performed in this framework.

An additional objective of the analysis was to confirm the explanation given for the reasons of constant IC flow when core power is varied.

3.3 Adopted nodalization

Considering the above objectives, the acquired experience in the use of the latest Relap5 code versions, the code user guidelines, ref. /19/, and the criteria proposed in ref. /20/ for nodalization development and qualification, a new PIPER-ONE input deck has been developed.

The sketch of the new nodalization is shown in Fig. 29. Actually this has been developed in the frame of the BIP (Boiling Instability Program) proposal, e.g. ref. /18/, and already used in that frame for the planning of experiments.

The main difference with respect to the original nodalization (e.g. ref. /16/) lies in the number of nodes that in this case is roughly three times larger. Moreover, the hardware modifications in the primary circuit of the facility have also been considered. In particular, the feedwater line has been added and the connection zone between downcomer and lower plenum and the region around the top of the separator have been slightly modified to better reproduce natural circulation in the reference reactor.

The IC system nodalization is essentially the same as adopted for the post-test analysis of the PO-SD-8 experiment (refs. /5/ and /6/); only the pool nodalization has been changed to account for the presence of a shroud enveloping the IC component.

Relevant input values related to the hydraulic volumes and to the connecting junctions of the nodalization, are summarized in Tabs. V and VI. The following items can be added to clarify Fig. 29 and the last tables:

- the nodes 100 to 140 (in total 14 nodes) represent the lower plenum which is connected with the jet-pump/downcomer region through the junction 325-03, with the core bypass through the junction 130-02 and with the IC system through the junction/valve 550; -the hydraulic volumes 325, 330, 335 and 345 (11 nodes) are also part of the lower plenum and constitute the connection region downcomer - lower plenum;
- the nodes 200, from 1 to 16 represent the core: among these, the nodes 200-01 to 200-14

constitute the active region;

- the nodes 145 to 180 (in total 40 nodes) represent the core bypass that is connected to lower plenum and to the core exit region (through the junction 205-02);
- the upper plenum region is simulated by nodes from 205-01, to 220-02 (4 nodes) and include connections to core, core bypass and to the volume surrounding the fuel box simulator (see below);
- the volume surrounding the fuel box simulator has been included to preserve the square cross section for the fuel box, at the same time avoiding unrealistic thickness to maintain the pressure; it is connected with the main loop through the junction 360-01;
- the separator region consists of nodes from 220-03 to 220-20 (18 nodes) and is constituted by a "PIPE" component;
- the steam dome is constituted by vertical and horizontal parts, i.e. nodes from 235 to 265 (21 nodes) and includes connections with the separator through the junction 235-01, with the 'separator annulus' (see below) through the junction 235-02, with the downcomer through the junction 270-01, with the IC system through the junction 245-03 and with "external systems" like the steam line, the pressure control, the SRV and the ADS through the TMDPJUN 433 and valves from 443 to 473;
- the 'separator annulus' is a region outside the separator region and has been introduced to avoid the return of possible wall condensed liquid directly to the core region, volumes 225 and 230 (9 nodes); it is connected with the downcomer through an horizontal line including nodes 290 and 295;
- the downcomer is constituted by a cylindrical part consisting of hydraulic volumes from 270 to 310 (22 nodes) and by an annular part, hydraulic volume 320 (15 nodes) surrounding the jet pump simulator; the downcomer is connected with the steam dome/separator region through the junction 270-01, with the feedwater system through the TMDPJUN 453, with the separator annulus through the junction 300-03 and with the jet-pump through the junction 310-03;
- the jet-pump simulator is constituted by the cylindrical hydraulic component 315 (15 nodes) directly connected with the downcomer and the lower plenum region;
- structures heating systems and cooling systems are part of the nodalization and reflect the characteristics of the components in the facility (ref. /13/);
- emergency systems have also been included according to the design of PIPER-ONE, e.g. nodes 410, 420, etc.;
- the IC system consists of:
  a) connecting pipes, i.e. hydraulic volumes 500 and 540 (37 nodes) connecting the IC to the primary circuit;
  b) the heat exchange zone constituted by parallel tubes (i.e. hydraulic volume 515), inlet and outlet plena, (i.e. hydraulic volumes 510 and 520) and single outlet tube i.e. hydraulic volumes 525 (21 nodes);
  c) the pool where the following zones can be recognized:
     c1) the heat transfer region internal to the shroud i.e. hydraulic volumes 552, 560 and 561 (14 nodes);
     c2) the outer annulus, i.e. hydraulic volumes 652, 660 and 661 (14 nodes);
     c3) plenum regions, i.e. hydraulic volumes 551 and 562 (2 nodes);
     c4) external pipes, i.e. hydraulic volumes 563 and 564 (44 nodes);
- structures are connected with each hydraulic volume: pipe walls have been separated from flanges;
- the active structures of the rod simulators have been subdivided into 10 radial meshes.

NODE	VOLUME ($m^3 x 10^3$)	HEIGHT/LENGTH (m)	ZONE
100-01	3.212	0.3	
110-01	2.677	0.25	
110-02	2.677	0.25	**Lower plenum**
110-03	1.545	0.1443	
110-04	1.545	0.1443	
110-05	1.193	0.1114	
111-01	1.730	0.1615	
112-01	1.713	0.16	
115-01	1.869	0.1745	
120-01	1.944	0.2	
120-02	1.944	0.2	
130-01	1.488	0.176	
135-01	1.692	0.2	
140-01	1.692	0.2	
325-01	1.393	0.327	
330-01	0.85	0.185	
335-01	1.079	0.257	
335-02	1.079	0.257	
335-03	1.943	0.257	
335-04	1.943	0.257	
345-01	1.21	0.16	
345-02	0.247	0.18	
345-03	0.247	0.18	
345-04	0.343	0.25	
345-05	0.343	0.25	
TOTAL	34.961		
200-01	0.78	0.265	
200-02	0.78	0.265	**Core**
200-03	0.78	0.265	
200-04	0.78	0.265	
200-05	0.78	0.265	
200-06	0.78	0.265	
200-07	0.78	0.265	
200-08	0.78	0.265	
200-09	0.78	0.265	
200-10	0.78	0.265	

Tab. V - Details of nodes geometry in the RELAP5 nodalization

NODE	VOLUME (m^3x10^3)	HEIGHT/LENGTH (m)	ZONE
200-11	0.78	0.265	
200-12	0.78	0.265	
200-13	0.78	0.265	
200-14	0.78	0.265	
200-15	0.814	0.229	
200-16	0.711	0.2	
TOTAL	12.445		
145-01	0.057	0.2	**Bypass**
145-02	0.057	0.2	
145-03	0.054	0.1892	
145-04	0.054	0.1892	
145-05	0.054	0.1892	
145-06	0.054	0.1892	
145-07	0.054	0.1892	
150-01	0.976	0.2468	
150-02	0.976	0.2468	
150-03	0.976	0.2468	
150-04	0.976	0.2468	
150-05	0.976	0.2468	
155-01	0.186	0.223	
160-01	0.178	0.2133	
160-02	0.178	0.2133	
160-03	0.178	0.2133	
160-04	0.178	0.2133	
160-05	0.178	0.2133	
160-06	0.178	0.2133	
160-07	0.178	0.2133	
160-08	0.178	0.2133	
160-09	0.178	0.2133	
160-10	0.178	0.2133	
165-01	0.168	0.2015	
170-01	0.196	0.235	
170-02	0.196	0.235	
170-03	0.196	0.235	
170-04	0.196	0.235	
170-05	0.196	0.235	
170-06	0.196	0.235	
170-07	0.196	0.235	
170-08	0.196	0.235	
170-09	0.196	0.235	

Tab. V - Details of nodes geometry in the RELAP5 nodalization (cont'ed)

NODE	VOLUME (m^3x10^3)	HEIGHT/LENGTH (m)	ZONE
170-10	0.196	0.235	
175-01	0.173	0.2075	
180-01	0.211	0.1776	
180-02	0.211	0.1776	
180-03	0.211	0.1776	
180-04	0.211	0.1776	
TOTAL	10.400		
205-01	1.262	0.22	**Upper plenum**
210-01	2.262	0.22	
220-01	2.200	0.214	
220-02	2.200	0.214	
TOTAL	8.924		
220-03	0.5651	0.2345	
220-04	0.5651	0.2345	
220-05	0.5651	0.2345	
220-06	0.5651	0.2345	
220-07	0.5651	0.2345	
220-08	0.5651	0.2345	
220-09	0.5651	0.2345	
220-10	0.5651	0.2345	
220-11	0.5651	0.2345	
220-12	0.5651	0.2345	
220-13	0.5651	0.2345	
220-14	0.5651	0.2345	
220-15	0.5651	0.2345	
220-15	0.5651	0.2345	
220-16	0.5651	0.2345	
220-17	0.5651	0.2345	
220-18	0.5651	0.2345	
220-19	0.5651	0.2345	
220-20	0.5651	0.2345	
225-01	2.447	0.34	
230-01	3.684	0.512	
230-02	3.375	0.469	
230-03	3.375	0.469	
230-04	3.375	0.469	
230-05	3.375	0.469	
230-06	3.375	0.469	
230-07	3.375	0.469	

Tab. V - Details of nodes geometry in the RELAP5 nodalization (cont'ed)

NODE	VOLUME (m^3x10^3)	HEIGHT/LENGTH (m)	ZONE
230-08	3.375	0.469	
235-01	2.554	0.246	
240-01	2.595	0.25	
240-02	2.595	0.25	
240-03	2.595	0.25	
240-04	2.595	0.25	
245-01	3.789	0.365	
250-01	1.555	0.289	
250-02	1.555	0.289	
250-03	1.555	0.289	
250-04	1.555	0.289	
250-05	1.555	0.289	
255-01	1.647	0.289	
255-02	1.647	0.289	
255-03	1.647	0.289	
255-04	1.647	0.289	
255-05	1.647	0.289	
260-01	1.662	0.25	
260-02	1.662	0.25	
260-03	1.662	0.25	
260-04	1.662	0.25	
265-01	1.635	0.246	
280-01	0.418	0.3295	
280-02	0.418	0.3295	
TOTAL	81.7548		
270-01	1.367	0.247	**Downcomer and jet pump**
275-01	2.009	0.362	
275-02	2.009	0.362	
275-03	2.009	0.362	
275-04	2.009	0.362	
280-01	1.660	0.3	
285-01	1.660	0.3	
285-02	1.660	0.3	
285-03	1.660	0.3	
285-04	1.660	0.3	
285-05	1.660	0.3	
285-06	1.660	0.3	

Tab. V - Details of nodes geometry in the RELAP5 nodalization (cont'ed)

NODE	VOLUME (m^3x10^3)	HEIGHT/LENGTH (m)	ZONE
295-01	1.078	0.39	
295-02	1.078	0.39	
300-01	0.988	0.283	
305-01	1.012	0.29	
305-02	1.012	0.29	
305-03	1.012	0.29	
305-04	1.012	0.29	
305-05	1.012	0.29	
305-06	1.012	0.29	
305-07	1.012	0.29	
305-08	1.012	0.29	
310-01	1.385	0.325	
315-01	0.355	0.273	
315-02	0.355	0.273	
315-03	0.355	0.273	
315-04	0.355	0.273	
315-05	0.355	0.273	
315-06	0.355	0.273	
315-07	0.355	0.273	
315-08	0.355	0.273	
315-09	0.355	0.273	
315-10	0.355	0.273	
315-11	0.355	0.273	
315-12	0.355	0.273	
315-13	0.355	0.273	
315-14	0.355	0.273	
315-15	0.355	0.273	
320-01	0.737	0.273	
320-02	0.737	0.273	
320-03	0.737	0.273	
320-04	0.737	0.273	
320-05	0.737	0.273	
320-06	0.737	0.273	
320-07	0.737	0.273	
320-08	0.737	0.273	
320-09	0.737	0.273	
320-10	0.737	0.273	
320-11	0.737	0.273	
320-12	0.737	0.273	
320-13	0.737	0.273	
320-14	0.737	0.273	
320-15	0.737	0.273	
TOTAL	49.849		

Tab. V - Details of nodes geometry in the RELAP5 nodalization (cont'ed)

NODE	VOLUME (m^3x10^3)	HEIGHT/LENGTH (m)	ZONE
360-01	1.926	0.429	**Filler**
370-01	2.379	0.53	
370-02	2.379	0.53	
370-03	2.379	0.53	
370-04	2.379	0.53	
370-05	2.379	0.53	
370-06	2.379	0.53	
370-07	2.379	0.53	
			IC
500-01	0.141	0.38	
500-02	0.141	0.38	
500-03	0.141	0.38	
500-04	0.141	0.38	
500-05	0.141	0.38	
500-06	0.115	0.312	
500-07	0.115	0.312	
500-08	0.115	0.312	
500-09	0.115	0.312	
500-10	0.078	0.212	
510-01	0.12	0.2	
515-01	0.1927	0.0632	
515-02	0.1927	0.0632	
515-03	0.1927	0.0632	
515-04	0.1927	0.0632	
515-05	0.1927	0.0632	
540-01	0.089	0.35	
540-02	0.089	0.35	
540-03	0.120	0.472	
540-04	0.120	0.472	
540-05	0.120	0.472	
540-06	0.120	0.472	
540-07	0.120	0.472	
540-08	0.120	0.472	
540-09	0.120	0.472	
540-10	0.120	0.472	
540-11	0.120	0.472	
540-12	0.120	0.472	
540-13	0.120	0.472	
540-14	0.120	0.472	
540-15	0.120	0.472	
540-16	0.120	0.472	
540-17	0.120	0.472	
540-18	0.120	0.472	
540-19	0.120	0.472	
540-20	0.120	0.472	

Tab. V - Details of nodes geometry in the RELAP5 nodalization (cont'ed)

NODE	VOLUME (m^3x10^3)	HEIGHT/LENGTH (m)	ZONE
540-21	0.120	0.472	
540-22	0.120	0.472	
540-23	0.102	0.4	
540-24	0.076	0.3	
540-25	0.089	0.35	
540-26	0.089	0.35	
540-27	0.089	0.35	
TOTAL	5.2295		
551-01	55.755	0.07875	**IC Tank**
552-01	7.875	0.07875	
560-01	7.875	0.07875	
560-02	7.875	0.07875	
560-03	7.875	0.07875	
560-04	7.875	0.07875	
560-06	7.875	0.07875	
560-07	10.0	0.1	
560-08	5.1	0.1	
560-09	5.5	0.0632	
560-10	5.5	0.0632	
560-11	5.5	0.0632	
560-12	5.5	0.0632	
561-01	5.5	0.0632	
562-01	65.9	0.1	
652-01	47.88	0.07875	
660-01	47.88	0.07875	
660-02	47.88	0.07875	
660-03	47.88	0.07875	
660-04	47.88	0.07875	
660-05	47.88	0.07875	
660-05	47.88	0.07875	
660-06	47.88	0.07875	
660-07	60.8	0.1	
660-08	60.8	0.1	
660-09	38.43	0.0632	
660-10	38.43	0.0632	
660-11	38.43	0.0632	
660-12	38.43	0.0632	
TOTAL	868.29		

Tab. V - Details of nodes geometry in the RELAP5 nodalization (cont'ed)

SIGNIFICANT JUNCTION	FLOW AREA m^2x10^4	K_D	K_R	POSITION
primary loop:				
130-02	2.86	0.	0.	bypass inlet
140-02	5.938	0.19	0.9	core inlet
205-01	16.49	14.5	10.6	core outlet
205-02	8.3	0.1	0.1	bypass outlet
220-02	24.1	0.	0.	separator inlet
235-01	24.1	0.	0.	separator outlet
235-02	3.94	100.	100.	separator annulus
235-03	42.6	0.1	0.1	steam dome lower connection
245-02	53.82	0.1	0.1	steam dome upper connection
310-02	27.	0.	0.	lower downcomer annulus
310-03	13.	1.	1.	jet pump inlet
340-00	8.5	1.	1.	lower plenum valve
IC loop				
505-00	3.	10.	10.	top valve
510-01	3.7	0.1	0.1	inlet pipe
510-02	3.	0.1	0.1	tube inlet
520-01	3.	0.1	0.1	tube outlet
520-02	1.7	0.1	0.1	outlet pipe
550-00	0.06	300.	-	bottom valve

Tab. VI - Details of relevant junction related parameters of RELAP5 nodalization

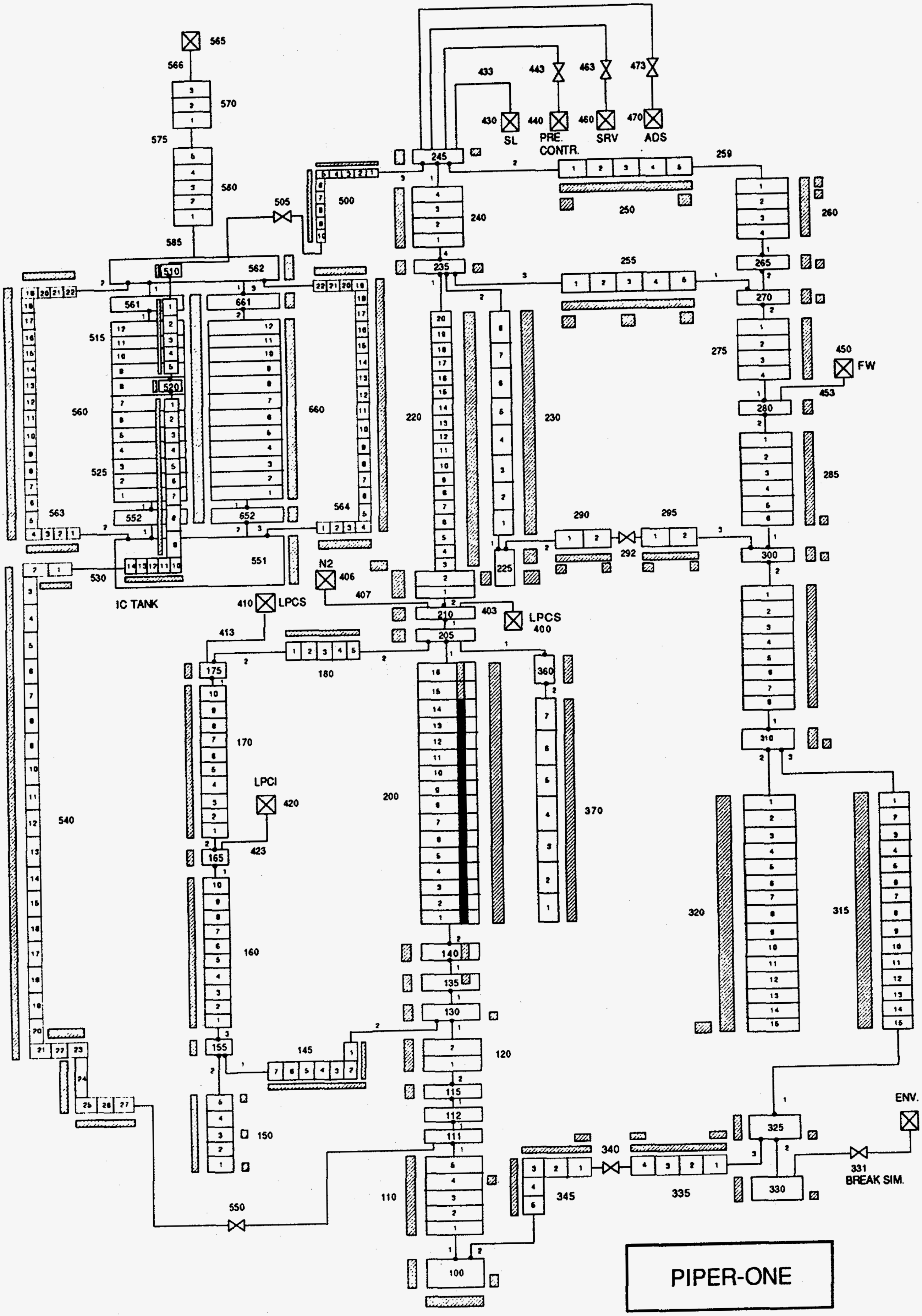


Fig. 29 - Nodalization of PIPER-ONE loop

4. ANALYSIS OF POST-TEST CALCULATION RESULTS

The pre-test results, that have been the basis for the design of the PO-IC-2 experiment, are not comparable with the actual data because of the differences between specified and actual values of the initial and boundary conditions. In particular, as already mentioned, the electrical power supply to the fuel rod simulator was limited to less than 100 kW.

For these reasons, the post-test analysis has comprised three phases:

1. achievement of good comparison between calculated and predicted trends of available primary circuit data;
2. definition of a reference calculation on the basis of the above activity;
3. execution of a series of sensitivity calculations aiming at reaching the stated objectives.

In the frame of the analysis at item 1., boundary and initial condition values related to the primary loop have been changed within the presumed experimental error bands, up to getting a satisfactory comparison between predicted and measured time trends in the primary circuit itself.

Once this process ended (this required a somewhat large effort because of the relative low power of the experiment+), the reference calculation results were also compared with the experimental values in the IC system (phase 2.).

The phase 3. of the analysis consisted of five different steps aiming at the evaluation of:

3a) influence of code version;
3b) influence of selected initial/boundary condition values;
3c) user effects;
3d) nodalization effects;
3e) sensitivity of code results when a geometric/hydraulic relevant parameter is changed in the input deck;

An additional calculation (identified as IC37 in the following) was performed to confirm the conclusions related to the reasons why IC flowrate remains constant when varying core supplied power; this is included in the above group 3e).

Finally, the results of a scaling analysis are shown; these demonstrate the suitability of the data base in relation to scenarios expected in SBWR plants (sect. 4.4).

4.1 Steady state calculations (Phase 1 of the post-test analysis)

As already mentioned, the main objective of the calculations was to match the primary circuit pressure trend.

The initial condition at the assumed "time zero" in the experiment was achieved at zero core power and zero flows inside feedwater and steam lines and at core inlet; structures heating systems were active to compensate heat losses to environment.

The very first series of calculations was carried out changing:

* the fluid temperature values around the loop (+/- 3K around the saturation value);

+ This means that minor variations in the boundary and initial condition values (e.g. changes of heat losses of +/-1 kw, of initial downcomer level of +/-0.2 m, of the timing of opening/closure of IC valves of 2 s, consideration of primary circuit leaks as low as 0.0001 kg/s) have a sensible effect on primary pressure values as it happens in all tests performed at low power in any experimental facility, temperatures imbalances in the fluid and in the structures with main reference to the thick flanges.

* the heat losses to environment (in the range 0 - 5 kW) and the related spatial distribution, excluding the heat losses through the chamber of rods electrical connectors (see below);
* downcomer and core regions level (in the range +/- 1 m around the available experimental value).

Subsequently, a leak was introduced in the lower downcomer (leak flow varied in the range 0. - 0.05 kg/s starting from 600 s into the transient). Moreover, the time trend of the heat losses across the rod connectors zone has also been varied during the transient accounting for changes in the flows of the cooling nitrogen in this zone .

Finally IC valves characteristics, e.g. opening/closure time and actuation time (varied in the ranges +/- 1s and +/- 2 s, respectively) have been changed.

The final situation considered for initial and boundary conditions can be seen in Tabs. VII and VIII including the comparison between calculated and measured (if available) values.

It should be noted that almost 30 code runs were necessary to achieve the reported final results.

The comparison between measured and calculated trends of primary pressure, lower plenum temperature and levels in the core region and in the downcomer, is given in Figs. 30 to 33. The calculated trends have been obtained from the code run IC31 (see below). A detailed analysis of the comparison can be found in sect. 4.2.

Here it is sufficient to emphasize three minor discrepancies in the pressure trend:
- at the transient beginning owing to the initial fluid temperature stratification not correctly considered in the code;
- during the phase of electrical power interruption mostly due to inadequate consideration of heat input to the fluid from the structures heating system;
- in the second phase of the test that is a consequence of the above.

The error in all the three cases is less than 0.1 MPa.

The measured lower plenum temperature is only bounded in the calculation (Fig. 31): this is due to the position of the thermocouple that is close to the connection between the main loop and the IC; in the Relap calculation an average volume related value is reported.

Larger differences appear from the level measurements (Figs. 32 and 33); in this case the reliability of the experimental signal is quite low. In the frame of the performed sensitivity calculations, it has been checked that large variations of these quantities (i.e. greater than the actual differences between measured and calculated trends) do not cause variations in the overall transient scenario with main reference to primary pressure and flowrate across the IC.

PARAMETER	UNIT	EXP	CALC (°)
LP pressure	MPa	5.1	5.1
LP temperature	°C	262.	258.5
Core level	m	11.9	11.8
DC level	m	10.7	10.5
IC line fluid temperature	°C	17.5	18.
IC pool fluid temperature	°C	17.5	18.
IC mass flowrate	kg/s	0.	0.
Core power	kW	0.	0.
Primary system heat losses: (*)			
- core region	kW	-	1.97
- steam dome	kW	-	8.5
- separator annulus	kW	-	- 0.43
- upper downcomer	kW	-	- 0.39
- lower downcomer	kW	-	3.4
- LP/core inlet	kW	-	2.5

(°) Reference case (IC31)
(*) Sign "-" refers to power added to the fluid, sign "+" to power lost

Tab. VII - Comparison between measured and calculated initial conditions

PARAMETER OR EVENT	TIME	
	EXP (s)	CALC (s)
Test initiation	0.	0.
Power versus time	as in Table IV	
IC top valve opens	4.	4.
IC bottom valve opens	32.	32.
IC top valve closes	508.	508.
IC bottom valve closes	-	508.
IC top valve opens	602.	605.
IC bottom valve opens	602.	606.
IC top and bottom valve close	1106.	1106.

Tab. VIII - Comparison between measured and calculated boundary conditions

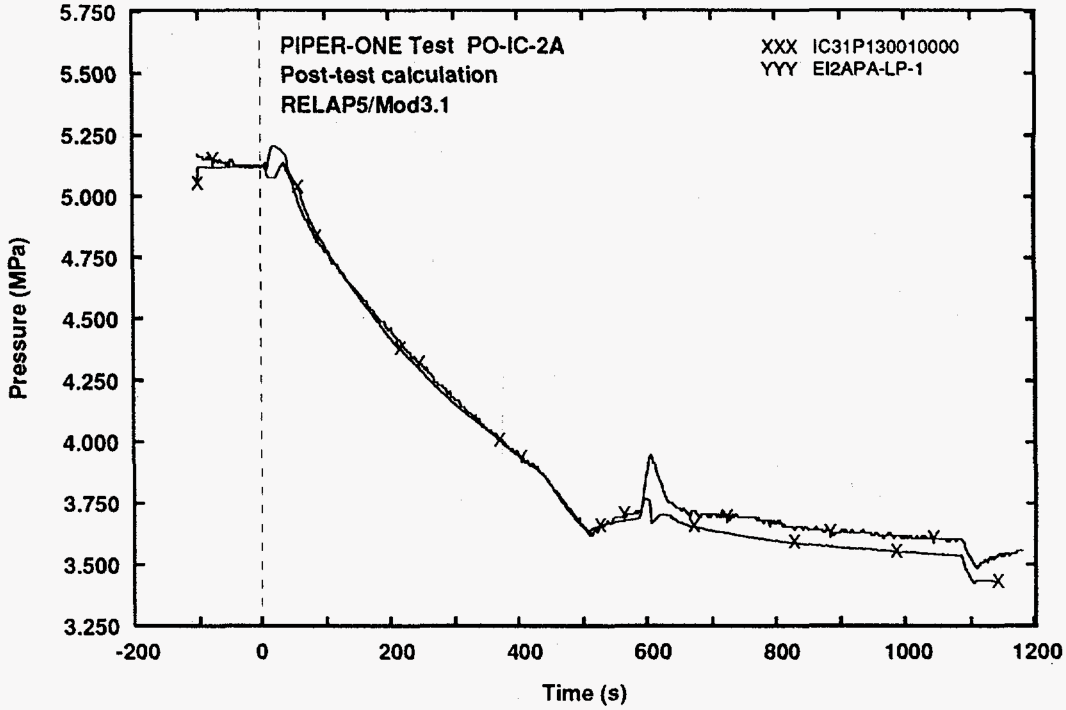


Fig. 30 - Measured and calculated trends of lower plenum pressure

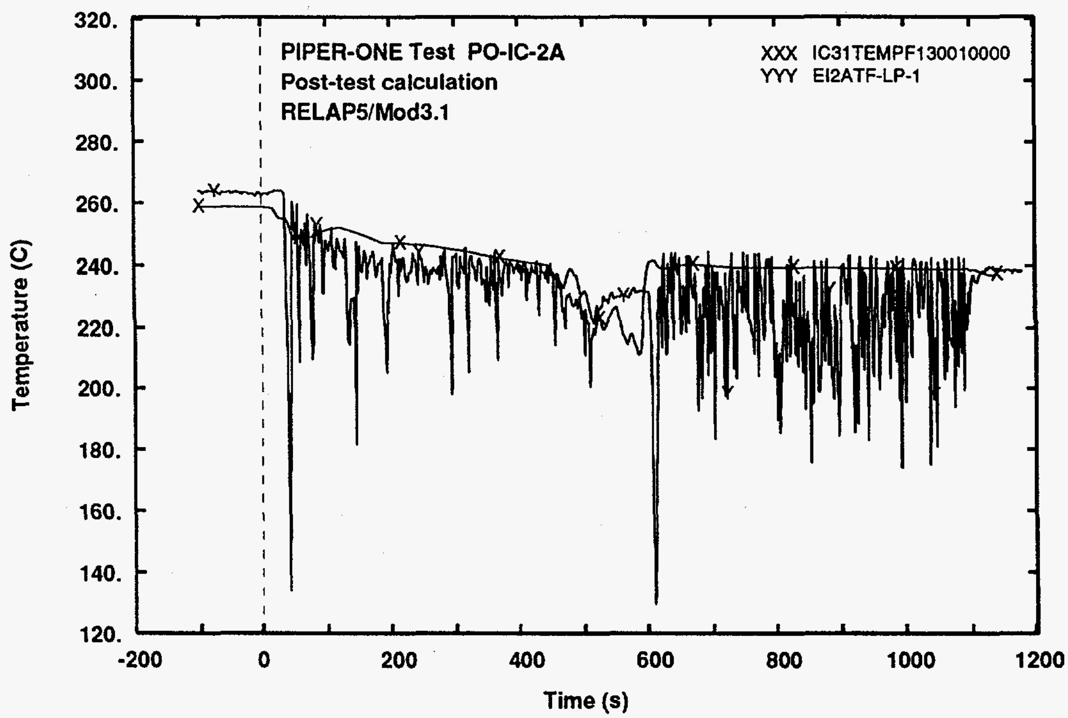


Fig. 31 - Measured and calculated trends of lower plenum temperature

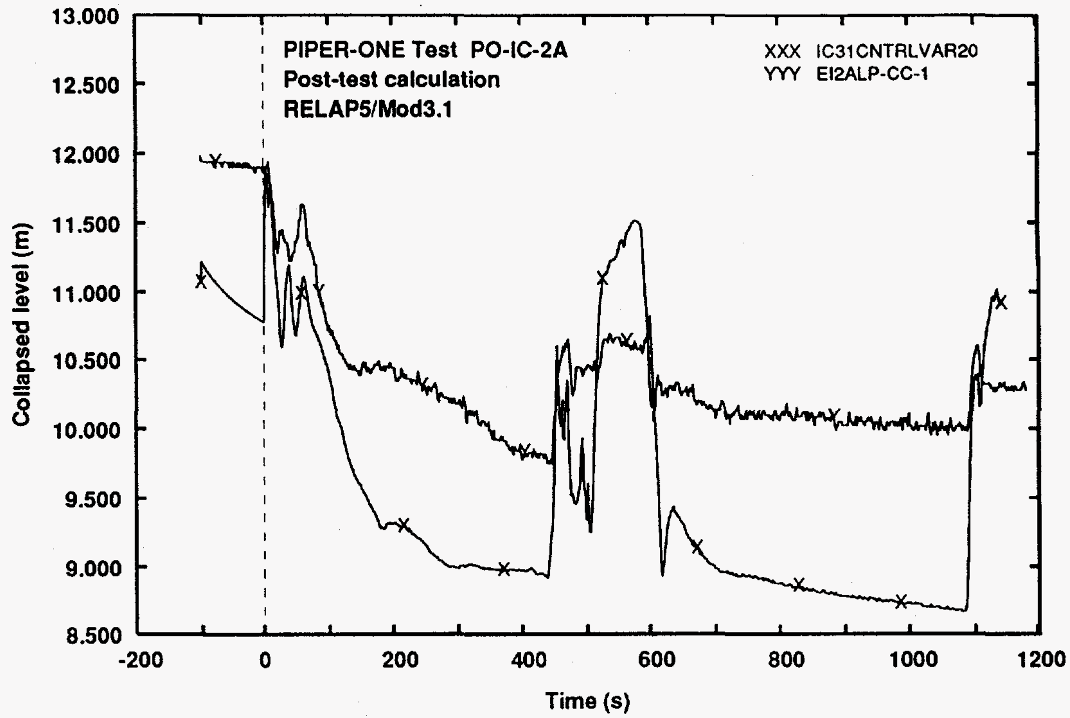


Fig. 32 - Measured and calculated trends of core level

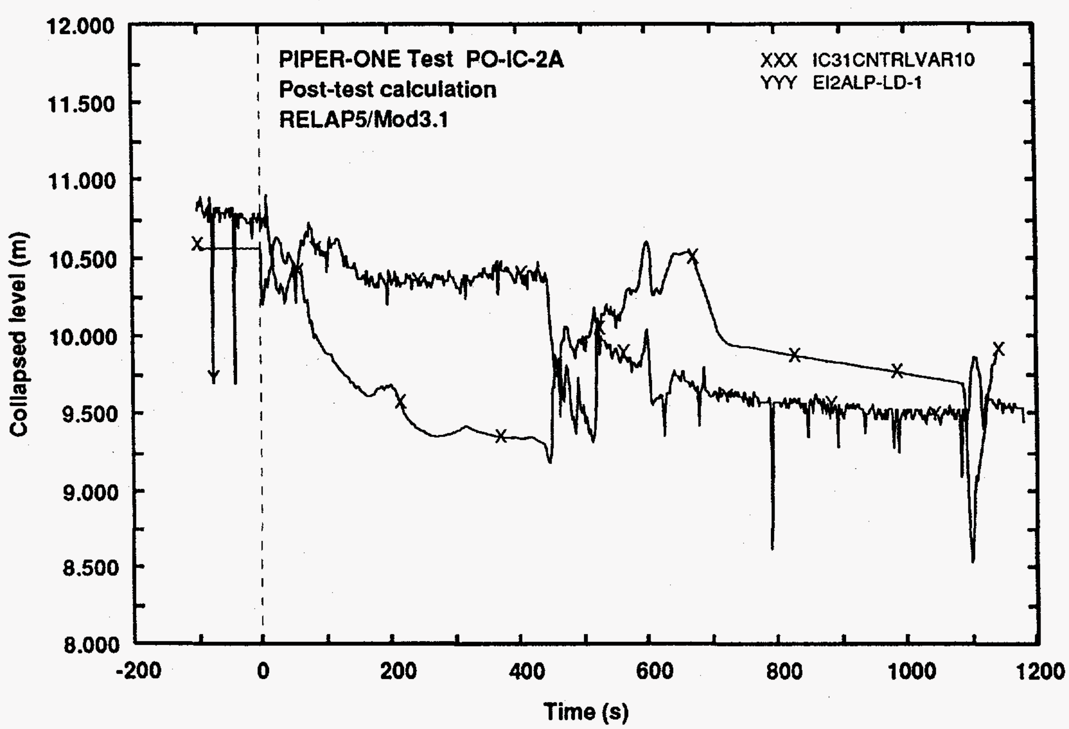


Fig. 33 - Measured and calculated trends of downcomer level

4.2 Reference calculation results (Phase 2 of the post test analysis)

Each of the performed calculations (see below) has been evaluated on the basis of 39 time trends of selected thermalhydraulic quantities. These can be subdivided into three main groups:

A) variables related to the primary circuit that have been selected considering the availability of experimental data (the numbers into parentheses below refer to the identification of figures in the Appendices):
- lower plenum pressure, (Fig. 1);
- lower plenum fluid temperature, (Fig. 2);
- rod surface temperature at level 9, (Fig. 3);
- core region level, (Fig. 4);
- downcomer levels, (Fig. 5);
- core power, (Fig. 6);

B) variables related to the IC system that have been selected considering the availability of experimental data:
- mass flow rate, (Fig. 7);
- differential pressure across the IC, (Fig. 8);
- fluid temperatures along the IC system - primary side, (Figs. 9 - 12 and Fig. 27);
- wall temperatures in the IC system, (Figs. 13 - 18);
- fluid temperatures in the pool, (Figs. 19 - 26);
- exchanged power across the IC (Fig. 28);
- temperature difference between selected points (Figs. 29 - 31);

C) calculated variables related to the IC system that are relevant for understanding the concerned phenomena and for evaluating the code behaviour:
- heat transfer coefficients in the IC, (Figs. 32 - 34);
- void fractions inside the IC tubes, (Fig. 35);
- liquid and steam velocities inside the IC tubes, (Figs. 36 and 37);
- internal and external heat transfer modes in the IC tubes (Figs. 38 and 39);
- differences between steam and liquid temperature of primary fluid (Fig. 40).

The reference calculation results, that is case IC31, are reported in App. 1 (Figs. 1 - 40) and are discussed in the next section.

<u>Computer related statistics</u>

The calculations performed by RELAP5/Mod 3.1 have been run on the IBM RISC 6000, as results from sect. 3.1. The following relevant code run statistics applies (specifically related to the IC31 calculation):

- CPU time is of the order of 20000 s (Fig. 41 in App. 1);
- time step ranges between 0.05 and 0.1 s (Fig. 42 in App. 1), with the exception of the period of IC isolation.

The relation between code selected time step and imposed maximum time step can be seen in Fig. 43 of App. 1.

4.2.1 Primary circuit behaviour

In order to better address the comparison between measured and calculated trends, five phenomenological windows (Ph.W) can be distinguished looking at the primary circuit pressure (Fig. 1):

* Ph.W 1 from transient beginning to 50 s: the prediction does not agree with the experiment owing to minor errors in initial conditions: the presence of a cold patch of liquid in the primary circuit (roughly 20 cm with less than 10 K of subcooling) or the initial temperature of the IC inlet pipe can be considered for improving the agreement between measured and calculated trends; however this does not affect the subsequent transient;
* Ph.W 2 from 50 s to 440 s: this constitutes the low power part of the test. An excellent qualitative and quantitative agreement between measured and calculated trends can be observed: this demonstrates that the IC removed power is very well predicted;
* Ph. W 3 from 440 s to 650 s: this includes the power shut-off period (i.e. from 440 s to 588 s) and the period necessary to achieve a "quasi steady-state" in the high power part of the test (i.e. from 588 s to 650 s). The disagreement in this Ph.W is mostly due to wrong estimation of the behaviour of the structure heating system, to the inaccurate modelling of the conduction heat transfer in the thick flanges (much larger number of meshes is required) and to the phenomena that occur inside the IC after its isolation. In particular, it is interesting to note that a sudden void collapse occurs in the IC primary system after its isolation; this brings the pressure from about 4 MPa to saturation values corresponding to the liquid temperature in the pool (i.e. of the order of 0.01 MPa). Two main consequences in terms of code calculation are:
  a) the time step required to predict the condensation shock is very low (of the order of 1.e-6 s) and the code appeared not qualified in this connection;
  b) the test conditions (essentially the insurge of liquid into the IC line) resulting from the shock occurrence affect the code prediction in the period 588 s to 650 s and are the main reason for the discrepancy in this period;
* Ph.W 4 from 650 s to 1088 s: this constitutes the high power part of the test. An excellent qualitative agreement between measured and calculated trends can be noted; the difference between the two curves is a result of the previous Ph.W and is less than 0.1 MPa. Again the overall trend shows that the IC exchanged power is very well predicted;
* Ph. W 5 from 1088 s to the end: power shutoff occurs in this period. The good agreement between measured and calculated trends confirms that the energy balance is well considered in the calculation.

It should be noted that the Ph.W 2 and 4 are of main interest in our study.

A few additional remarks related to the comparison between measured and predicted trends of the remaining primary circuit related quantities (Figs. 2 - 6 of App. 1) are as follows:

- the negative peaks in the measured lower plenum temperature (Fig. 2), as already mentioned, are due to the cold water coming from the IC; a volume averaged value is calculated by the code; the discrepancies during the Ph. W 3 are due to cold liquid stratification caused by the cooling of the rod connectors chamber;
- discrepancies in the rod surface temperatures are essentially due to the position of the thermocouple that does not coincide with the surface of the rod (Fig. 3);
- inaccuracies in the experimental signal and minor leaks from the primary circuit are to be considered when examining the discrepancies in levels (Figs. 4 and 5 of App. 1), as well as the fact that core and DC levels are influenced by the fluid velocity. However this does not hold for the lower DC level measurement (signal LP-LD-1); a code inadequacy

seems evident in this respect;

- the calculated quantity is the heat transferred from the rods to the fluid while the experimental quantity is the electrical power supply to the rods: this explains the errors (not present during the "quasi steady- state") in the core power curves (Fig. 6 of App. 1).

4.2.2 IC behaviour

Primary System

The mass flowrate across the IC is quite well predicted by the code (Fig. 7 of App. 1); the zero flow resulting from the turbine signal in the first 200 s is originated by a malfunction of this device, as already mentioned. Peaks in the experiment during the Ph.W 1, 3 and 5 are not predicted. It can be concluded that the calculated result is within the experimental error bands in the Ph. W 2 and 4 that are of main interest in the present study.

Some more work is necessary to qualify the measured pressure drop signal (Fig. 8); nevertheless the prediction can be retained within the experimental error bands in the Ph. W 2 and 4.

The fluid temperatures at the IC inlet are represented in Figs. 9 and 27 of App. 1. The agreement between measured and calculated trends is quite good during all the considered Ph.W. Moreover, Fig. 27 shows that saturation temperature is measured and calculated during the Ph.W 2 and 4 at the IC entrance. The presence of subcooled liquid at the IC inlet during the Ph.W 1 and 3 can be deduced from the trends in Fig. 9, although information about absolute pressure in the IC line is not available.

Fluid temperature is very well predicted by the code at the center of the IC: the calculated trend (liquid temperature) lies between the two measured signals in Fig. 10 of App. 1. Subcooling in the lowest three nodes of the IC can be deduced from the analysis of Fig. 11 of App. 1: all the steam is condensed in the first two nodes in both the Ph. W 2 and 4.

The comparison of fluid temperatures at the outlet of the IC, Fig. 12 of App. 1, confirms that the overall heat transfer to the pool is satisfactorily predicted by the calculation: this appears to be true also considering separately the tubes region (where both condensation and heat transfer to the pool from subcooled liquid take place) and the single tube region (where only heat transfer to the pool from subcooled liquid takes place).

The data in Fig. 13 of App. 1 show an overestimation of the surface temperature by the code: this is true for all the surface temperatures, i.e. both in the inner and in the outer surface of the tubes, during the Ph. W 2 and 4, as it also results from Figs. 15, 16, 17, and 18 of App. 1. Considering that the overall power exchanged is quite well predicted, one can deduce a code error in predicting the heat transfer coefficient either in the inner surface or in the outer surface, either in both the surfaces (an average error of the external surface temperature of 20 K results in underestimating the heat transfer coefficient of about 20% in the conditions of Ph. W 2 at the top of the IC, see also sect. 4.2.3). This conclusion is also supported by the observation that measured and calculated surface temperatures are very close during the Ph. W 1, 3 and 5, i.e. when flowrate and exchanged power are nearly zero.

An abrupt external surface temperature change can be observed at about 900 s (Ph. W 4) in the calculation (Fig. 17 of App. 1): this is a consequence of a change in heat transfer coefficient from mode 2 (forced convection) to mode 3 (nucleate boiling) as it results from Fig. 39 of App. 1; mode 3 is also the heat transfer coefficient mode during the entire Ph. W 2 (Fig. 39).

Discrepancies between measured and calculated trends during the Ph. W 3 appear from Fig. 18 of App. 1; in this connection it should be noted that in order to perform the calculation in this Ph. W, it has been necessary to add two TMDPVOL and related TMDPJUN connected with the IC nodes: the reason for adding these components was to smooth the abrupt pressure collapse due to sudden condensation; the effect of the added nodes can be seen, as far as Ph. W 3 is concerned, in the Fig. 18 of App. 1.

Pool

The good agreement between measured and calculated trends of pool temperature at different axial elevations (essentially, Figs. 19, 20, 23 and 24 of App. 1) constitutes an independent proof of the agreement in the overall exchanged power. Three additional aspects should be noted from the analysis of figures from 19 to 26 of App. 1:

- changes in the slope of the predicted trends during the Ph. W 3 (e.g. Fig. 19) are due to the necessity of the TMDPVOL discussed in the previous paragraphs;
- discrepancies in some measured and predicted trends (e.g. Fig. 20 or Fig. 26) are either of minor importance (only 3 K in Fig. 26, within the experimental error band), either due to different positions considered in the calculation and in the experiment (Fig. 20);
- external and internal side pool temperature are nearly the same demonstrating that conduction across the shroud prevents the possibility of establishing sufficient temperature difference to give rise to natural circulation inside the pool.

In definitive, from observing:

a) fluid temperature at IC inlet, outlet and inside IC,
b) surface temperatures in the tubes and,
c) fluid temperature in the pool,

it can be deduced that variables a) and c) are well predicted (also flowrate and overall exchanged power are well predicted); but, variables b) are overestimated. The conclusion is that the heat transfer coefficients across the tubes (either on the internal or external surface) are calculated with some error (see sect. 4.2.3). Figures from 29 to 31 of App. 1 support this conclusion.

Furthermore, the temperature increase in the pool results from Fig. 31: the smooth increase of fluid temperature in the pool leads to a smooth decrease of the temperature difference between tubes inner wall surface temperature and pool temperature itself. Removed power remain constant: this means an average increase of the overall heat transfer coefficient during the experiment.

Calculated quantities

As already mentioned, calculated quantities that have not a corresponding measured trend are reported in Figs. 32 - 40 of App. 1.

As far as heat transfer coefficients are concerned during the Ph.W 2 and 4, the following observations can be made (Figs. 33 to 35 and 38, 39 of App. 1; inner and outer coefficients can be recognized by the last two digits in the variables labels at the right uppermost corner in the figures, "00" and "01", respectively):

- in the upper zone of the tubes Heat Transfer Coefficients at the inner wall (HTCI) are always smaller than Heat Transfer Coefficients at the outer wall (HTCO); in particular average values of HTCI and HTCO are 15000 and 18000 W/m2K, respectively;
- both HTCO and HTCI become noticeably lower along the axis reaching values as low as 1200 W/m2/K for HTCO in the bottom of the IC tubes;
- at the bottom of IC tubes HTCO is much smaller than HTCI, thus controlling the overall heat transfer process;
- the effect of the sharp transition from mode 2 to mode 3 of the HTCO can also be observed in Fig. 33 at about 900 s into the transient (see also Fig. 39 and the previous discussion);
- no sharp transitions during PH.W 2 and 4 can be observed in HTCI (Fig. 38).

The void fraction trends along the axis confirm that condensation is predicted only in the top two nodes simulating the IC tubes (Fig. 35): only liquid is present in the bottom three nodes during the whole experiment.

As reasonable, higher liquid velocities are calculated in the upper two nodes (liquid is entrained by steam, Fig. 36) than in the bottom three nodes.

An apparently unphysical steam velocity trend is calculated in the central node (upward oriented steam velocity in a node where void fraction is zero), Fig. 37: this does not happen in the two lowest nodes.

The degree of subcooling calculated for each of the 5 nodes representing the IC tubes, can be drawn from Fig. 40 of App. 1. It can be noted that, in the second IC node from the top (where both steam and liquid are simultaneously present and predicted void fraction around 0.9, Fig. 35), roughly 20 K subcooling are calculated during both Ph.W 2 and 4.

4.2.3 Heat transfer coefficient across the IC tubes

In order to better understand the comparison between calculated and experimental data in the reference calculation, relevant data were put in the frame of the Tabs. IXa and IXb, considering the Ph.W 2 and 4, respectively.

Each row deals with one of the five axial zones in which the IC tubes have been subdivided.

The first four columns deal with measured and calculated values of temperature differences between primary fluid and inner surface (T_{fi} and T_{wi}) and between outer surface and pool fluid (T_{wo} and T_{fo}). If surface temperature is not available from the experiment at a given level, the assumption is made, for that level, that calculated fluid temperature is the same in the experiment. This is justified by the comparisons between measured and calculated fluid temperatures (Figs. 9, 10, 12, 19, 20, 23, 24 of App. 1).

The second group of four columns deals with calculated values of exchanged power across each axial level at the inner (subscript "i") and at the outer surface of the IC tubes (subscript "o"). The four values of power (symbol "PO"), from left to right in the tables, have been calculated starting from inner "HTC", outer "HTC", inner "Q" value and outer "HTRNR" values, respectively (HTC, Q and HTRNR are Relap5 output quantities).

The following remarks can be done from the analysis of the tables, with reference to both the selected phenomenological windows:

* exchanged power is much higher in the uppermost two nodes than in the remaining three bottom nodes;
* power calculated from the HTC is not consistent with actual value at the inner surface in the uppermost three nodes;
* only one temperature difference has been obtained for the inner surface: this seems not enough to draw conclusions;
* experimental temperature differences at the outer surface are substantially lower than calculated values (factor 1.5 - 2): calculated heat transfer coefficient can be retained underestimated for the same amount. The presumable error coming from "fin" effect introduced by the externally welded thermocouples has not been considered in this conclusion.

In the above analysis, the assumption has been made that the phenomenon is quasi-stationary: this is supported by the time trends of the main quantities. Furthermore, the good agreement between measured and calculated levels (pressure drop inside the tubes) confirms this assumption.

Ph.w.2 (300. s)								
IC ZONE	T_{fi} - T_{wi} (K)		T_{wo} - T_{fo} (K)		PO_i (kW)	PO_o (kW)	$PO^{Q,i}$ (kW)	$PO^{H,o}$ (kW)
	EXP	CALC	EXP	CALC	CALC	CALC	CALC	CALC
1	106. (2)	39	50. (1)	76	21.8	73.	22.	23.3
2	-	70.5	68. (1)	84.5	11.2	59.	6÷23	14÷17
3	-	61.	50. (2)	85.	6.	30.	6.	6.
4	-	53.	-	62.	4.5	4.5	4.5	4.5
5	-	43.5	32.(2)	50.	3.2	3.1	3.2	3.1

$T_{fi/o}$ = inside/outside fluid temperature
$T_{wi/o}$ = inside /outside wall surface temperature
PO_i = inside exchanged power evaluated from HTC
PO_o = outside exchanged power evaluated from HTC

$PO^{Q,i}$ = inside exchanged power calculated by code (variable "Q")

$PO^{H,o}$ = outside exchanged power evaluated from heat flux (variable "HTRNR")

(1) = actual value

(2) = experimental fluid temperature equal to calculated one

Tab. IXa - Evaluation of the heat transfer coefficient (Ph.w.2)

Ph.w.4 (900. s)								
IC ZONE	T_{fi} - T_{wi} (K)		T_{wo} - T_{fo} (KW)		PO_i (KW)	PO_o (KW)	$PO^{Q,i}$ (KW)	$PO^{H,o}$ (KW)
	EXP	CALC	EXP	CALC	CALC	CALC	CALC	CALC
1	94. (2)	33.5	25. (1)	44	22.8	4.6.	22.7	22.7
2	-	45.5	35. (1)	65	17.5	54.	5.2÷22	19÷15
3	-	61.	43. (2)	65.	5.7	22.9	5.5.	5.5
4	-	50.	-	53.	4.1	4.1	4.3	4.2
5	-	40.7	31.(2)	44.	3.	3.	3.1	3.1

$T_{fi/o}$ = inside/outside fluid temperature
$T_{wi/o}$ = inside /outside wall surface temperature
PO_i = inside exchanged power evaluated from HTC
PO_o = outside exchanged power evaluated from HTC

$PO^{Q,i}$ = inside exchanged power by code (variable "Q")

$PO^{H,o}$ = outside exchanged power evaluated from heat flux (variable "HTRNR")

(1) = actual value

(2) = experimental fluid temperature equal to calculated one

Tab. IXb - Evaluation of the heat transfer coefficient (Ph.w.4)

4.3 Sensitivity Calculations (Phase 3. of the Post-test analysis)

A large number of sensitivity calculations has been carried out as results from Tab. X, where the varied parameters have been reported together with some qualitatively significant effects on the results.

The calculation ICA6 was carried out with rough boundary conditions, already producing a "good" overall agreement with experimental data (App. 4). After that, some "tuning", changing the parameter values within the experimental error bands, was done: almost 30 calculations were performed, among which the IC19-IC31 specifically mentioned in Tab. X.

The result of the tuning was the reference calculation IC31 (App. 1).

Calculations from IC28 to IC36 in Tab. X aimed at finding parameters having large influence on the results: e.g. it was found that conduction heat transfer mesh size has almost no effect on the results (calculation IC32), while IC tubes node length introduces heavy oscillations in the relevant output quantities (calculation IC34).

Finally, calculation IC37 (App. 3) was carried out as a counterpart of calculation IC31 to demonstrate the influence of the presence of a large parallel circuit (i.e. vessel downcomer) upon the IC global performance.

CODE RUN	CHARACTERISTICS/VARIED PARAMETERS	MAIN RESULTS
ICA6 (1)	Rough boundary conditions	Overall system behaviour qualitatively predicted
IC19÷IC27	Sensitivity analyses - varied parameters: - heat losses (value and distribution) - core and downcomer initial levels; - core and downcomer initial liquid temperature distribution; - leaks in primary system; - IC valves operation.	Effects on primary system response ; minor changes on IC behaviour
IC31 (2)	Reference case	
IC28÷IC30	Liquid insurge in the IC line during the power switch-off and IC isolation phase. Varied parameter: - IC boundary condition modelling	Effect on primary system pressure soon after the power switch-on and IC restart
IC32	Heat exchanger modelling. Varied parameter: - IC tube structure mesh size	No effect
IC33/IC36 (3)	- Heated diameter of IC tube wall external side	Large effect on IC outlet liquid temperature
IC34	- IC tube node number	Small effects on IC fluid temperature distribution and primary system behaviour Strong oscillations in the wall surface temperature of IC tubes
IC35	- IC tube material thermal conductivity	Small effects
IC37 (4)	Recirculation rate in primary system. Varied parameter: - LP valve closure during transient	Step increase in IC mass flow rate

(1) Results in Appendix 4
(2) Results in Appendix 1
(3) Results in Appendix 2
(4) Results in Appendix 3

Tab. X - List of calculations and varied parameters

4.3.1 Significant results

Five main groups of calculations have been distinguished following the discussion under sect. 4. These are classified in Tab. XI where the varied parameter ranges are reported, if applicable. In the last part of Tab. XI, the differences between measured and calculated values of surface temperature in the lowest node of the IC tubes, are reported too. This is done at 100, 300 and 1000 s into the transient, the first two values belonging to Ph.W 2 and the last one to Ph.W. 4. It can be noted that in almost all the cases, calculated outer surface temperature values are larger than measured values (the consideration about possible thermocouples "fin" effect should be made here, too). Assuming that heat transfer power and fluid temperature are the same in the experiment and in the calculation, it can be concluded that calculated HTC values are lower than in the experiment, as it also results from sect. 4.2.3.

GROUP	CASE	VARIED PARAMETER	EFFECT ON PREDICTED IC PERFORMANCE		
			(TS-IC-7) - (HTTEMP15050510)		
			100.s	300.s	1000.s
3a)		USED CODE VERSION			
INFLUENCE OF	IC31*	RELAP5/Mod3.1	-16.9	-17.1	-12.
CODE VERSION	IC7J	RELAP5/Mod3V7J	-14.6	-0.1	-
	ICV8	RELAP5/Mod3V80	-14.8	-0.4	-
	ICM2	RELAP5/Mod2.5	-14.7	-14.8	-17.1
3b)					
INFLUENCE OF					
INITIAL AND BOUNDARY	IC31*	INITIAL AND	-16.9	-17.1	-12.
CONDITIONS	ICA6*	BOUNDARY CONDITIONS	-12.9	-13.3	-4.6
3c)					
USER EFFECT	IC31*	IN/OUT FLOW TO	-16.9	-17.1	-12.
	IC28	IC CONTROL VOLUMES	-16.7	-16.7	-11.8
	IC29		-16.9	-16.9	-11.4
	IC30(°)		-16.9	-17.2	-
3d)		MESH NUMBER OF IC			
NODALIZATION EFFECTS		PIPE WALL:			
	IC31*	10	-16.9	-17.1	-12.
	IC32	20	-17.1	-17.5	-12.4
		NODE NUMBER OF IC PIPE AND CORRESPONDING INTERNAL POOL ZONE:			
	IC31	5	-16.9	-17.1	-12.
	IC34	10	-10.6	-14.6	-8.4
		IC PIPE MATERIAL THERMAL CONDUCTIVITY			
	IC31	STANDARD STEEL	-16.9	-17.2	-12.
	IC35	STANDARD STEEL *2	-17.3	-17.5	-12.3
3e)		HEATED DIAMETER IN THE			
CHANGES OF RELEVANT		EXTERNAL SIDE OF IC PIPE			
PARAMETERS		WALL:			
	IC31*	0.005 m	-16.9	-17.1	-12.
	IC33	0.1 m	-43.7	-44.	-37.3
	IC36*	0.001 m	-3.0	-3.4	0.3
	IC37	LP-VALVE CLOSURE AT 300.s IN THE TRANSIENT	-16.6	-17.2	-31.9

(°) without control volumes in the IC   * Results in Appendix (see Tab. X)

Tab. XI - Documented calculations

In all cases, six quantities have been selected to characterize the influence of the varied parameter:

- lower plenum pressure;
- IC tubes surface temperature (external side level 3);
- IC tubes internal fluid temperature (level 3);
- IC outlet fluid temperature;
- IC HTC inside tubes (level 3);
- IC HTC outside tubes (level 3).

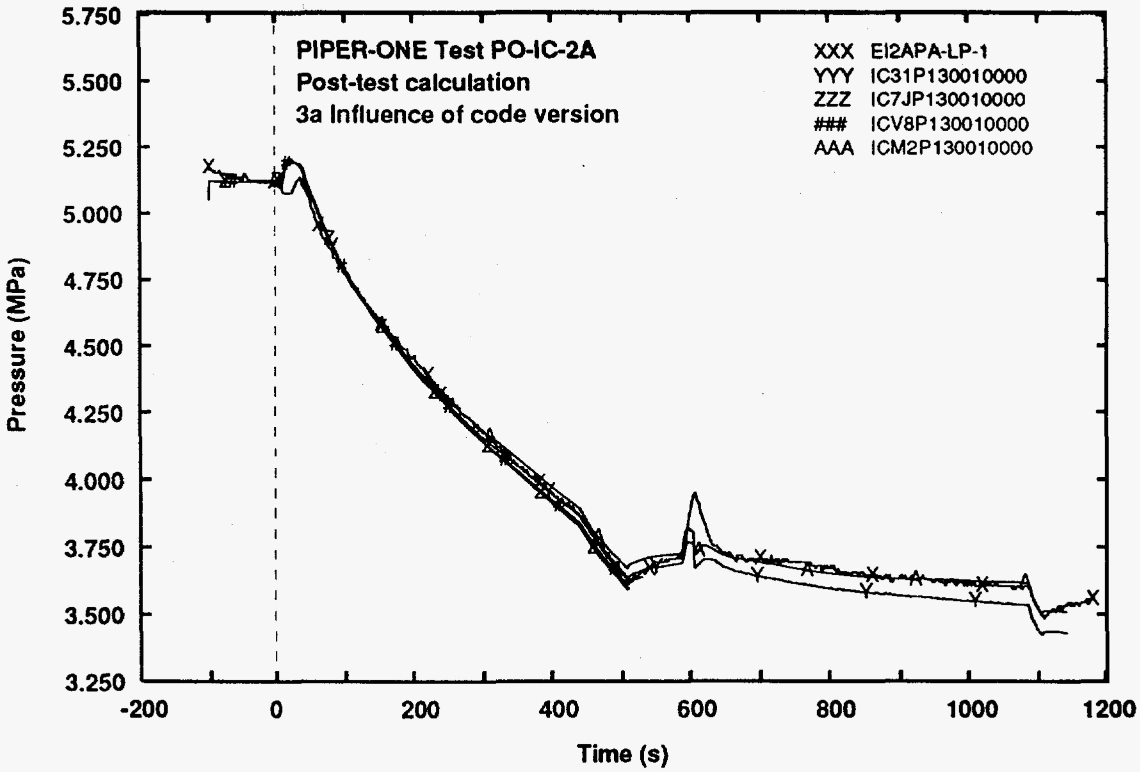


Fig. 34 - Lower plenum pressure

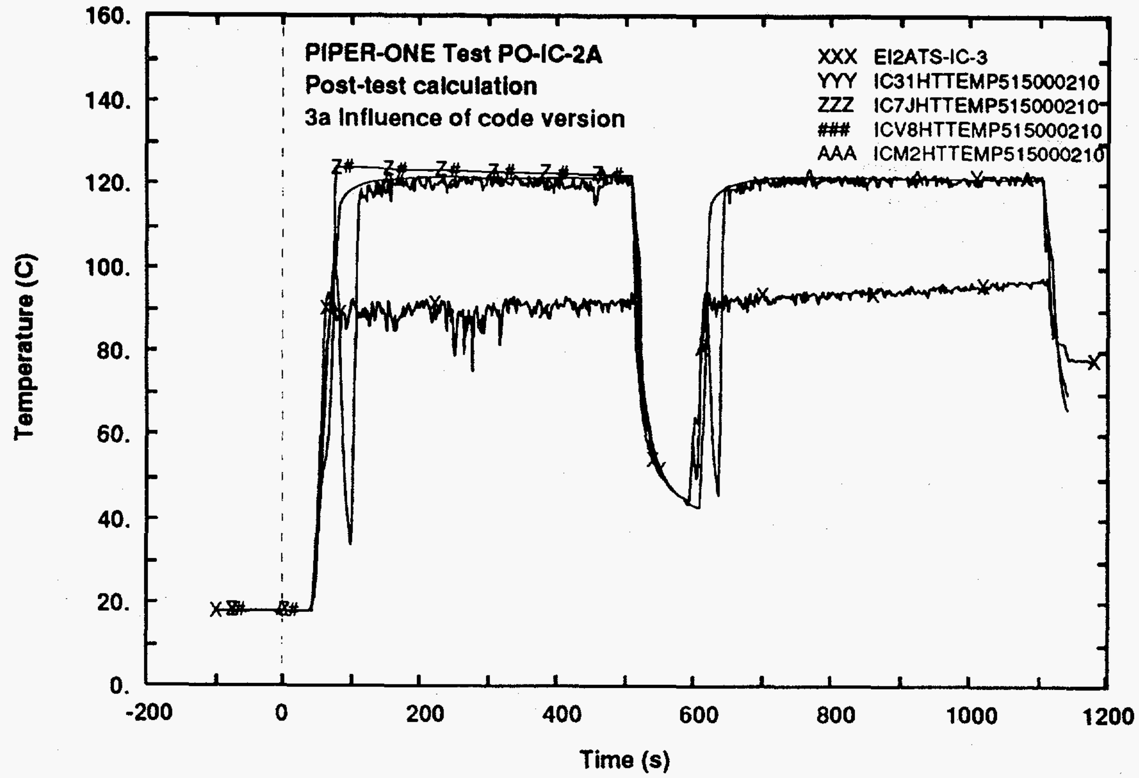


Fig. 35 - IC tubes wall surface temperature (external side level 3)

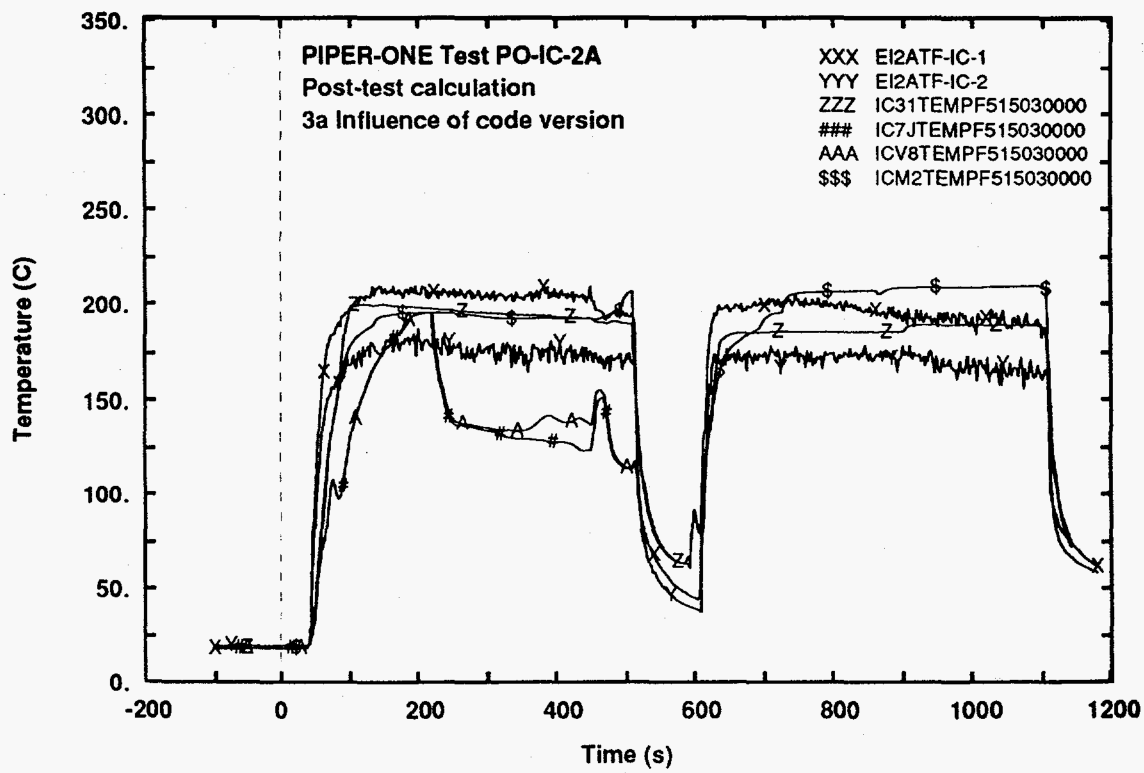


Fig. 36 - IC tubes fluid temperature (middle elevation)

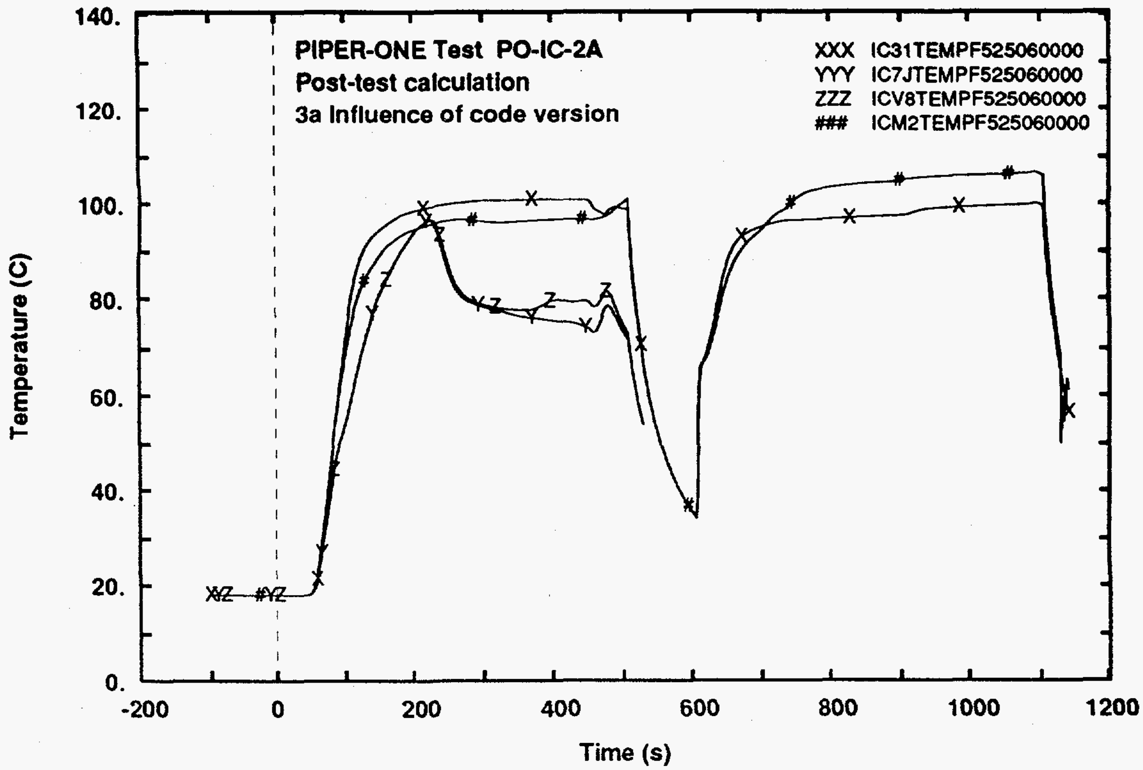


Fig. 37 - IC outlet fluid temperature

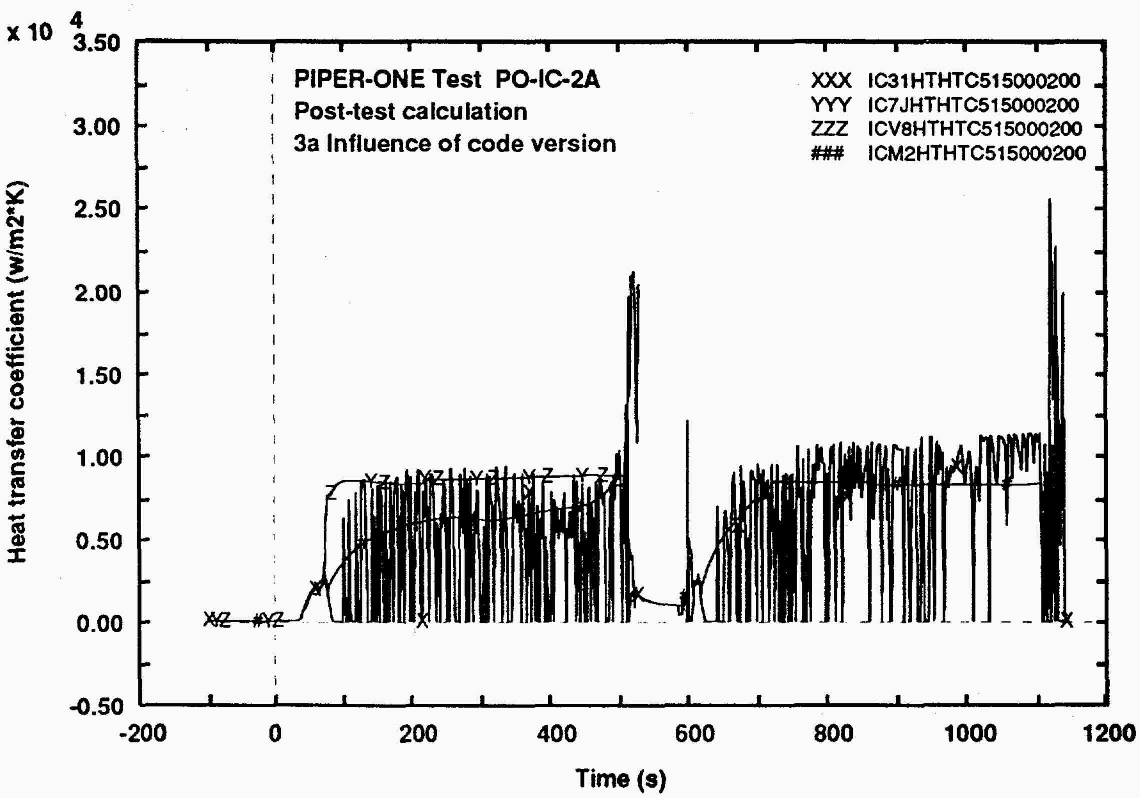


Fig. 38 - Heat transfer coefficient at the inside of IC tubes wall (level 3)

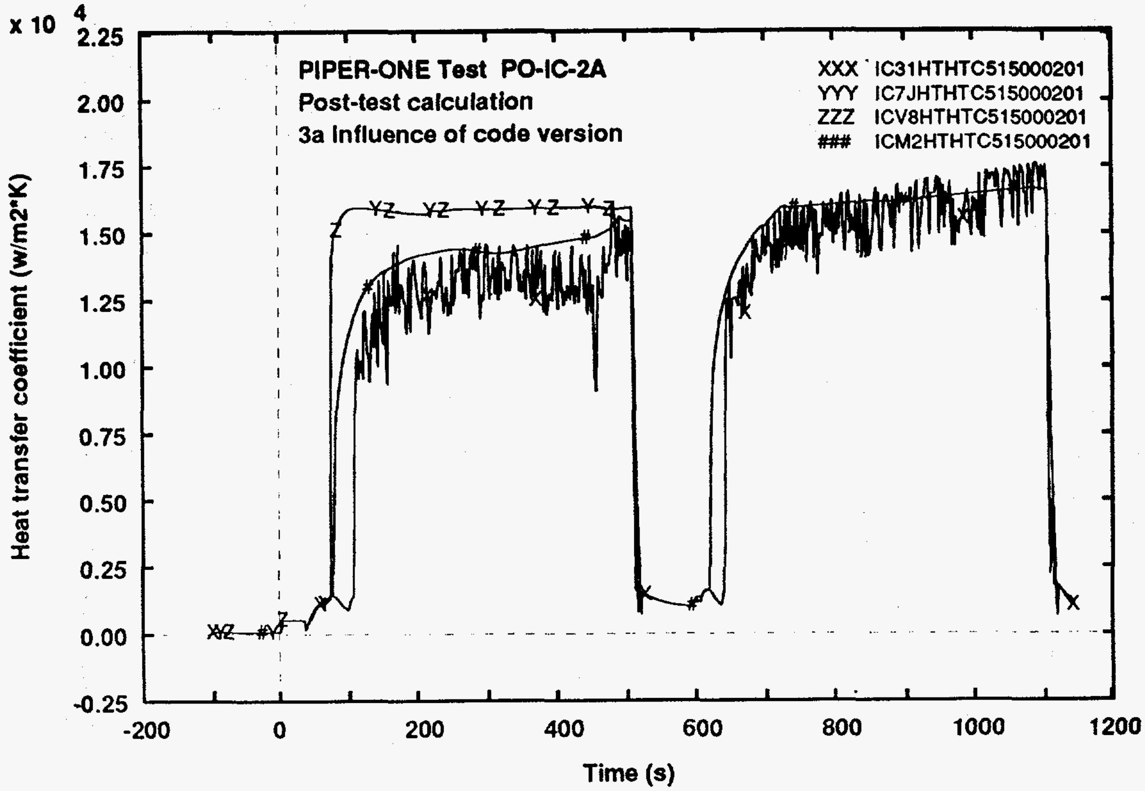


Fig. 39 - Heat transfer coefficient at the outside of IC tubes wall (level 3)

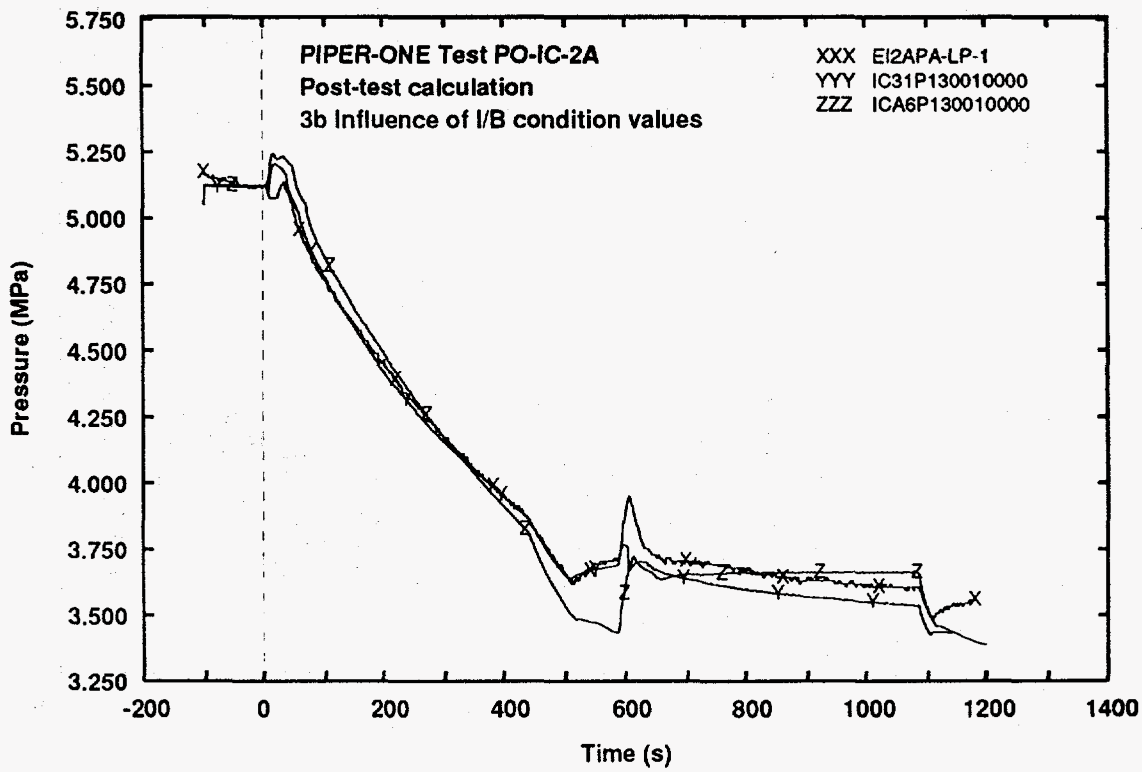


Fig. 40 - Lower plenum pressure

Influence of code version

The nodalization used for calculation IC31 has been modified (if necessary) and run with different code versions as specified in Tab. XI. The six selected quantities are compared in Figs. 34 to 39. Primary pressure is not very much affected by code version (Fig. 34). Overestimation of external temperature appears from all code versions (Fig. 35).

The unphysical behaviour for fluid temperature already noted in the analysis of the experiment PO-SD-8 by the 7J code version (ref. /6/), can also be noted in Figs. 36 and 37 also with reference to the v80 version.

Internal heat transfer coefficient is oscillating only in Relap5/mod3.1 (Figs. 38 and 39); HTC values are lower in the case of v 3.1. Calculations with 7J and v80 versions stopped at almost 500 s into the transient.

Influence of initial and boundary conditions

A large number of boundary conditions has been varied between ICA6 and IC31 calculations (ICA6 can be retained a blind post-test), as already mentioned. Differences in the results can be appreciated looking at figures from 40 to 45.

The influence of the considered changes cannot be retained relevant as far as the IC behaviour is concerned. HTC are lower in ICA6 than in IC31 calculations (Fig. 45).

User effects

Almost arbitrary conditions were imposed to run the calculations during PH.W 3, attempting to prevent calculation failure due to shock condensation.

Mostly, changes in the duration and phenomenology of Ph.W 3 can be noted in the results (Figs. 46 to 51); the influence on the subsequent Ph.W 4 seems negligible.

Nodalization effects

The studied nodalization effects include the increase in the number of conduction heat transfer meshes and the increase in the number of hydraulic nodes, (calculations IC32 and IC34 in Tab. XI, respectively). The change of steel conductivity (calculation IC35 in Tab. XI) has also been included in this group, although it could have been in the calculation group 3e) of Tab. XI. The results are shown in Figs. 52 - 57 with reference to the chosen six quantities: IC31 results are also reported.

The effects of these variations at a global level, i.e. considering primary circuit pressure (Fig. 52) or fluid temperature at the IC outlet (Fig. 55) are negligible. However, local effects can be very important as shown by the inner wall surface temperature in Fig. 53 and by the heat transfer coefficient in Fig. 57.

In particular the comparison of IC34 and IC31 related trends in Fig. 57 leads to the conclusion that (condensation) heat transfer coefficient should be in someway connected with node dimensions: a given HTC correlation can produce satisfactory results with nodes of given dimensions, but unacceptable results if node dimensions are changed.

Changes of relevant parameters

For simplicity, only the effect of hydraulic diameter change in the secondary side of the IC is discussed under this item. Calculations IC33 and IC36 are characterized by hydraulic diameters 20 times and 5 times, respectively, larger and lower than the value of the same quantity in calculation IC31. Relevant results are shown in Figs. 58 - 63.

This quantity has a strong effect both regarding primary pressure (Fig. 58) and IC related quantities, like fluid temperature at the outlet (Fig. 61) and heat transfer coefficient (Fig. 63).

The judgement about the preferable value for hydraulic diameter is difficult from the presented data.

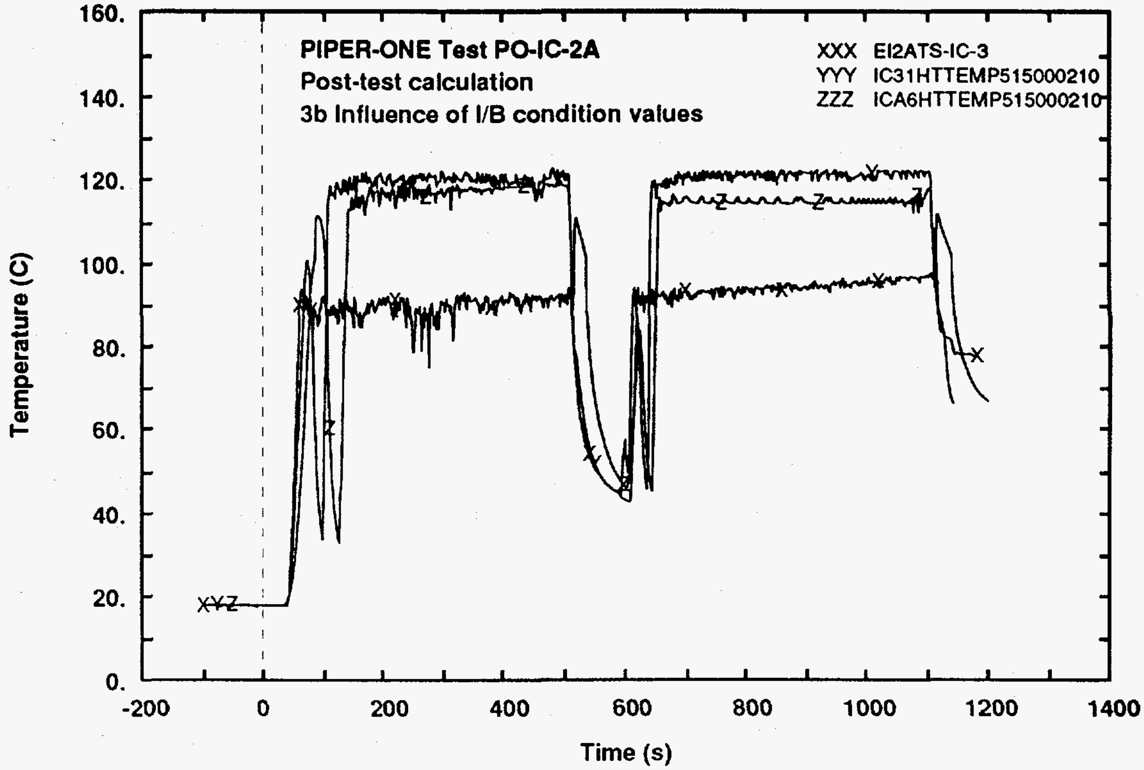


Fig. 41 - IC tubes wall surface temperature (external side level 3)

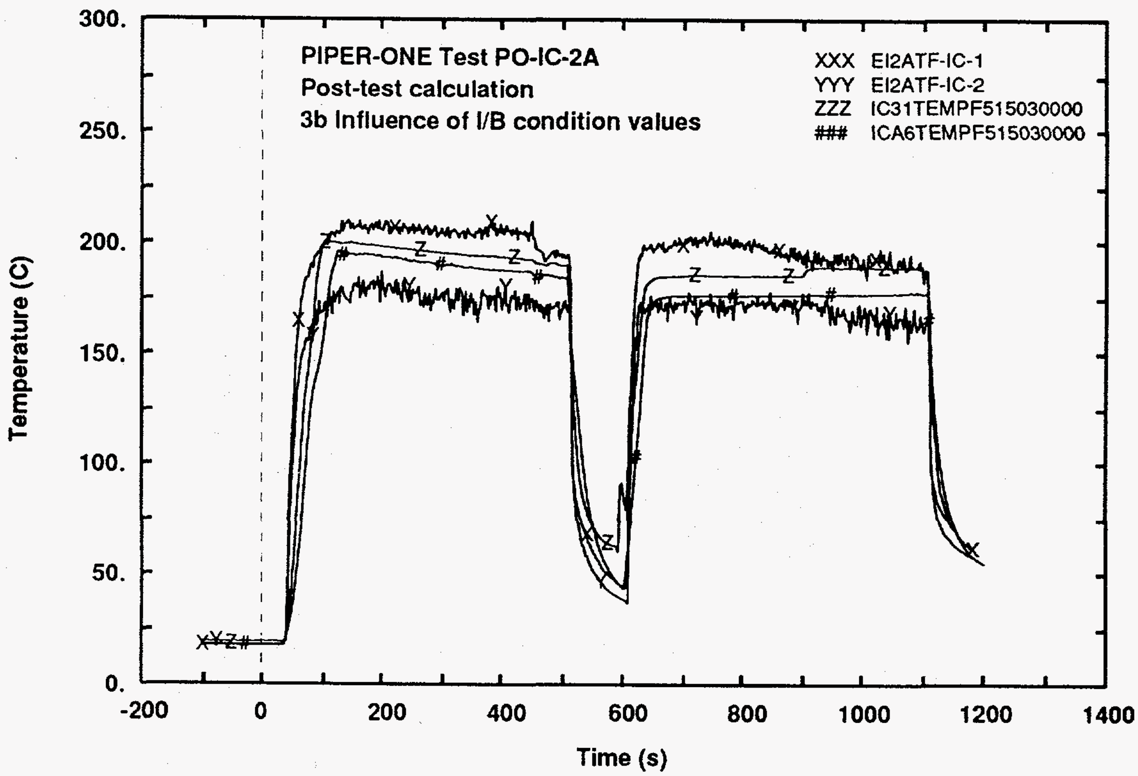


Fig. 42 - IC tubes fluid temperature (middle elevation)

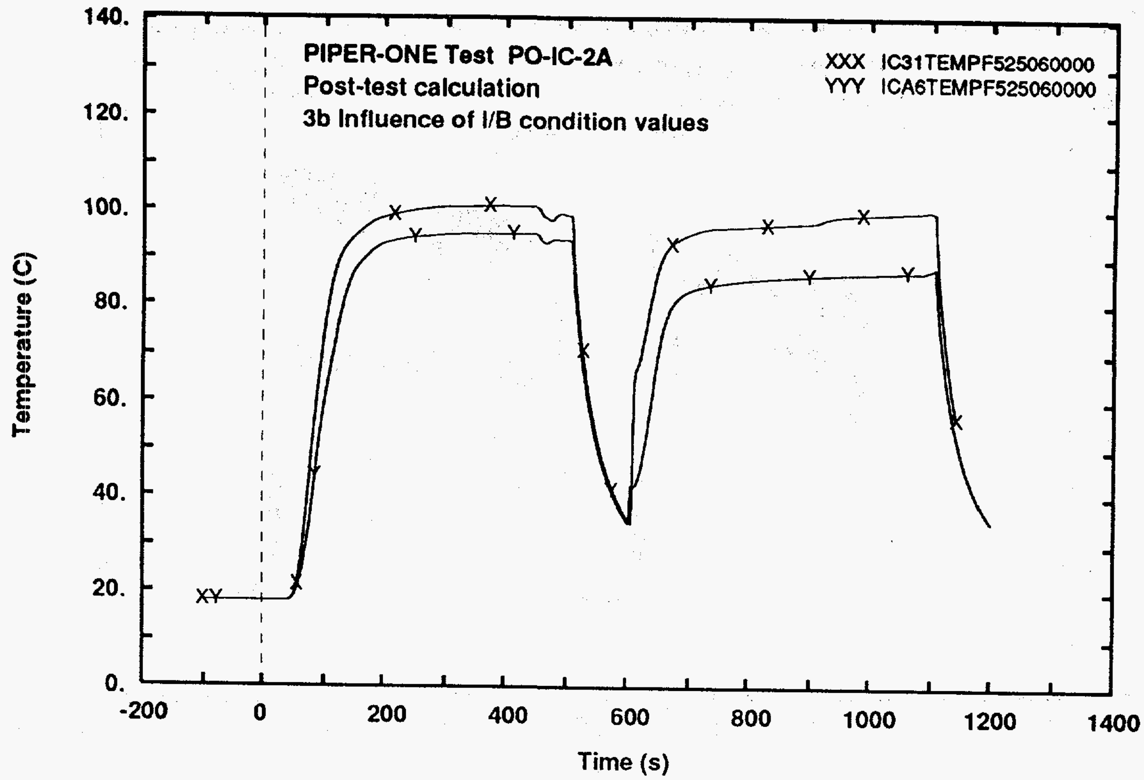


Fig. 43 - IC outlet fluid temperature

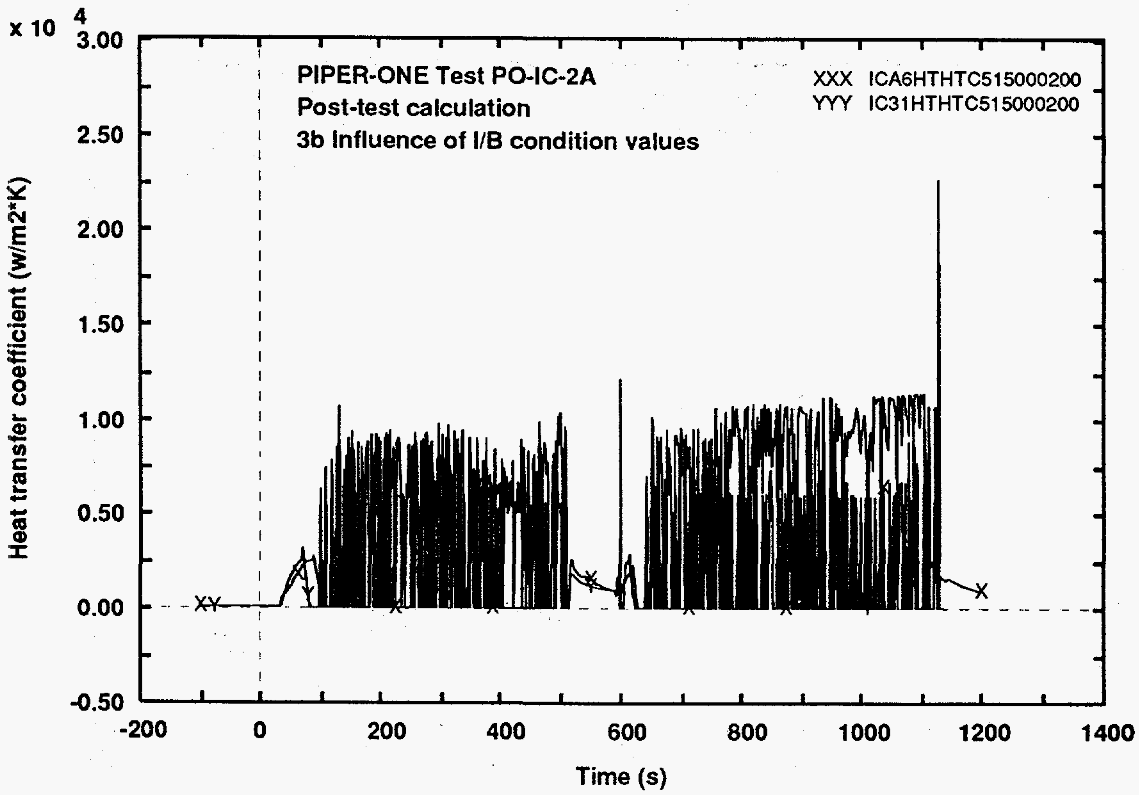


Fig. 44 - Heat transfer coefficient at the inside of IC tubes wall (level 3)

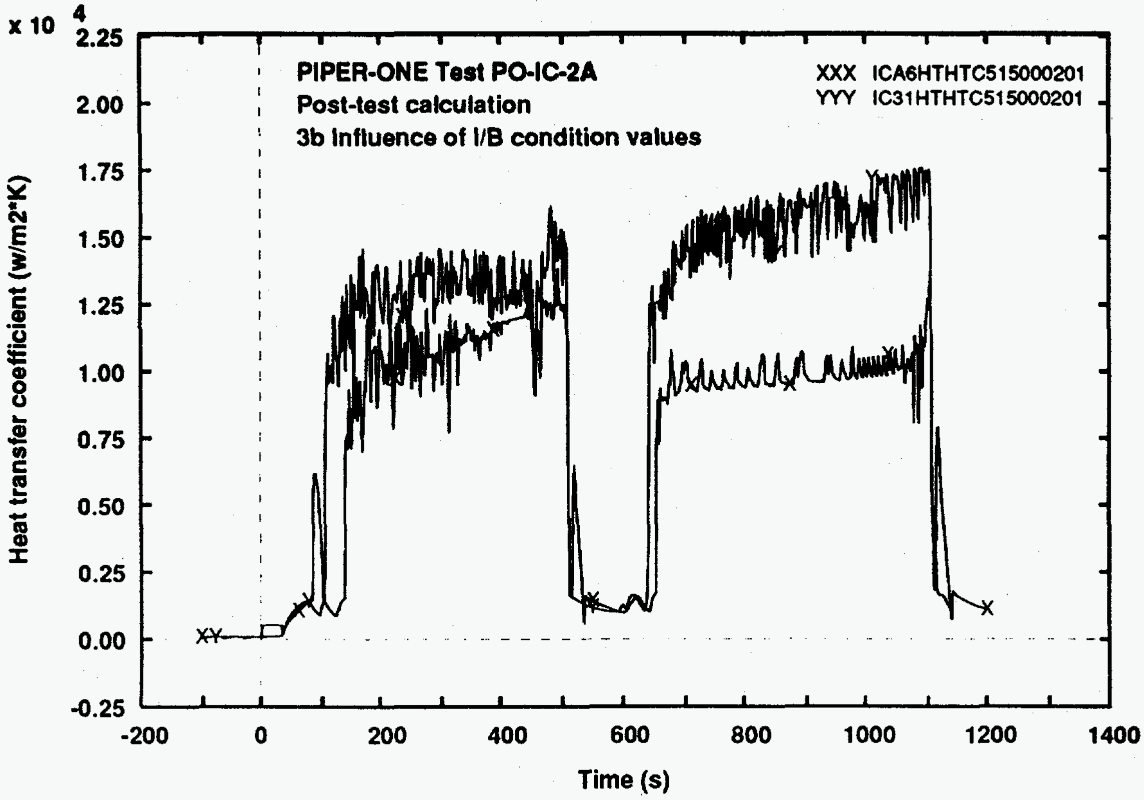


Fig. 45 - Heat transfer coefficient at the outside of IC tubes wall (level 3)

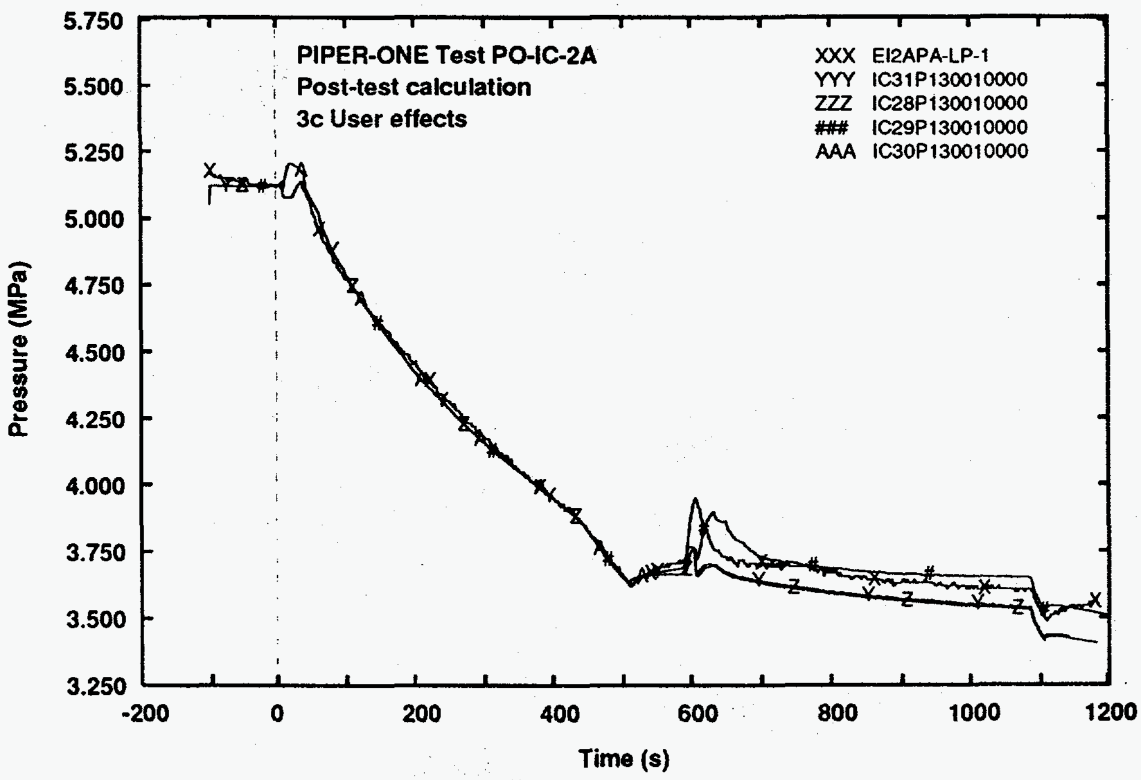


Fig. 46 - Lower plenum pressure

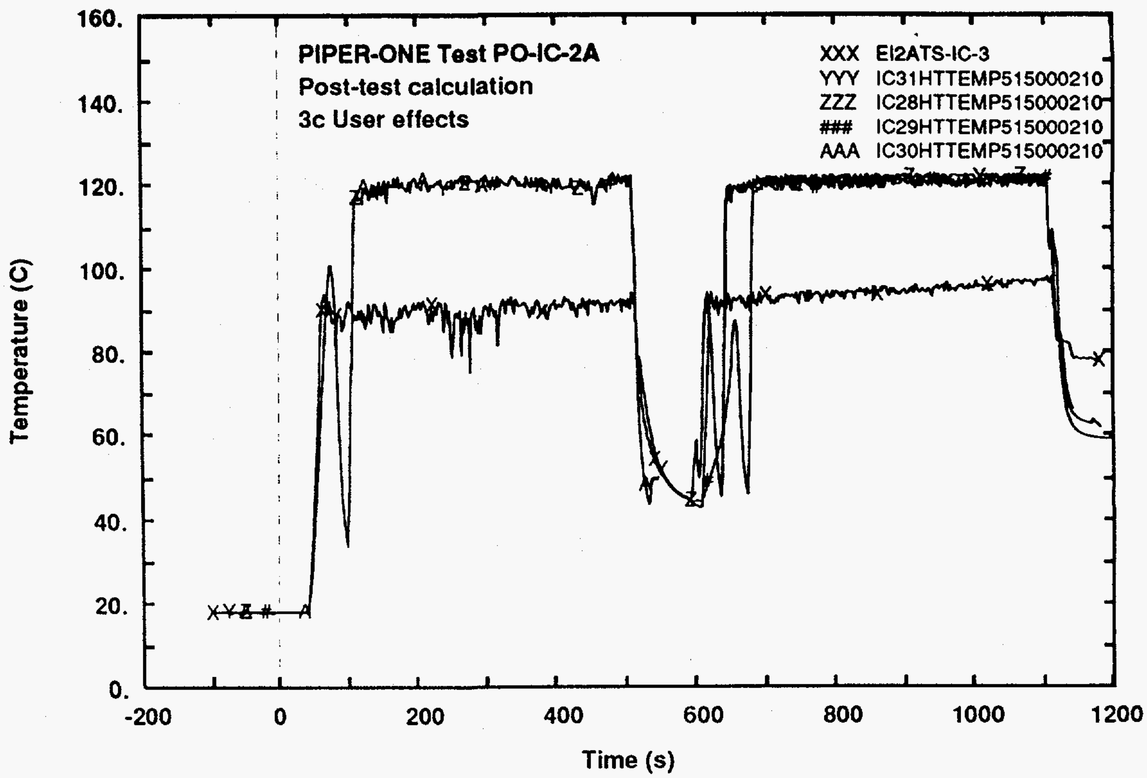


Fig. 47 - IC tubes wall surface temperature (external side level 3)

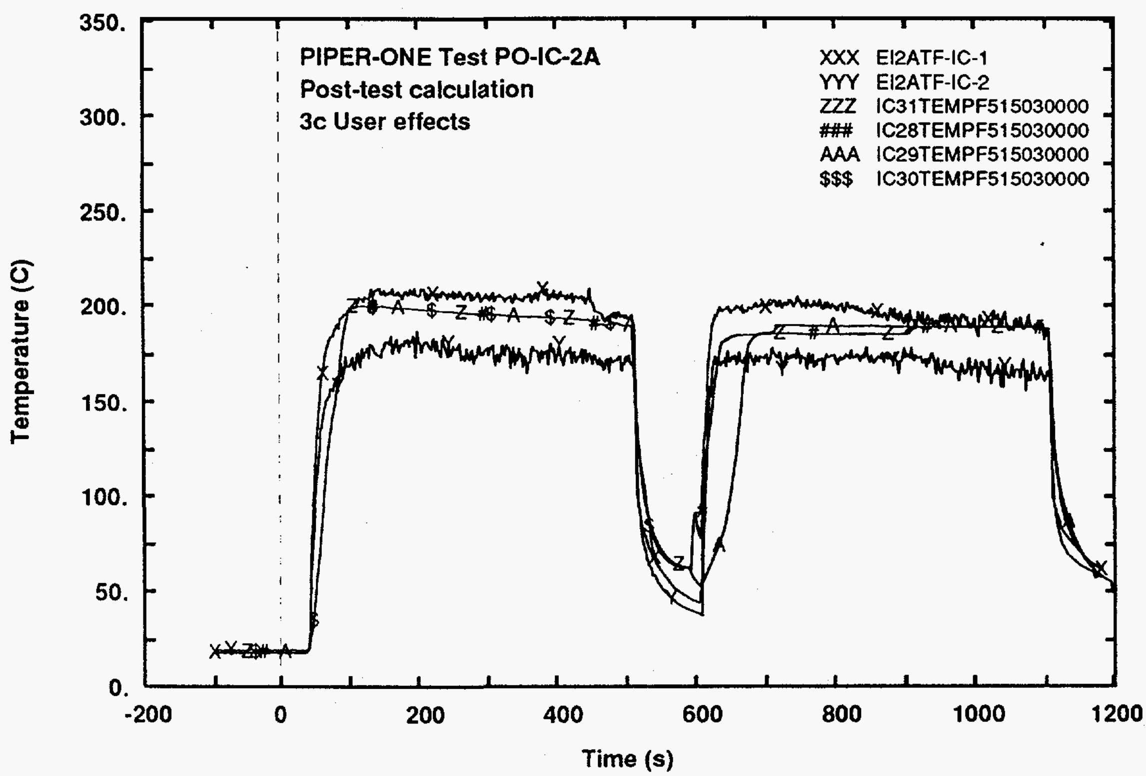


Fig. 48 - IC tubes fluid temperature (middle elevation)

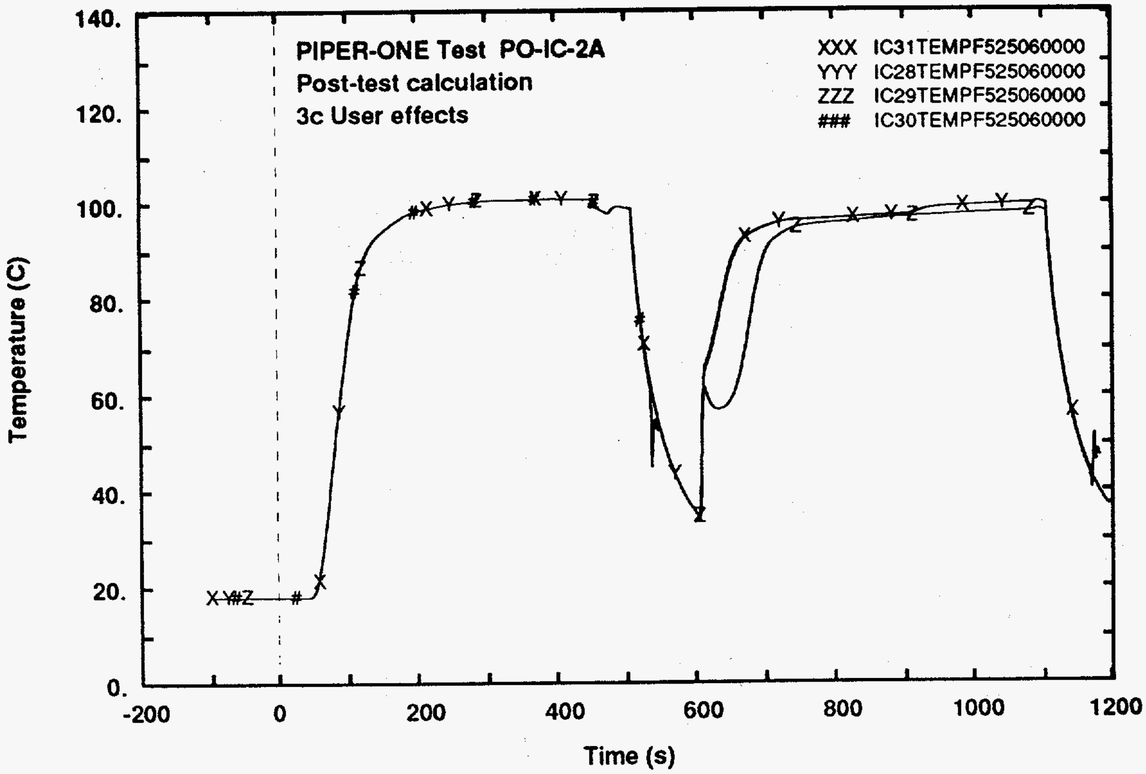


Fig. 49 - IC outlet fluid temperature

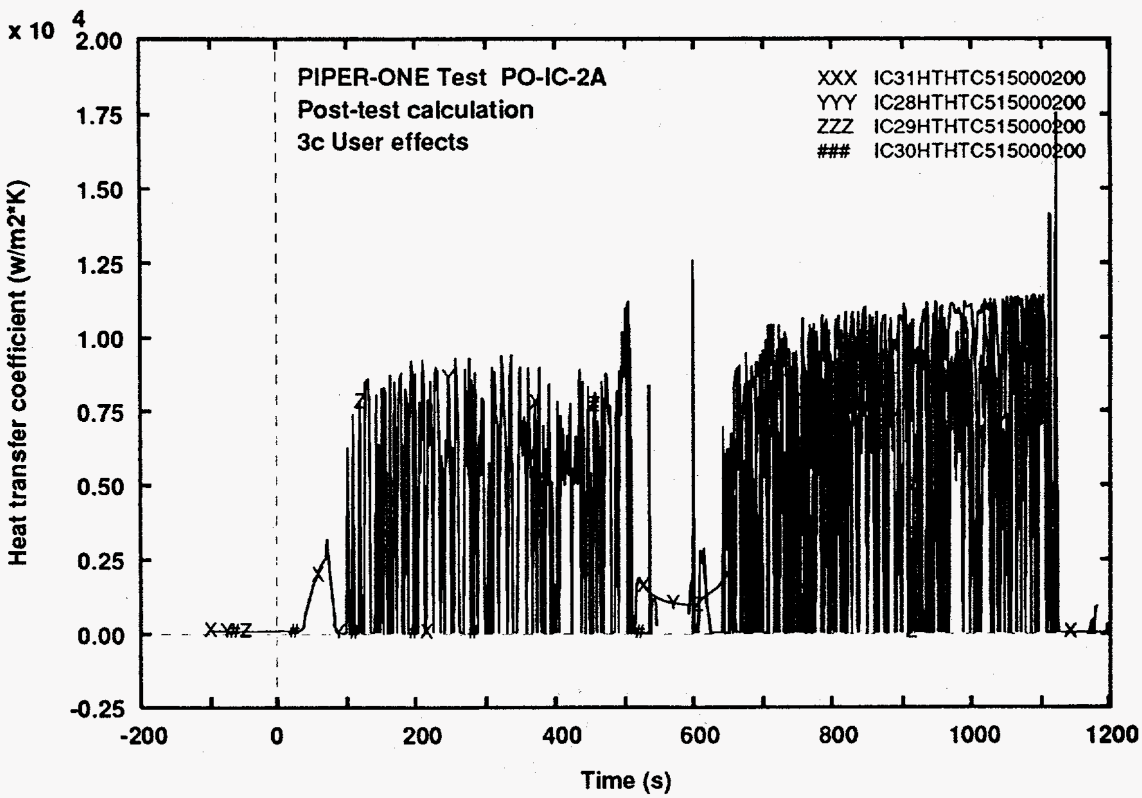


Fig. 50 - Heat transfer coefficient at the inside of IC tubes wall (level 3)

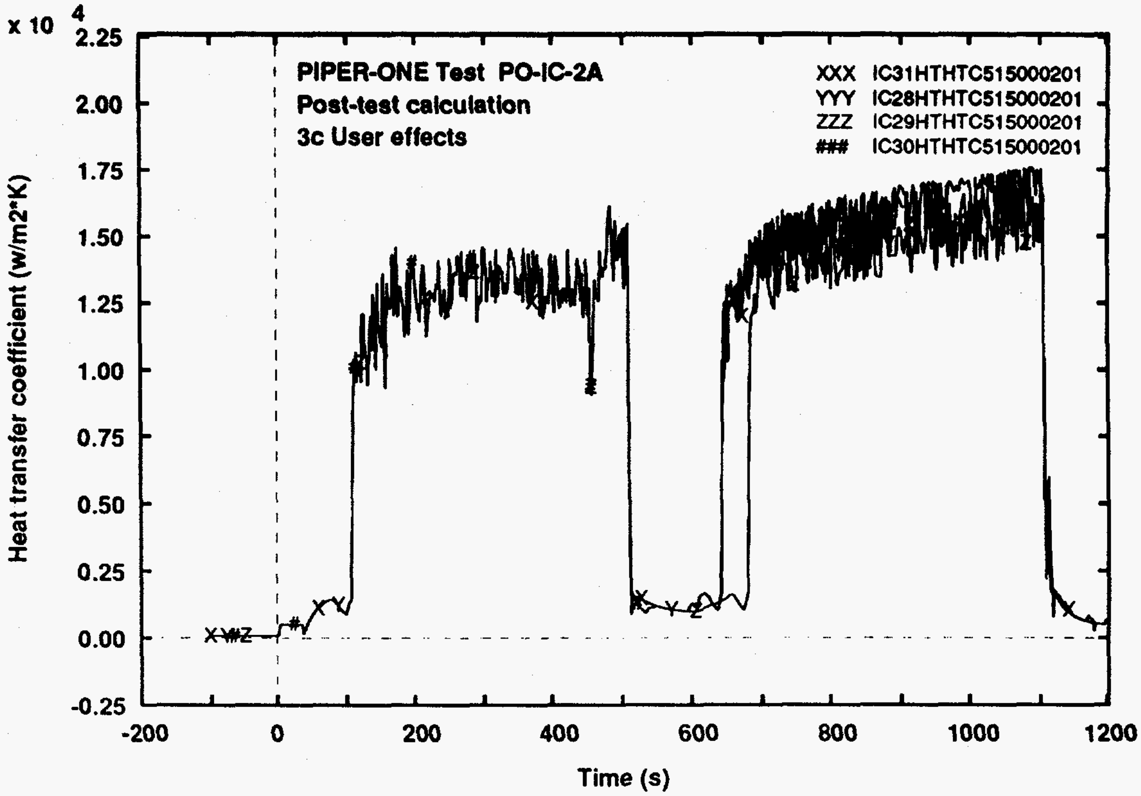


Fig. 51 - Heat transfer coefficient outside of IC tubes wall (level 3)

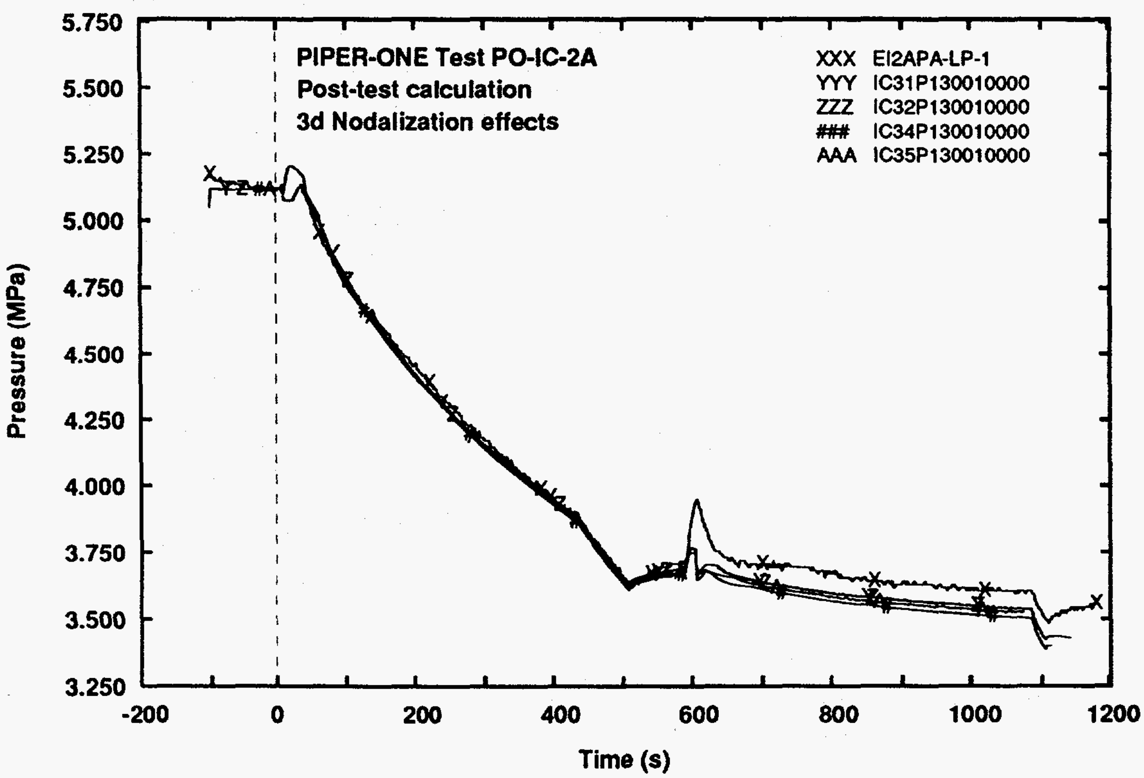


Fig. 52 - Lower plenum pressure

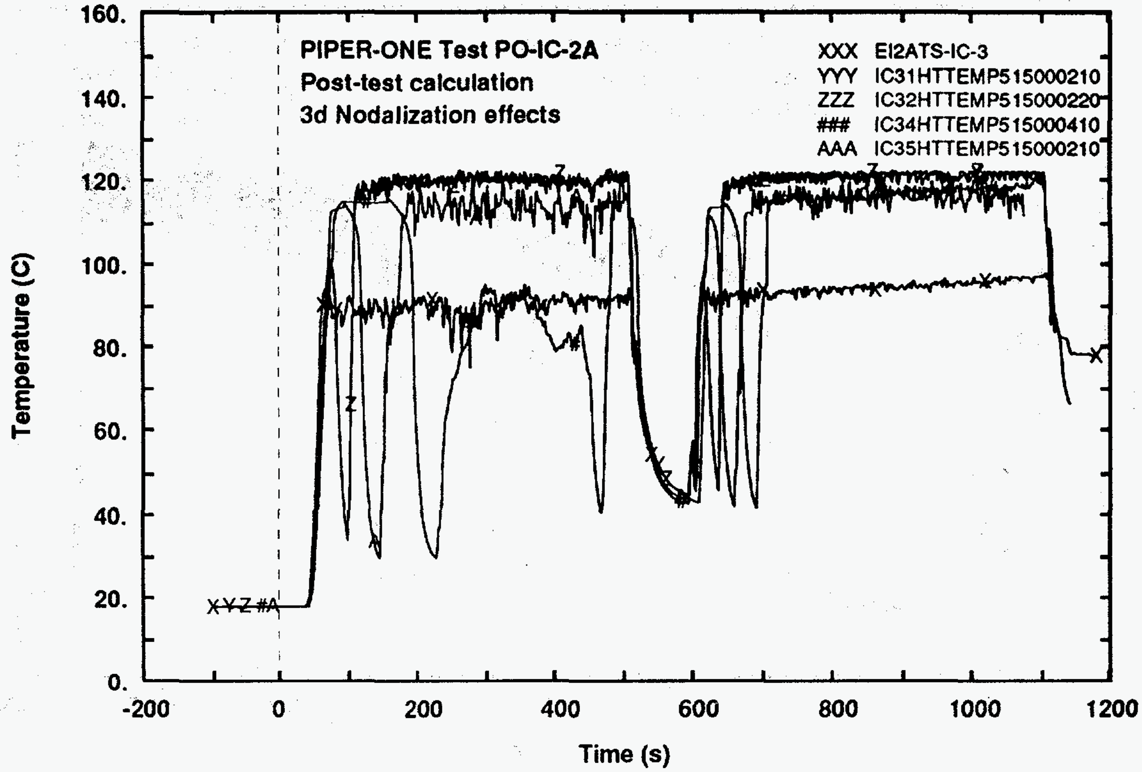


Fig. 53 - IC tubes wall surface temperature (external side level 3)

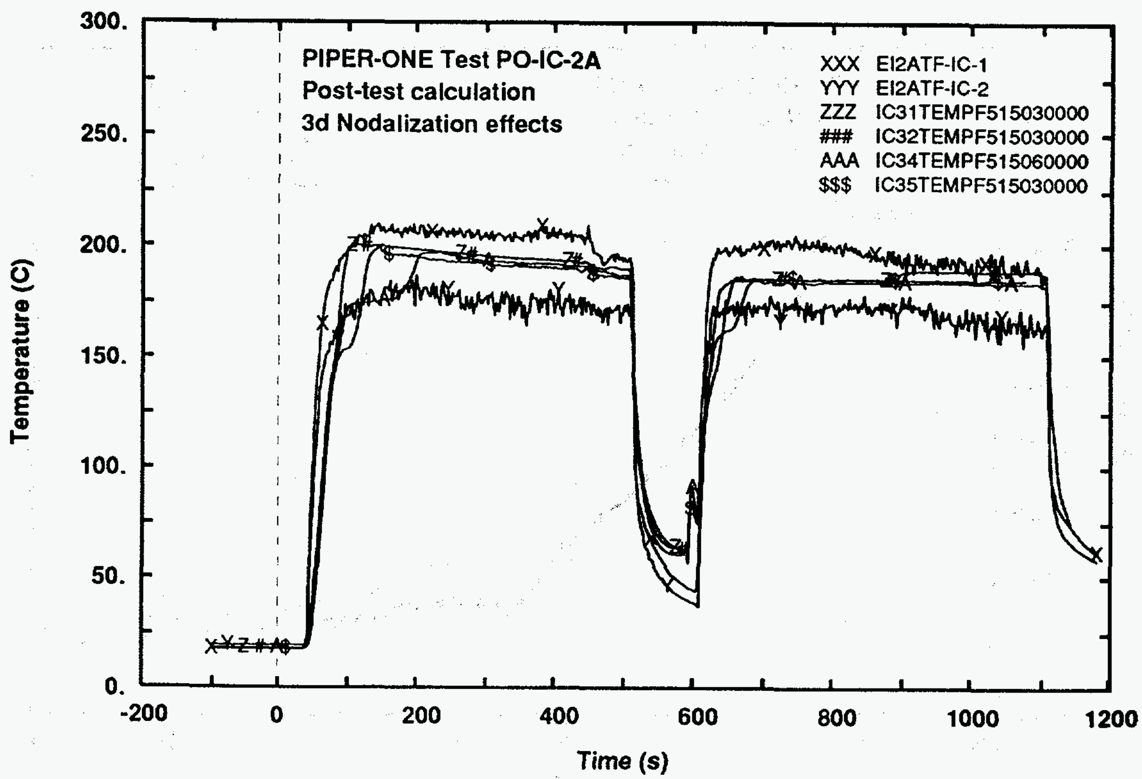


Fig. 54 - IC tubes fluid temperature (middle elevation)

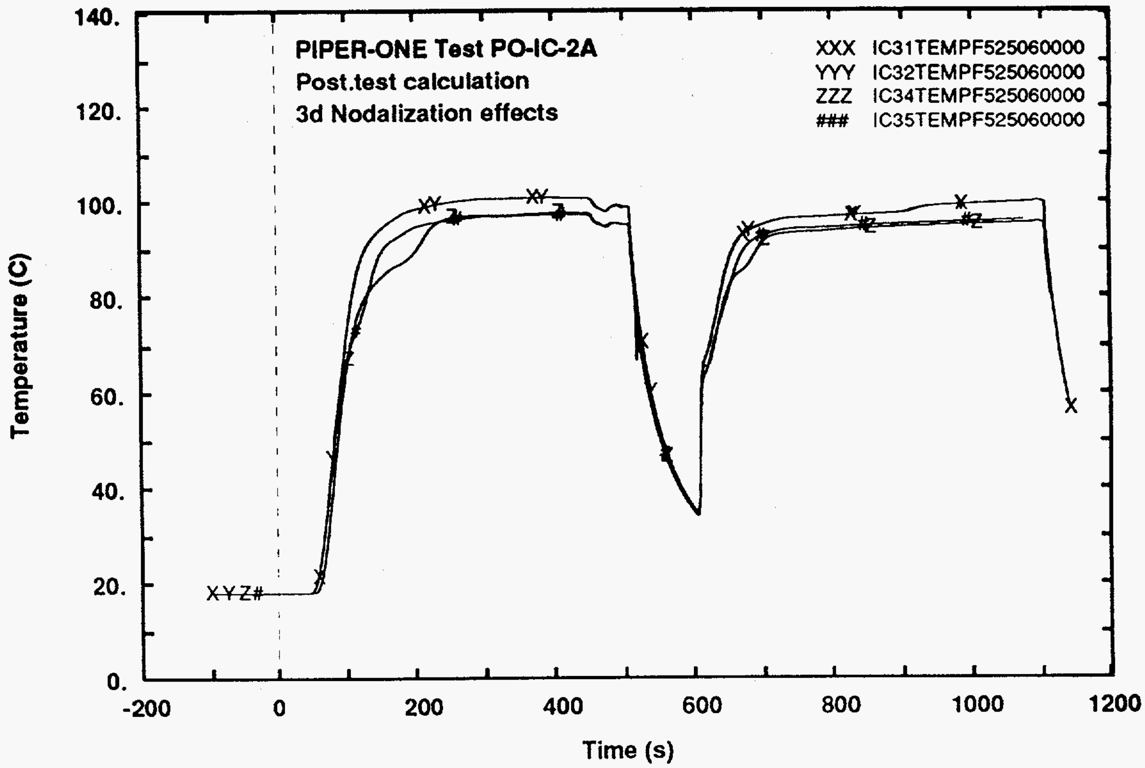


Fig. 55 - IC outlet fluid temperature

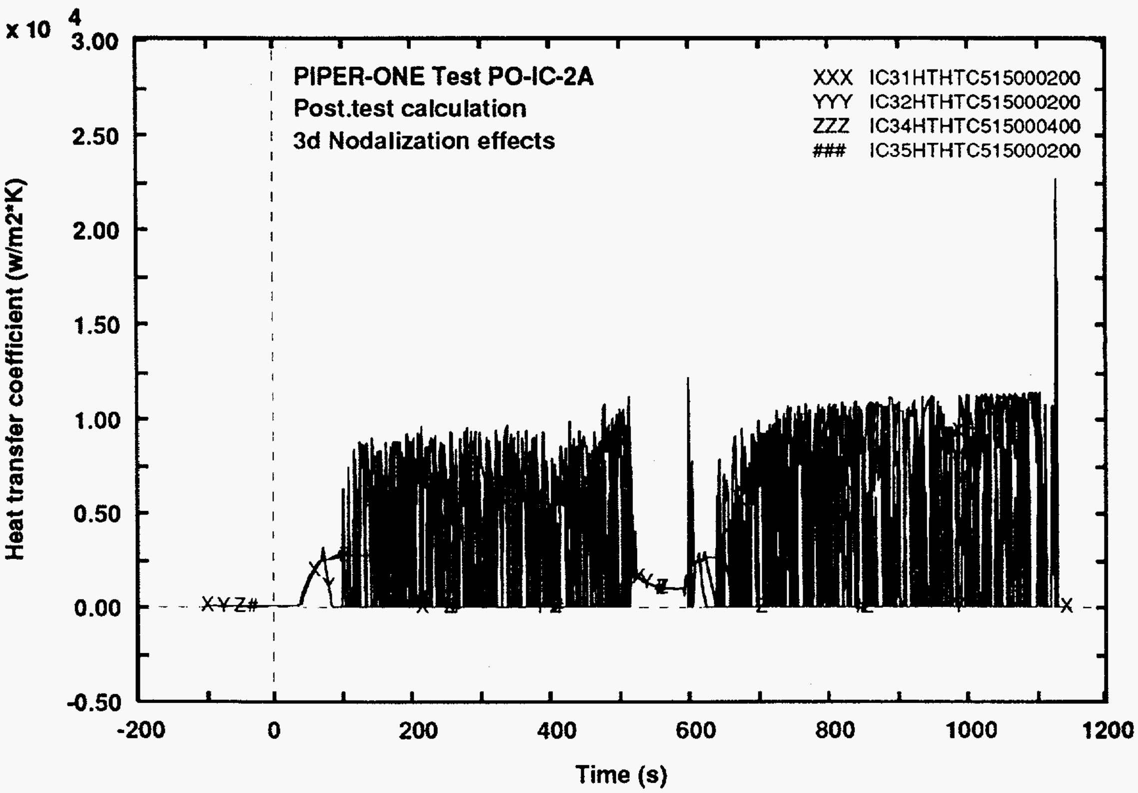


Fig. 56 - Heat transfer coefficient at the inside of IC tubes wall (level 3)

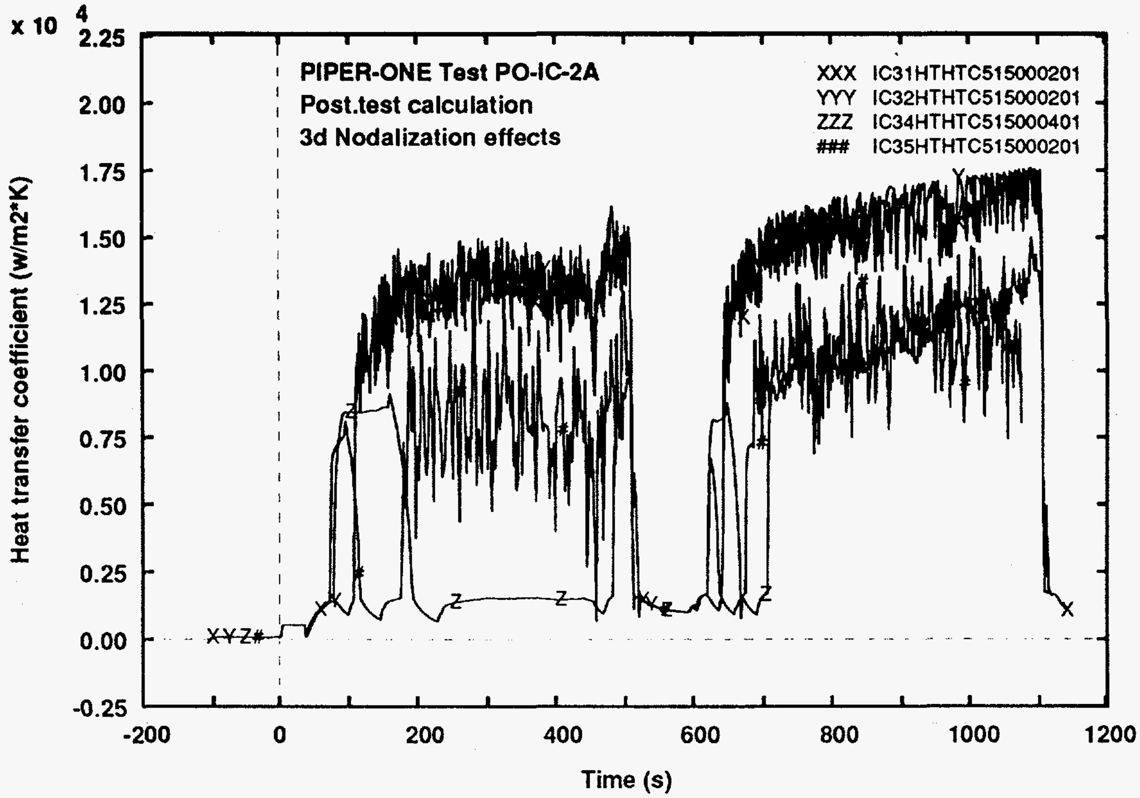


Fig. 57 - Heat transfer coefficient at the outside of IC tubes wall (level 3)

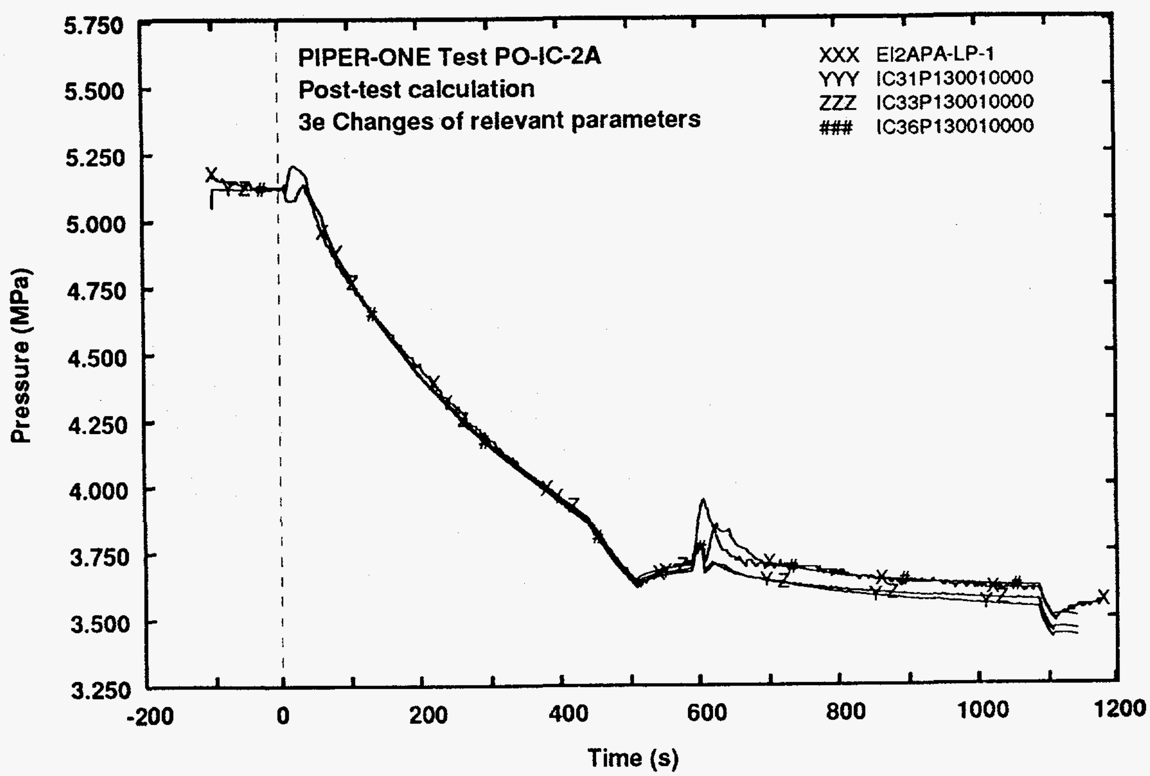


Fig. 58 - Lower plenum pressure

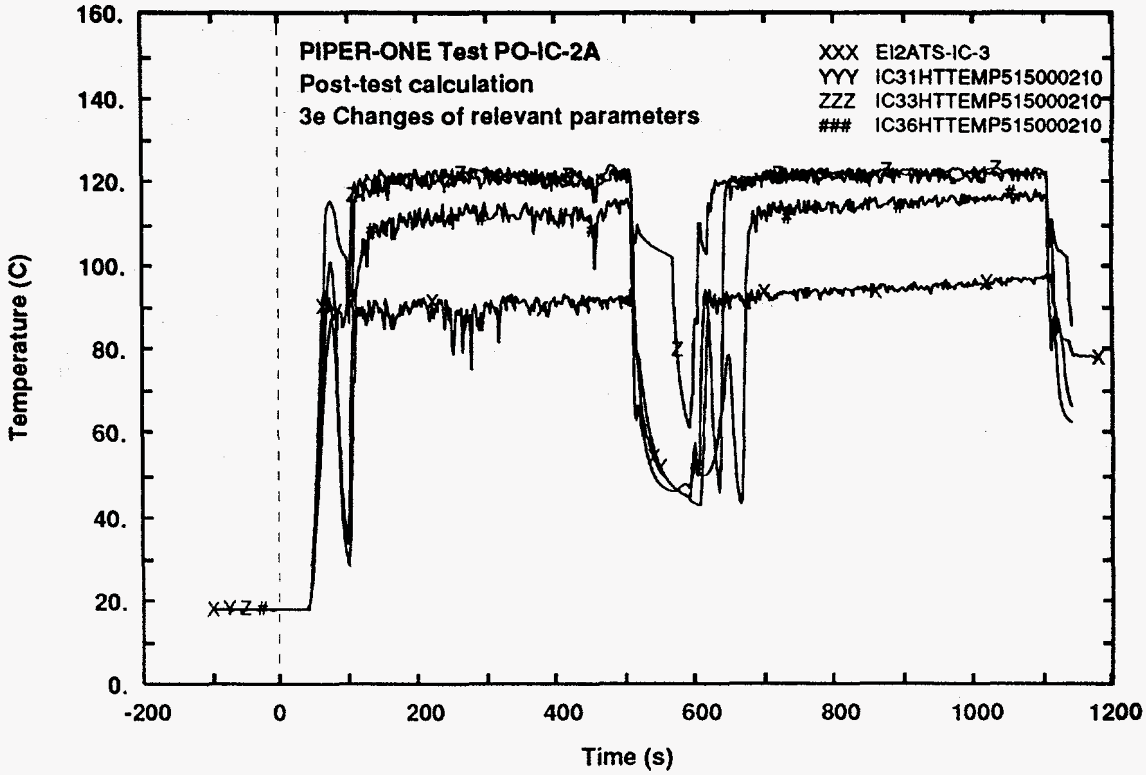


Fig. 59 - IC tubes wall surface temperature (external side level 3)

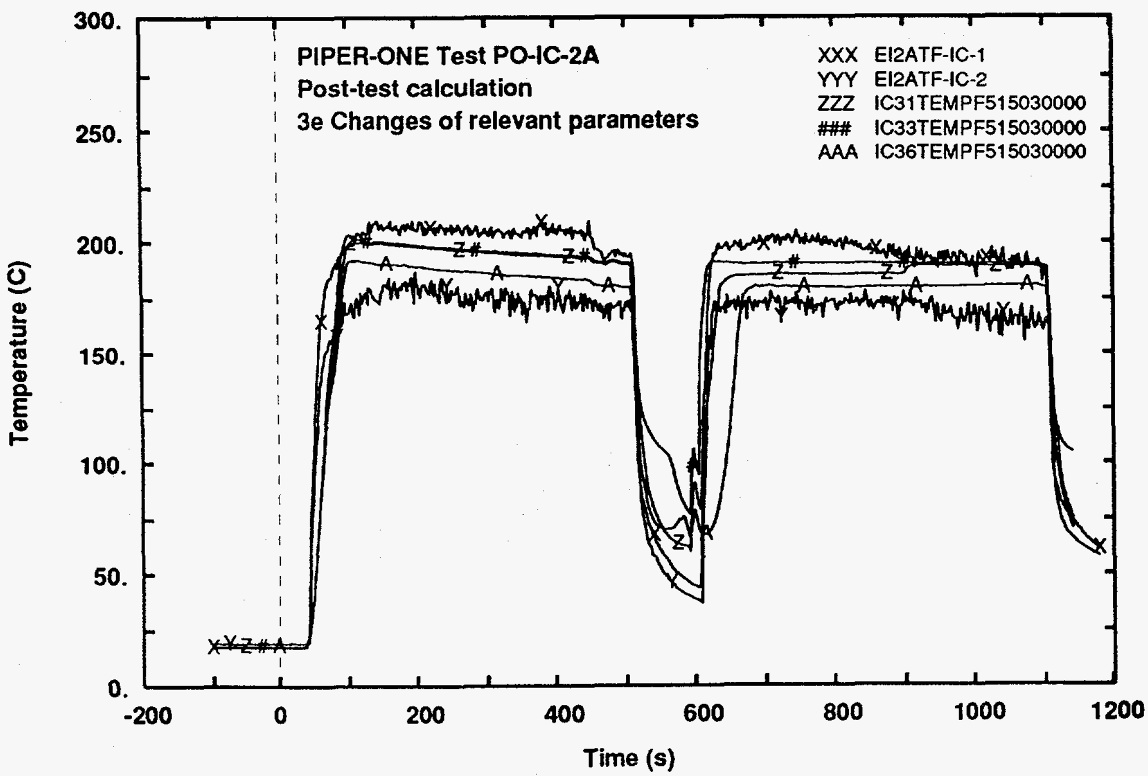


Fig. 60 - IC tubes fluid temperature (middle elevation)

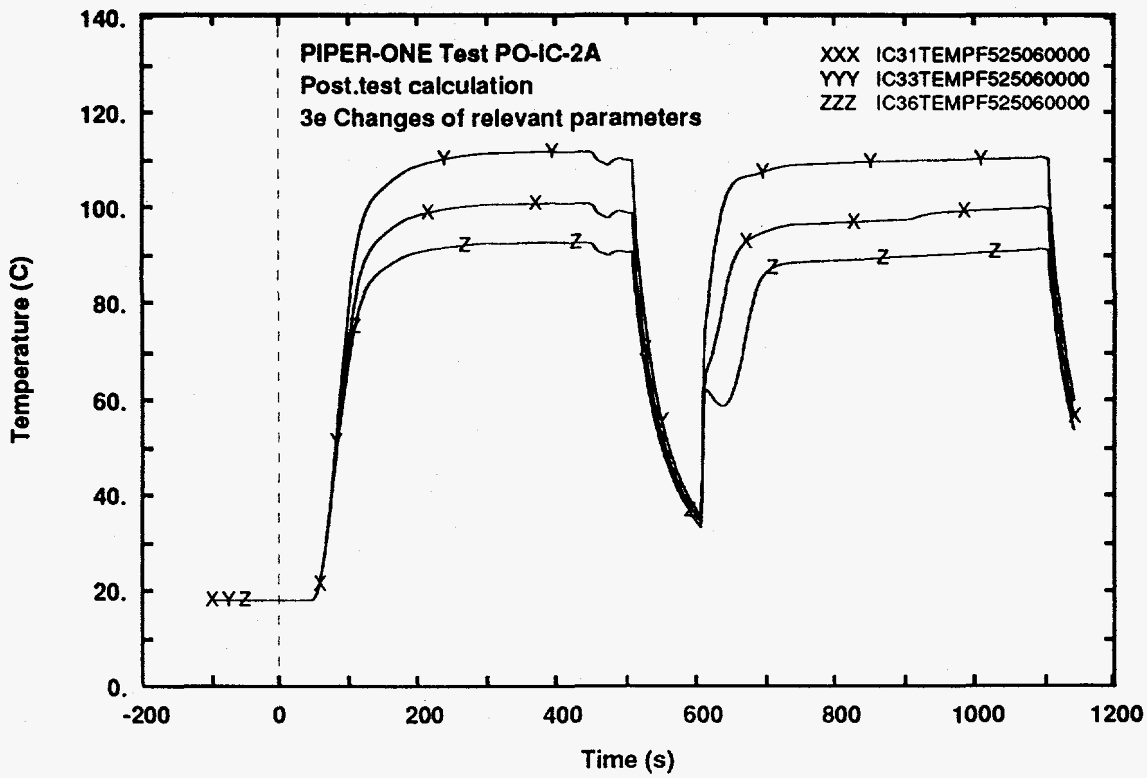


Fig. 61 - IC outlet fluid temperature

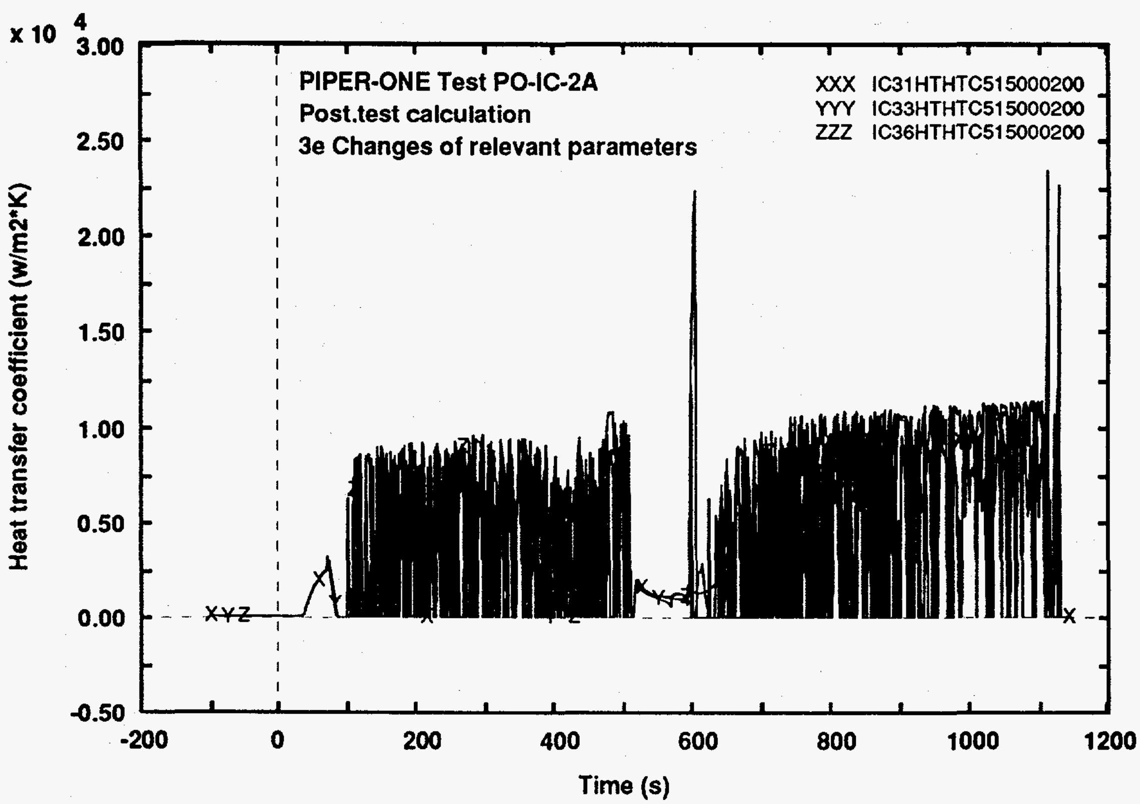


Fig. 62 - Heat transfer coefficient at the inside of IC tubes wall (level 3)

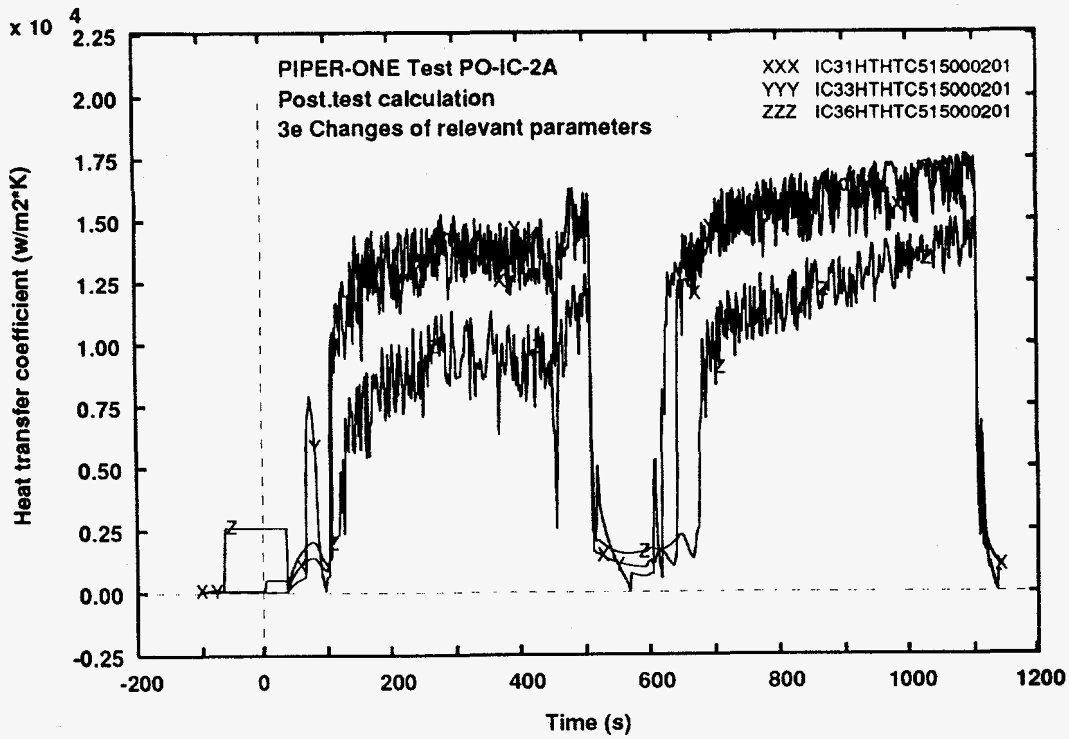


Fig. 63 - Heat transfer coefficient at the outside of IC tubes wall (level 3)

4.3.2 Results in Apps. 2 and 4

The results of calculation IC36 are shown in App. 2. It can be noted that the (arbitrary) variation (i.e. reduction) in the hydraulic diameter value of the pool nodes largely improves the comparison between measured and predicted wall temperatures (e.g. Figs. 17 and 18 in App. 2) with respect to the reference calculation IC31 (see also data in the last columns of Tab. XI). The primary side related quantities are either unaffected (e.g. downcomer level, Fig. 2 of App. 2), either better predicted (e.g. pressure, Fig. 1 in App. 2).

The results related to the calculation ICA6 are reported in App. 4, just because ICA6 can be considered as a blind post test. Some comments have already been given above.

4.3.3 Isolation of downcomer (App. 3)

The isolation of downcomer was assumed to demonstrate that IC flowrate and exchanged power increase with core supplied power, if the IC constitutes the only path for the steam coming from the core.

The IC37 calculation has the same input as the IC31 calculation, the only difference being the closure of the isolation valve between core and downcomer region at 300 s into the transient. The following effects can be noted:

a) IC flowrate in Ph.W 2 increases after the isolation (Fig. 7 of App. 3);
b) IC flowrate in Ph.W 4 is larger than in Ph.W 2 (Fig. 7 of App. 3);
c) as a consequence of the above, IC exchanged power is also larger (Fig. 28 of App. 3) in Ph.W 4 with respect to Ph.W 2; this conclusion can also be inferred from the primary circuit pressure (Fig. 1 of App. 3) that decreases during Ph.W 4;
d) condensing steam is present in the third volume from the top (Fig. 35 of App. 3): this is the local cause for the increase of the IC exchanged power as also results from observing HTC in Fig. 33 of App. 3;
e) the pressure peak in Ph.W 3 is better predicted in calculation IC37 than in calculation IC31. This confirms the conclusion that pressure increase in the test is caused by steam production without circulation from the downcomer: the consequent stratification effect is underestimated by the code in the reference calculation.

4.4 Scaling analysis

The problem to be raised in the frame of a scaling study, can be synthesized by the following questions:

- is the experimental data base representative of situations expected in the reference plant (SBWR in this case)?
- are the code capabilities and limits (detected in this study) applicable to plant predictions?

The first question is addressed in the present framework (details in App. 6, ref. /22/). The second question needs the availability of counterpart tests; some aspects are discussed in ref. /23/.

A few details, taken from App. 6, are reported below.

The following parameters are considered in the analysis of scaling efforts:

1) Elevation of IC relative to TAF;
2) Length of IC tubes;
3) Diameter of IC tubes;
4) Total heat exchange area of IC;
5) Inlet flow area of IC.

Each of the selected parameters is varied in the range from the actual value up to the right scaled value and for each variation a new nodalization is set up and a calculation is run. A final calculation is performed including all the variations at the same time.

The results can be summarized as follows:

a) no new phenomena occurred in any of the calculations;
b) the most important parameter in this analysis, i.e. the largest scaling distortions in PIPER-ONE apparatus, is constituted by the elevation of the IC (parameter nr. 1), above).

The qualitative scenario in the final calculation (i.e. the one including all the variations) does not differ from the experimental scenario.

5. CONCLUSIONS

The present document reports the analysis performed with Relap5 in relation to the PIPER-ONE experiment PO-IC-2. The test is the follow-up of the similar experiment PO-SD-8 and aims at characterizing phenomena connected with the operation of Isolation Condenser in a geometric configuration typical for SBWR. The test studied was conducted at high pressure (around 5 MPa) to study code performances in this situation.

Conclusion can be drawn in relation to:

A) overall system performance;
B) thermalhydraulic phenomena inside the IC;
C) code capabilities;
D) effect of various changes in the calculation conditions.

It has been confirmed that a constant removed power characterizes the IC performance (item A)) whatever are the primary loop thermalhydraulic conditions. From the analysis of experimental data supported by specific code calculations, the reason why IC exchanged power remains constant, when core power conditions are varied, has been made clear. This is a consequence of IC flowrate that is determined by the pressure difference created in the downcomer of the main loop; this remains almost constant during the performed experiment. Constant IC flowrate means constant condensation length in the IC tubes and constant transferred power to the pool (see also below).

The shroud put in the pool was not effective in provoking natural circulation because of the high conductivity across its wall, that led to fluid temperature stratification with the same characteristics in the inner and outer zones of the pool.

Heat transfer coefficients are several (3-7) times larger in the condensing zones of the IC tubes than in the single phase liquid region (item B)); the fluid pool temperature increase (up to 70 K) has a negligible role in this connection (high pressure steam). Liquid level in the IC remains almost constant when varying core power.

A new detailed nodalization of PIPER-ONE apparatus was adopted for this study. The standard version of Relap5/mod3.1 is able to catch the overall phenomenology during the four main periods of the experiment (item C)).

Discrepancies have been identified mainly concerning the IC tubes surface temperatures, that are overestimated by the code, particularly on the outer surface: this means underestimation by the code of the outer heat transfer coefficient, provided that the overall exchanged power is well predicted. However the possible "fin" effect originated by thermocouples has not been considered in this conclusion. An unphysically high heat transfer coefficient is produced in the output by the code although apparently not used (Tab. IX). During the phenomenological window nr 3 (i.e. during the period of power shut-off) the code was not able to simulate the condensation shock occurring in the IC line.

An extensive series of sensitivity calculations has been carried out (item D)). These demonstrated:

* some improvements in the code results when passing from the earliest to the latest Relap5/mod3 code versions; however oscillations in condensation heat transfer value are much larger in the reference code version. Furthermore the transition logics from heat transfer mode 2 to 3 (and viceversa) could be improved;
* changes in the equivalent diameter of the pool side of the IC has an important effect on the calculation of the local quantities like heat transfer coefficient and temperatures;
* changes in nodalization can also have a noticeable effect as far as the calculation of the above mentioned quantities is concerned. The last item stressed the need to define some relationship between the (condensation) heat transfer coefficient and the average node

dimensions: this seems necessary to get reproducible results especially when condensation heat transfer is involved.

The performed scaling analysis (see also App. 6) demonstrated that the scaling distortions identified in the PIPER-ONE hardware, do not affect, qualitatively, the phenomena occurring during the selected experiments.

Analyses, related to the same test have been carried out by CATHARE code, e.g. ref. /24/.

Further activity in this area includes the analysis of a companion experiment during which nitrogen gas was injected into the primary circuit and actually caused large degradation of the IC removed power.

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APPENDIX 1:

RESULTS OF REFERENCE CALCULATION

(Post-Test IC 31)

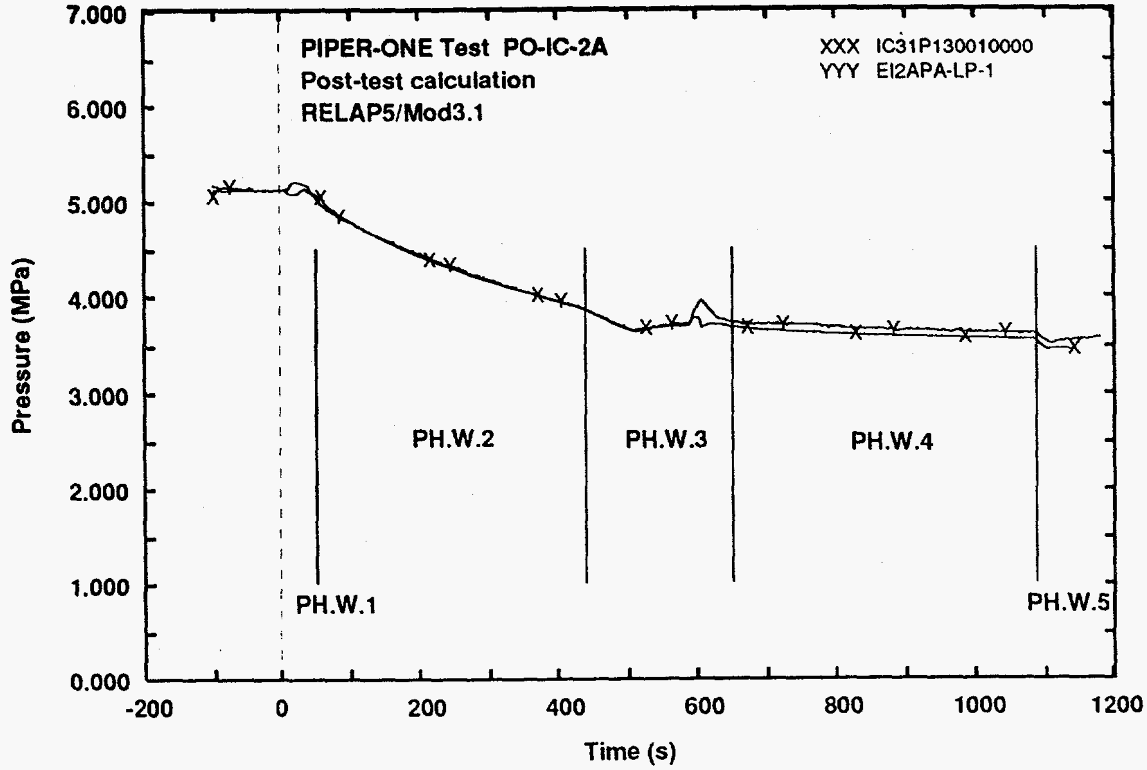

Fig. 1 - Measured and calculated trends of lower plenum pressure

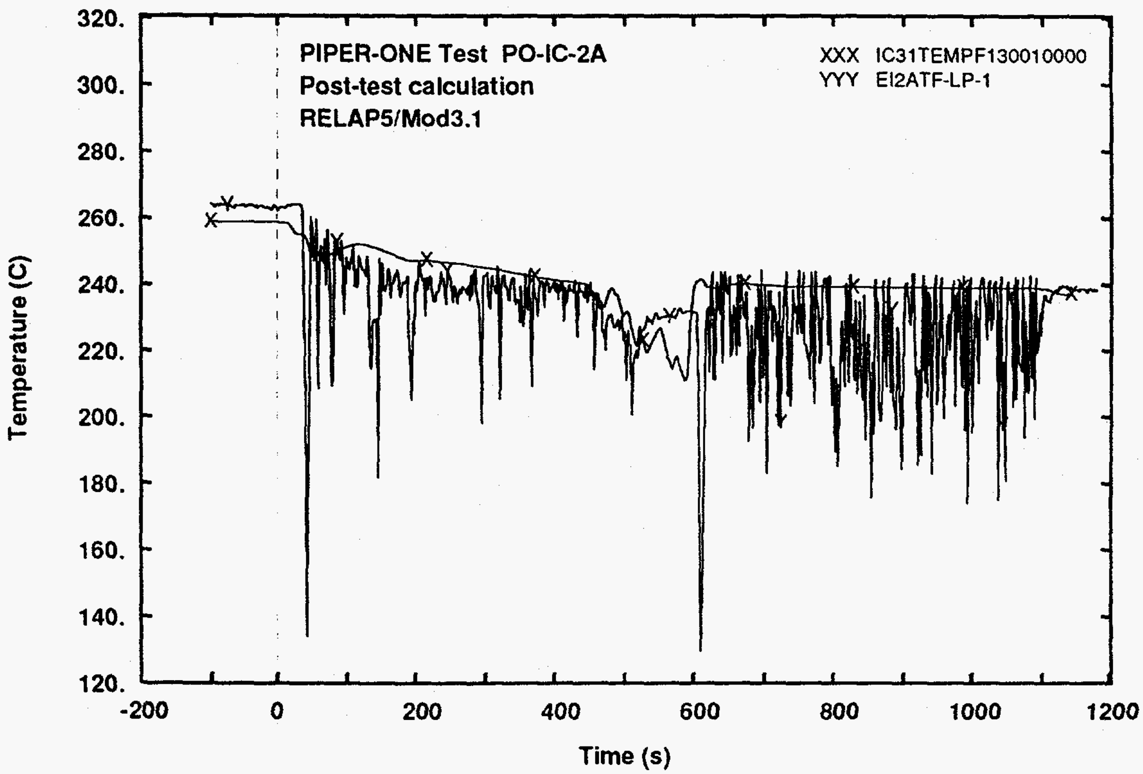

Fig. 2 - Measured and calculated trends of lower plenum temperature

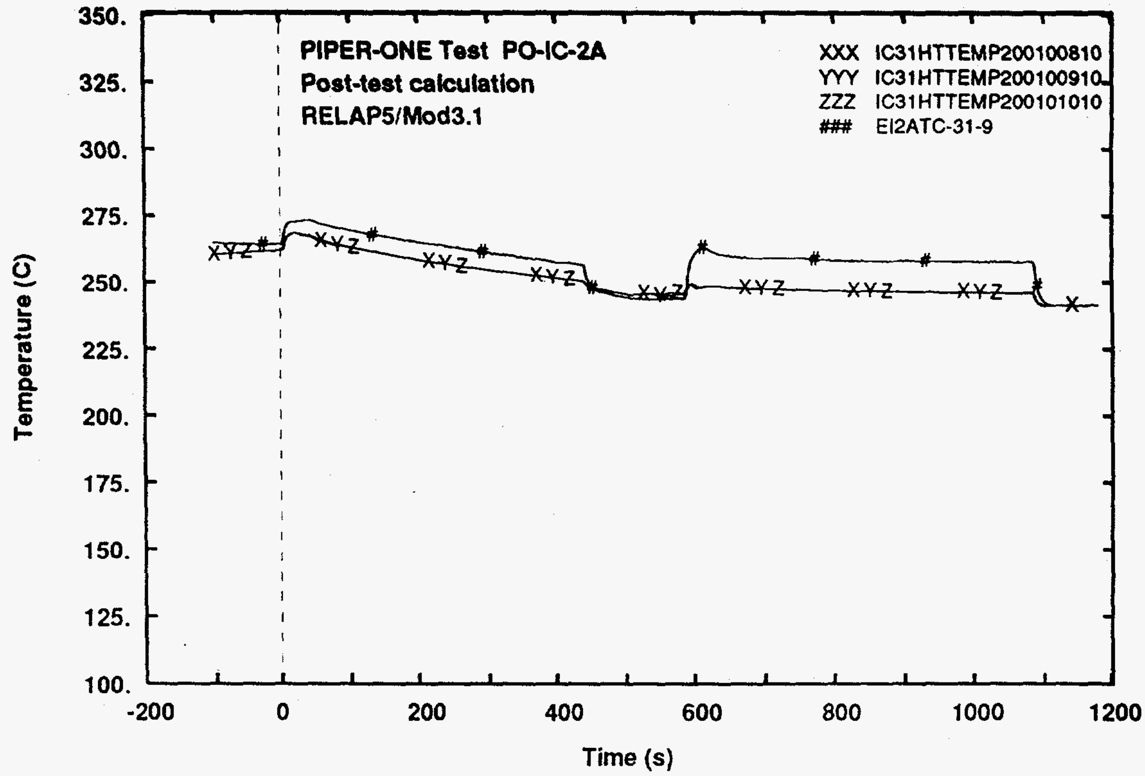

Fig. 3 - Measured and calculated trends of rod surface temperature (level 9)

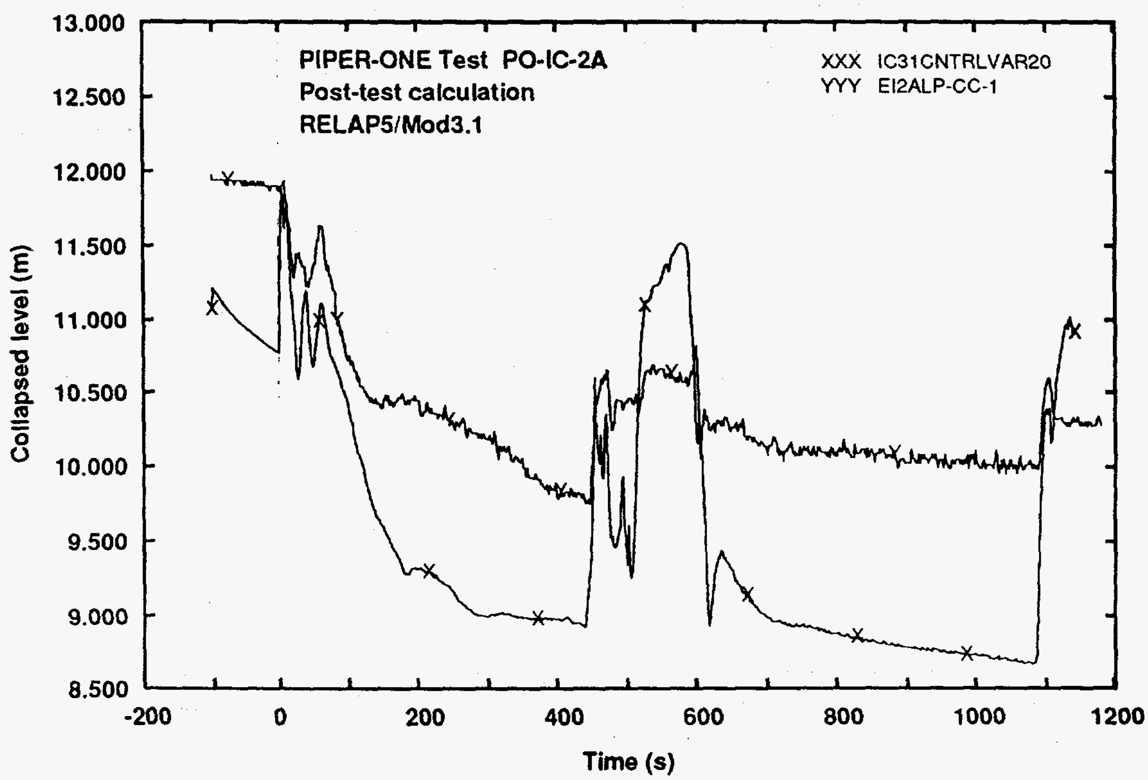

Fig. 4 - Measured and calculated trends of core level

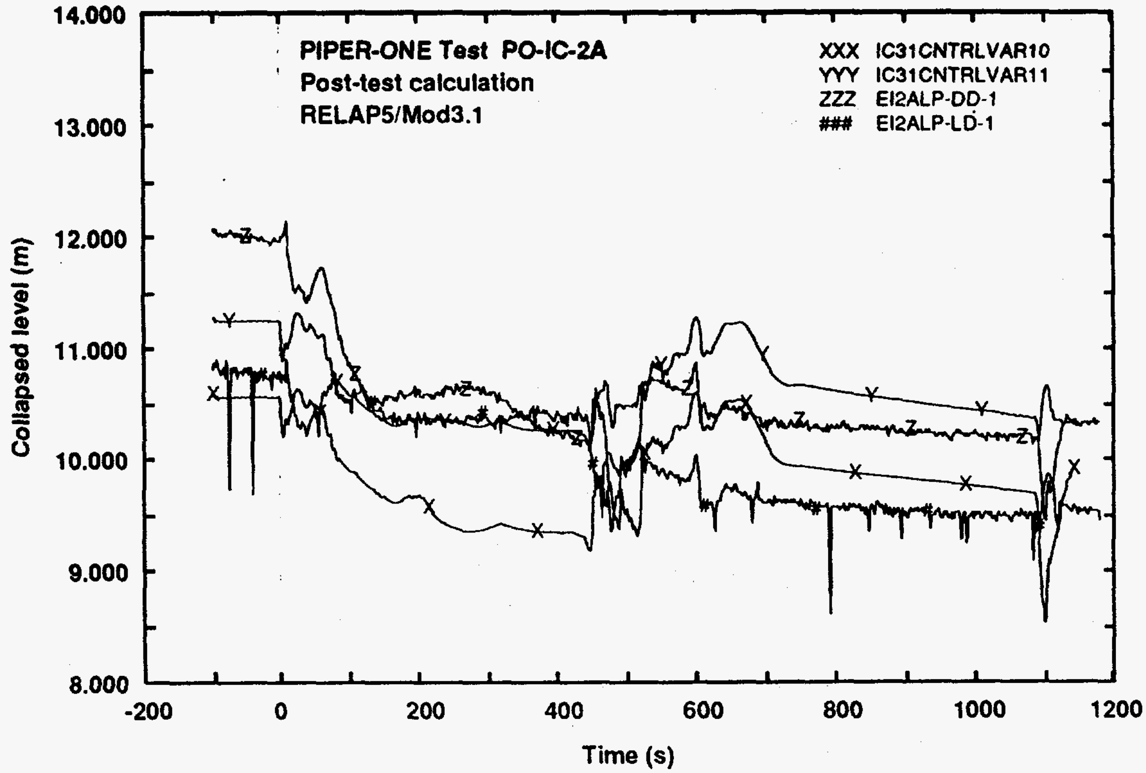

Fig. 5 - Measured and calculated trends of downcomer level

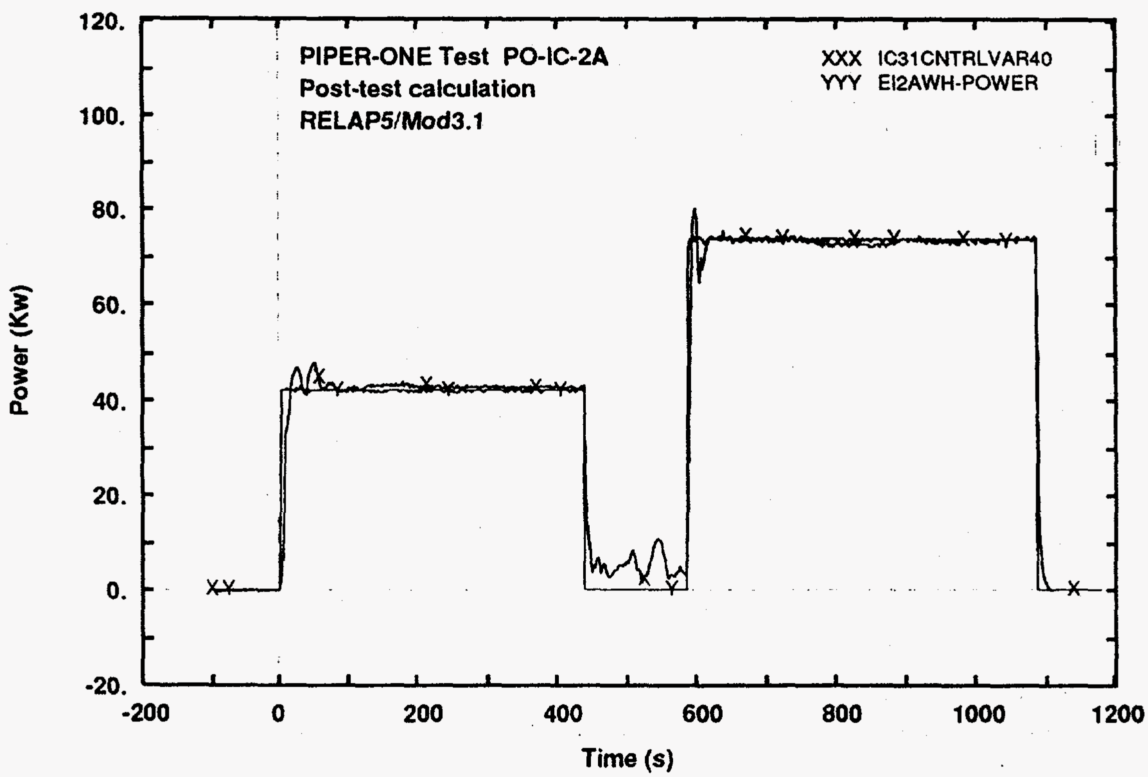

Fig. 6 - Measured and calculated trends of core power

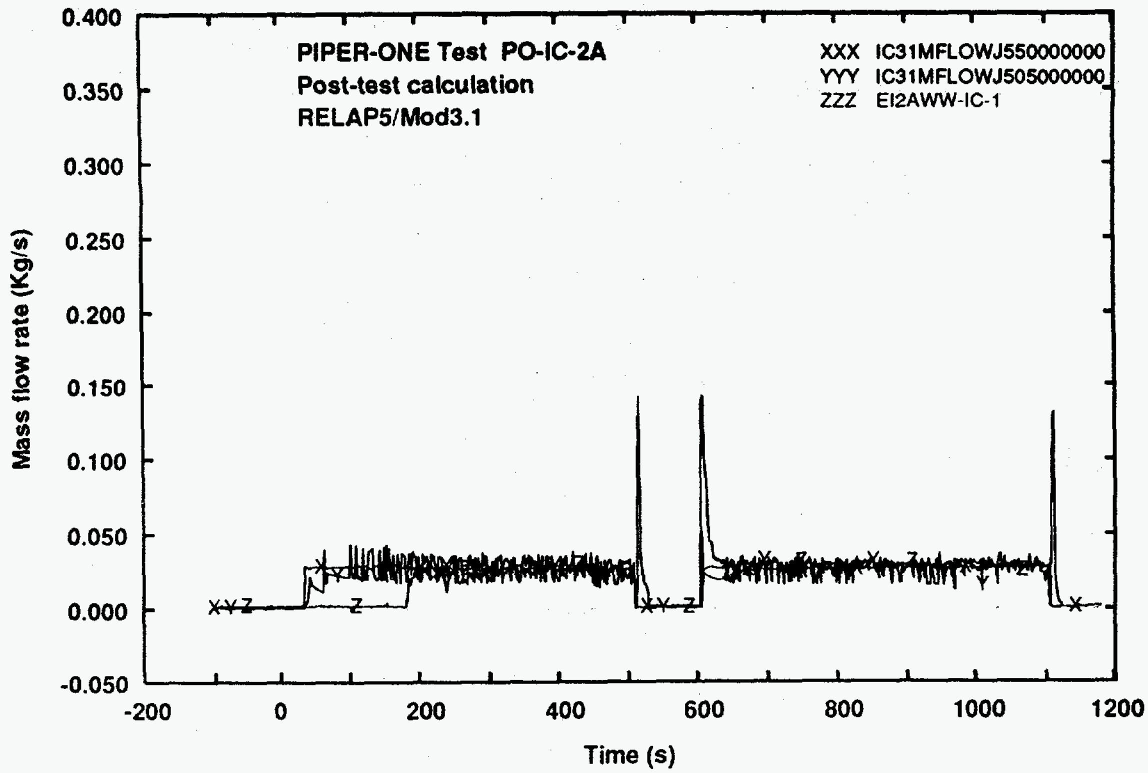

Fig. 7 - Measured and calculated trends of IC mass flow rate

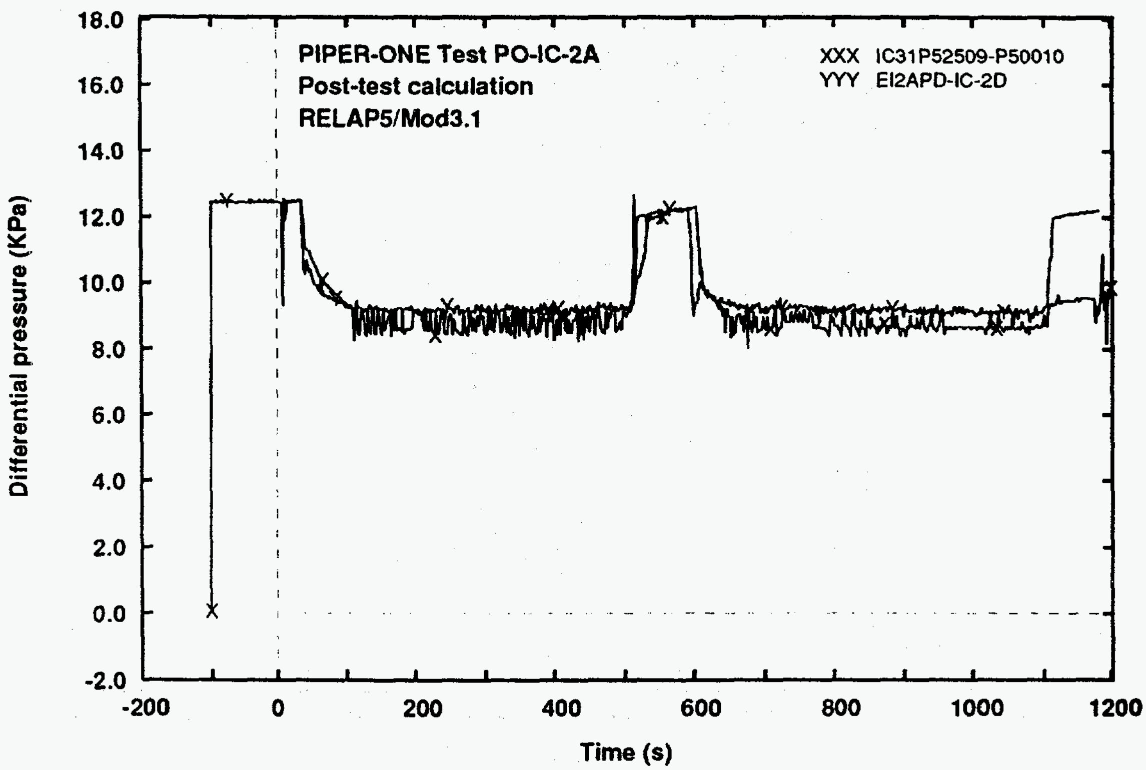

Fig. 8 - Measured and calculated trends of IC differential pressure

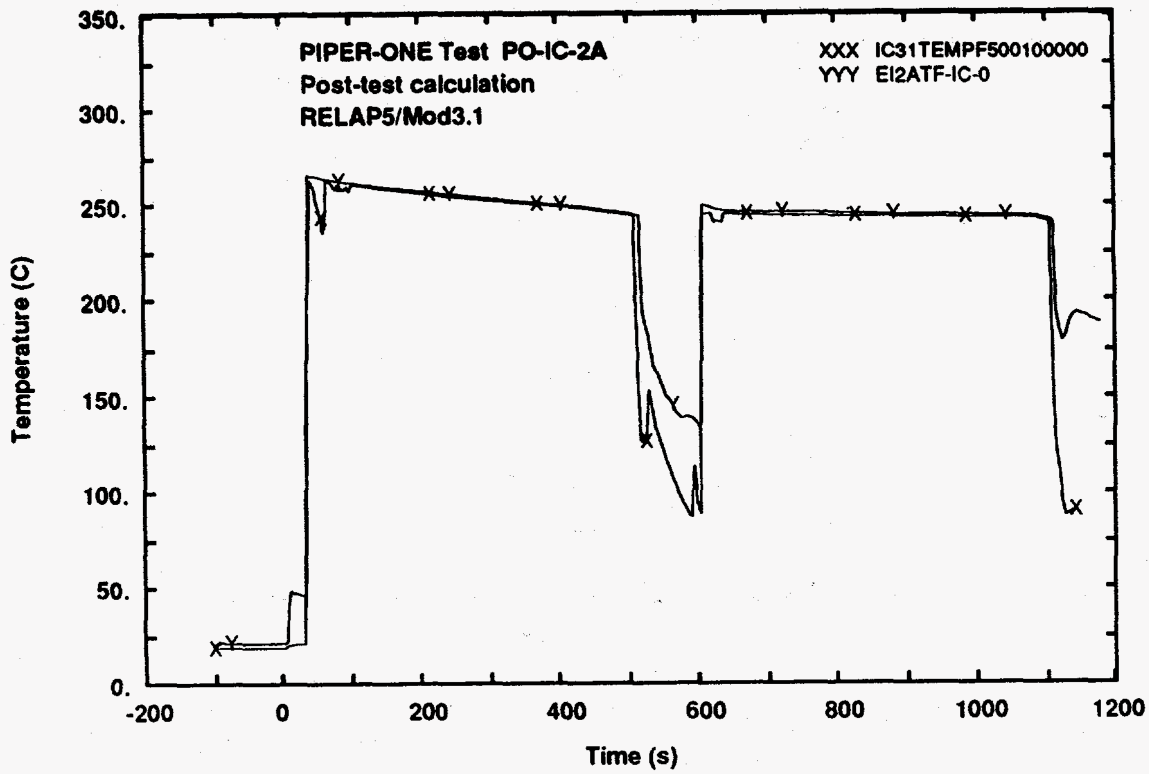

Fig. 9 - Measured and calculated trends of IC inlet fluid temperature

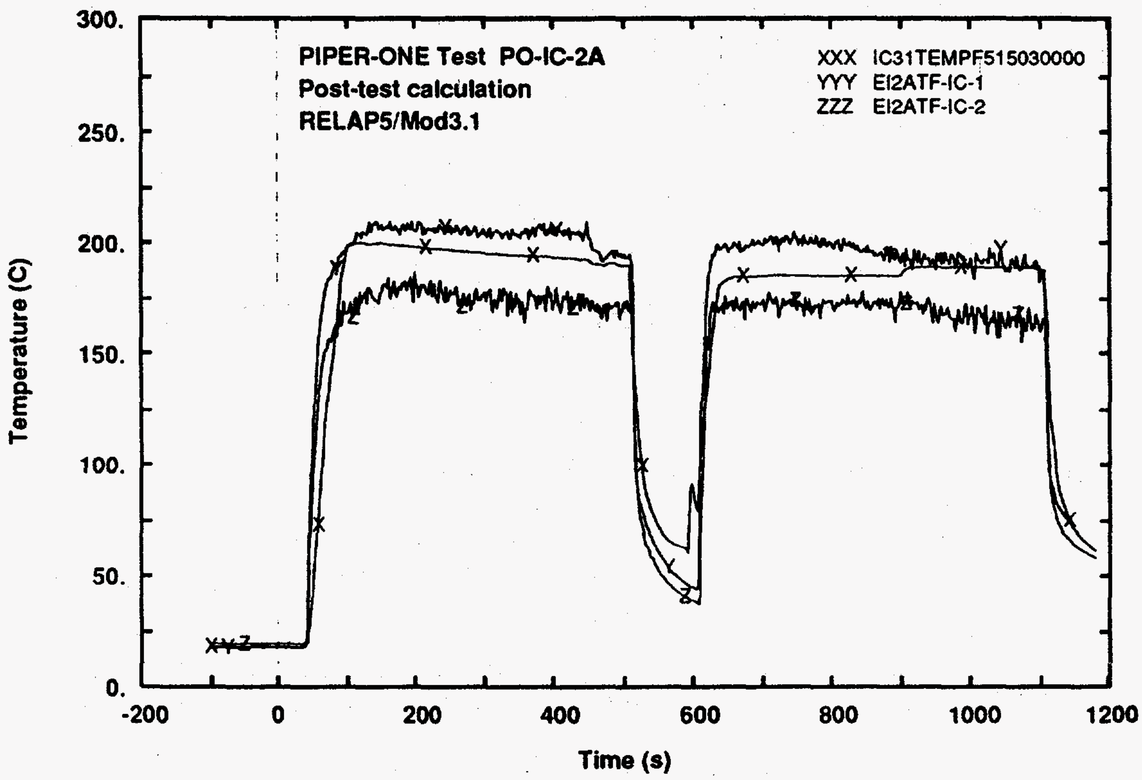

Fig. 10 - Measured and calculated trends of IC tubes fluid temperature
(middle elevation)

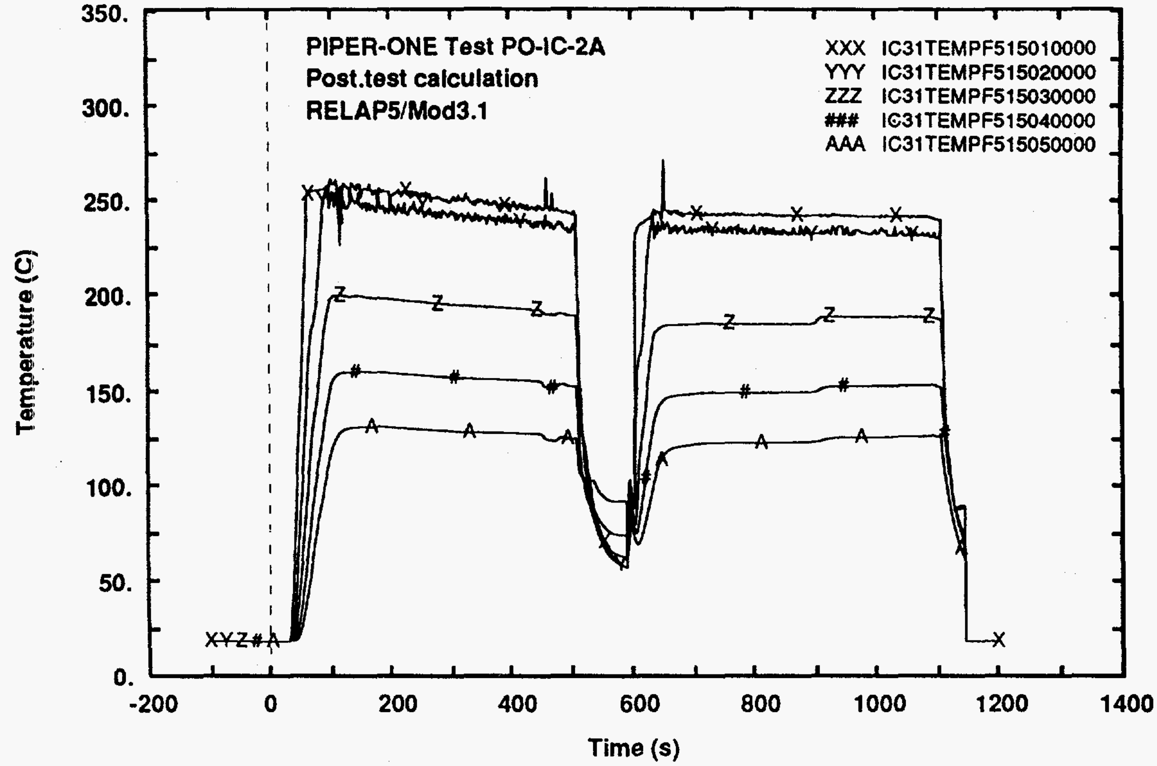

Fig. 11 - Calculated trends of IC fluid temperature along the axis

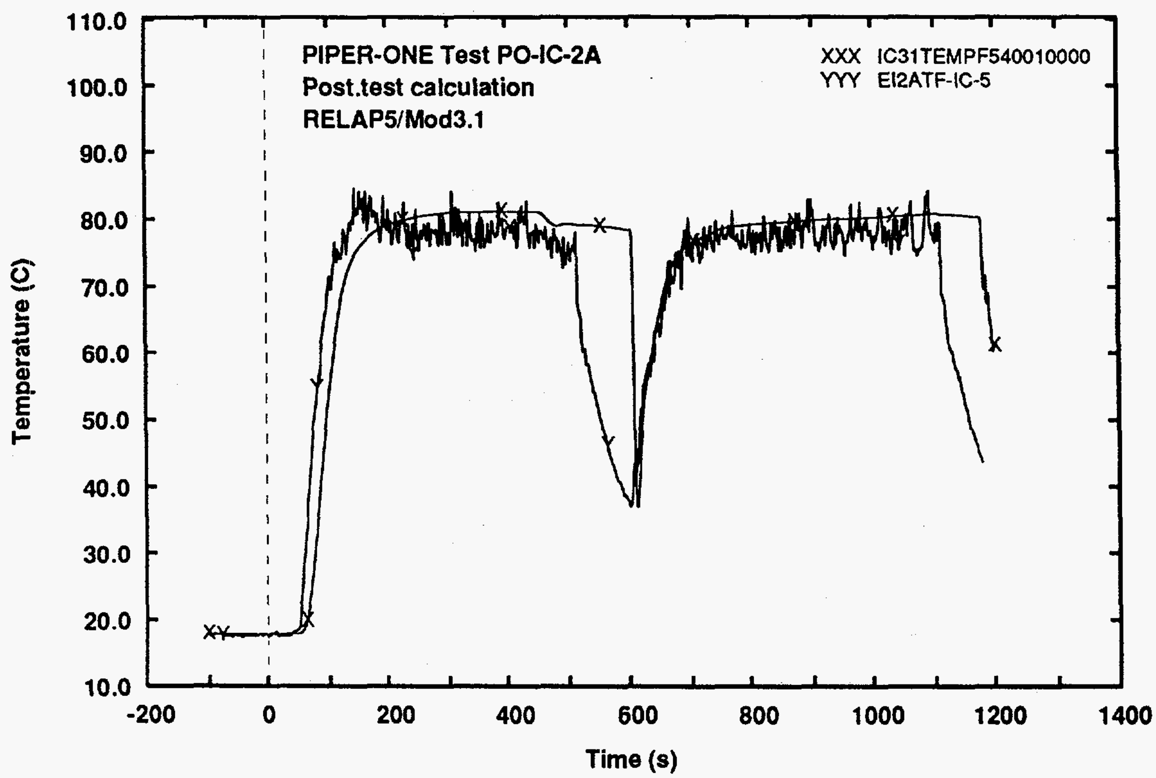

Fig. 12 - Measured and calculated trends of IC outlet fluid temperature

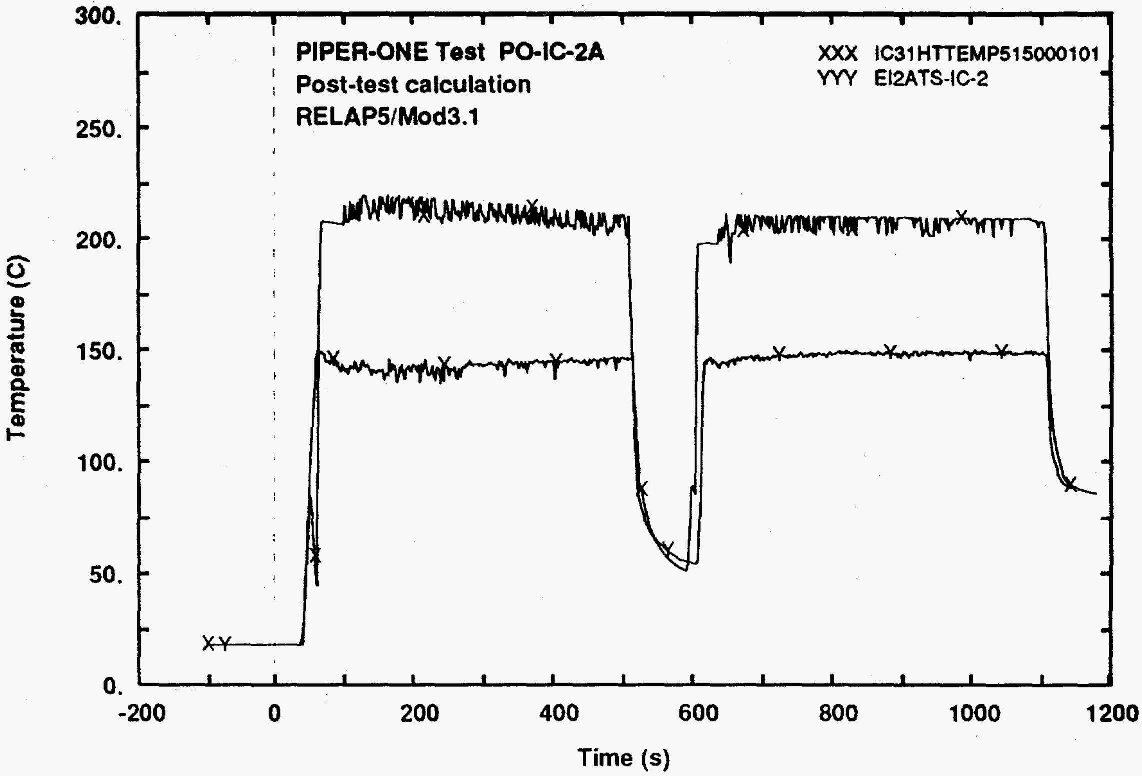

Fig. 13 - Measured and calculated trends of IC tubes wall surface temperature (internal side top elevation)

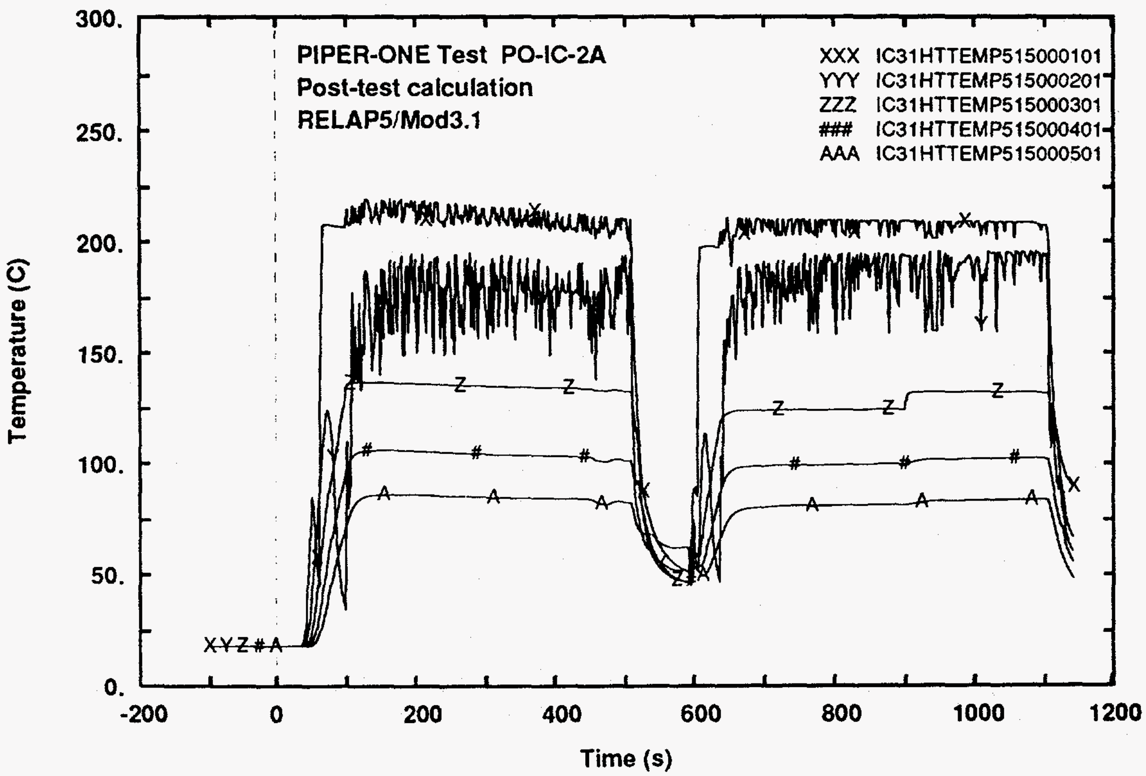

Fig. 14 - Calculated trends of IC tubes wall surface temperature along the axis (internal side)

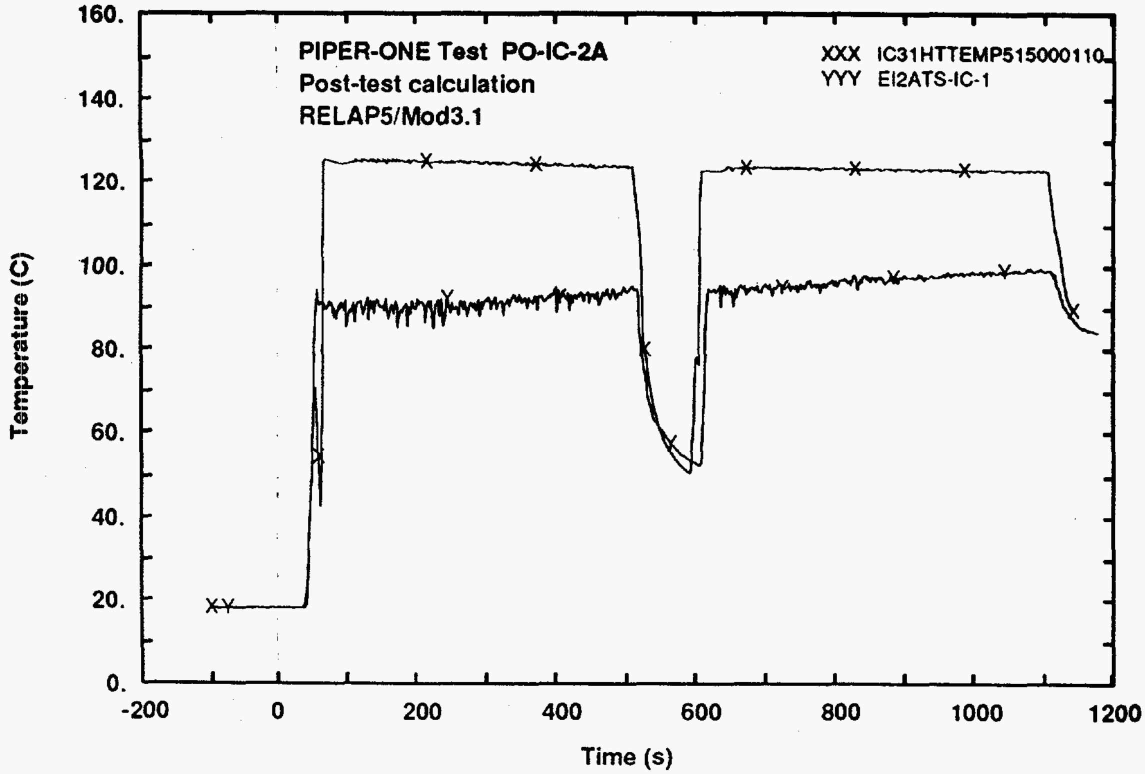

Fig. 15 - Measured and calculated trends of IC tubes wall surface temperature (external side top elevation)

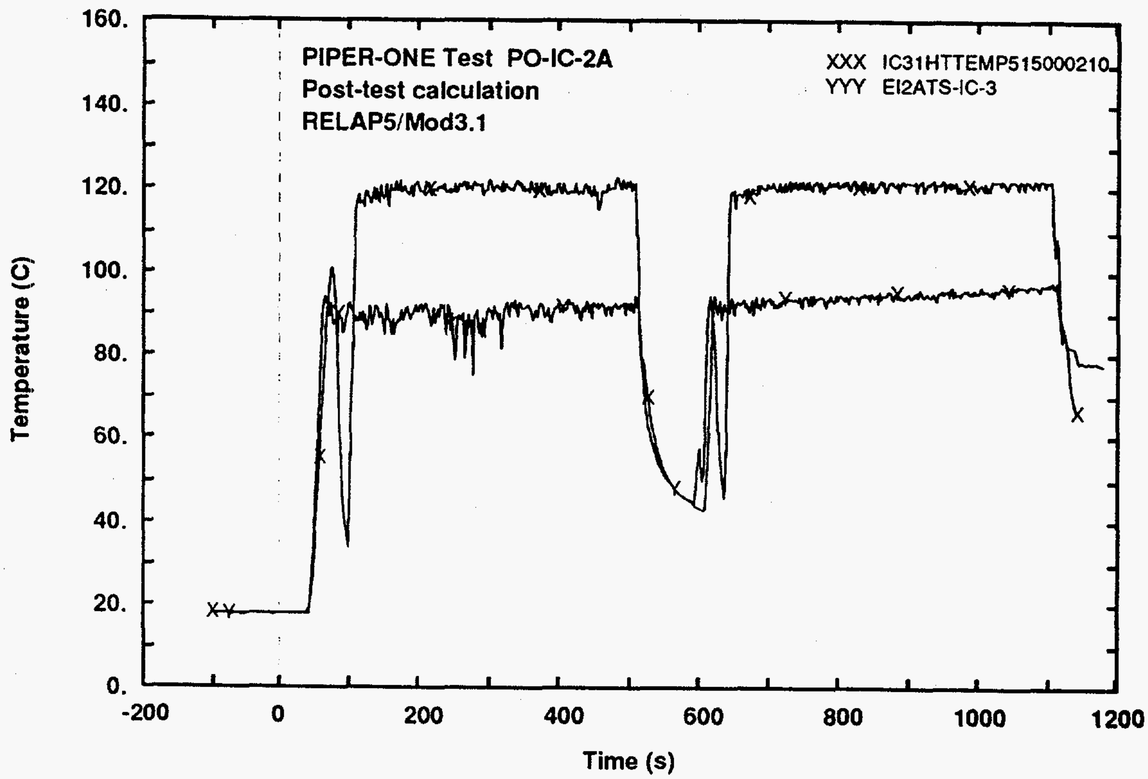

Fig. 16 - Measured and calculated trends of IC tubes wall surface temperature (external side level 3)

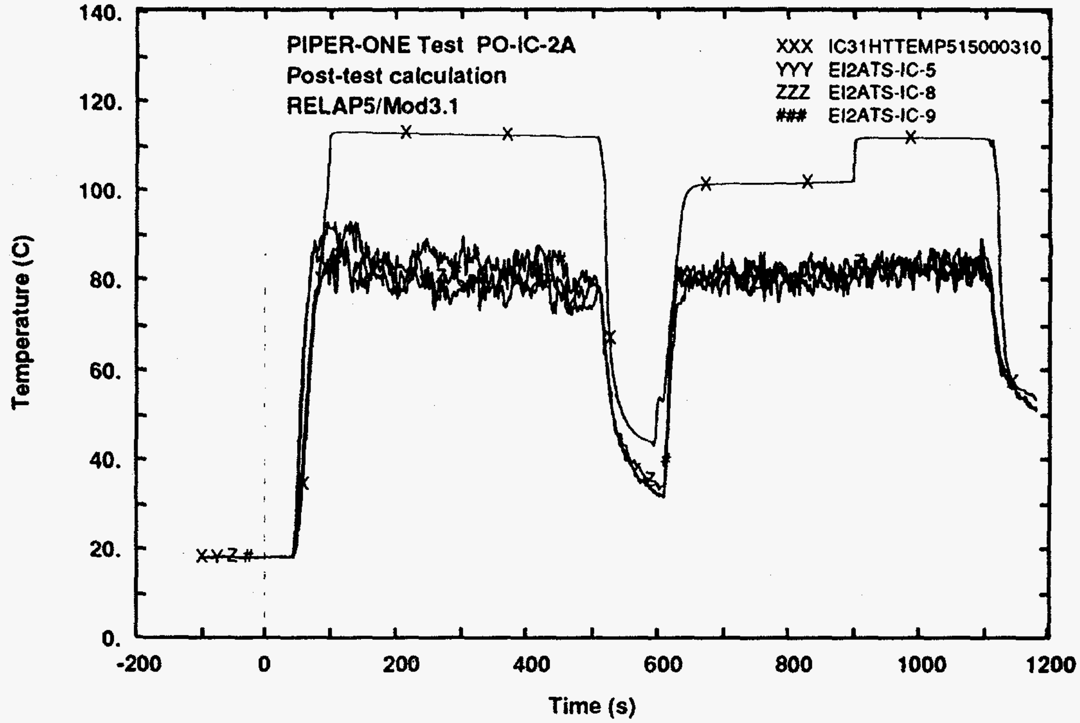

Fig. 17 - Measured and calculated trends of IC tubes wall surface temperature (external side middle elevation)

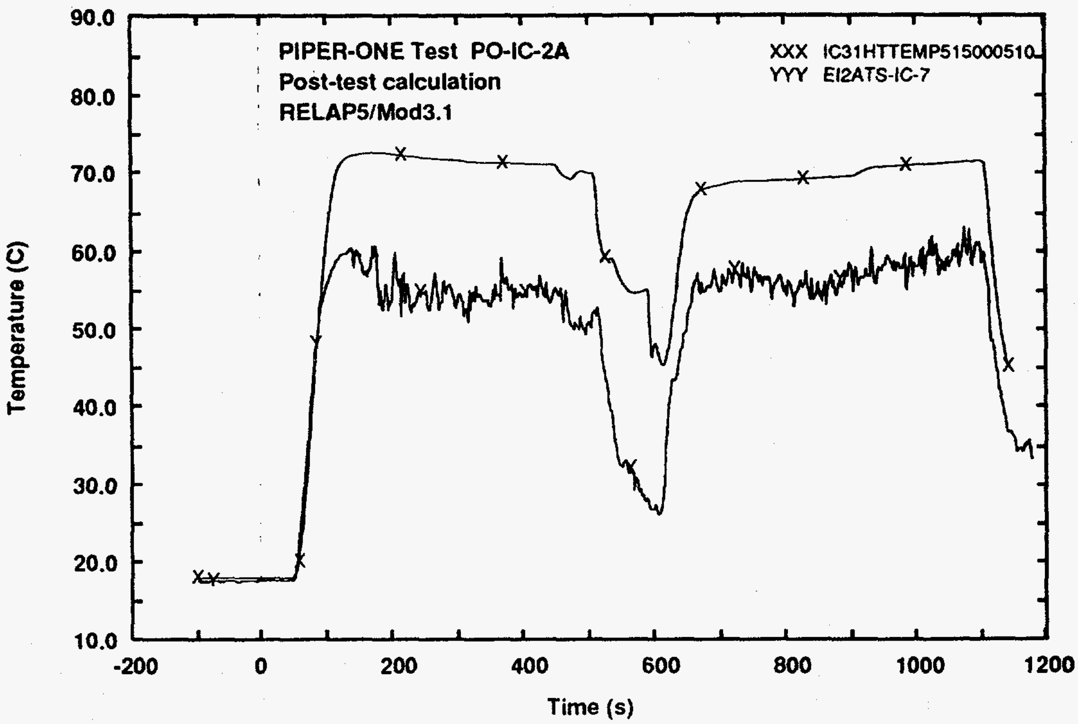

Fig. 18 - Measured and calculated trends of IC tubes wall surface temperature (external side bottom elevation)

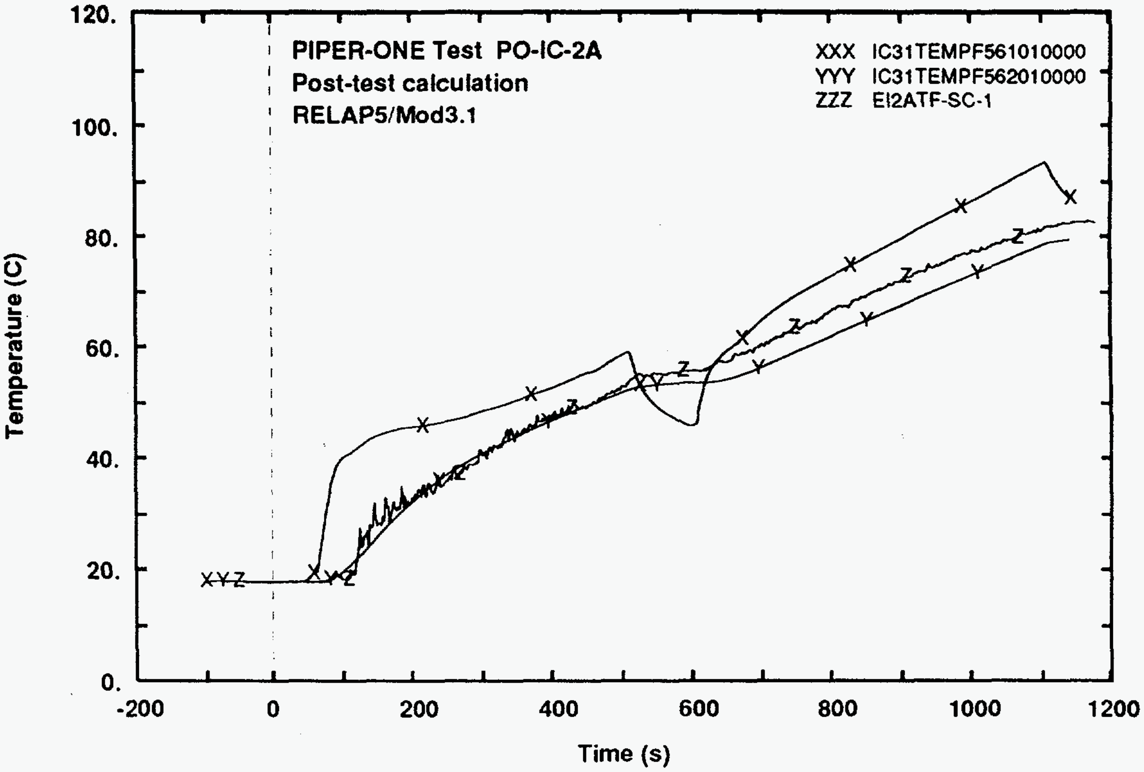

Fig. 19 - Measured and calculated trends of IC internal pool fluid temperature (top level)

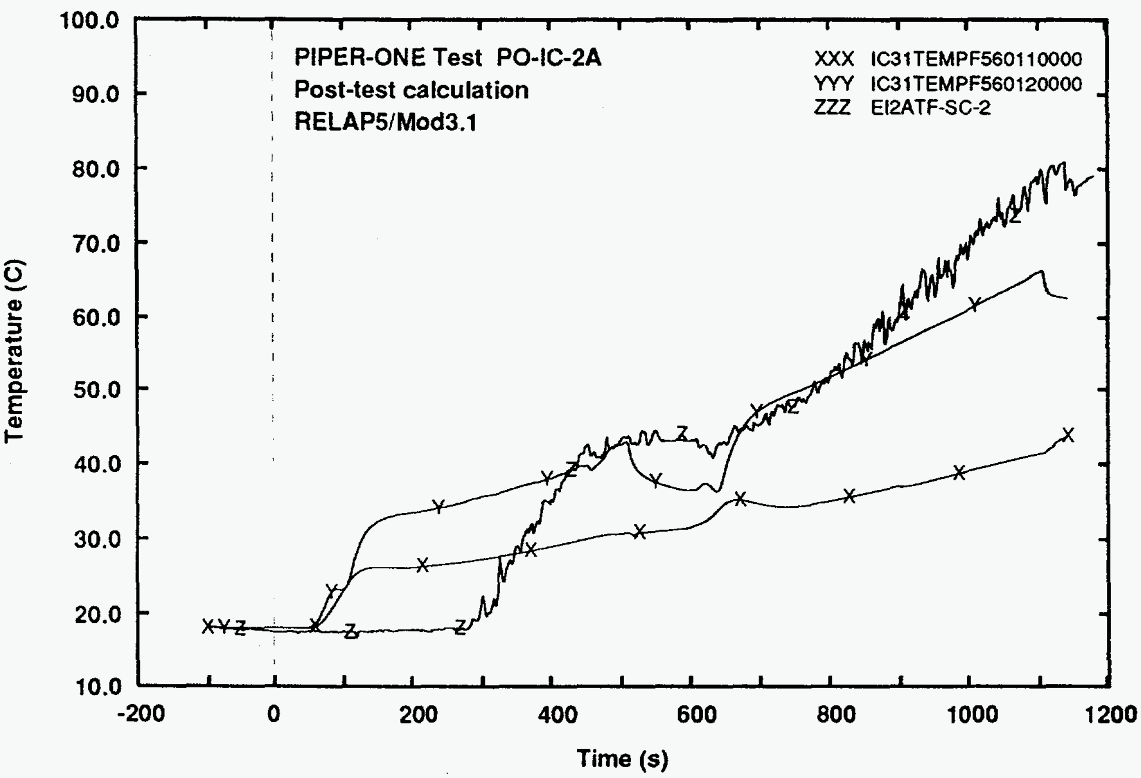

Fig. 20 - Measured and calculated trends of IC internal pool fluid temperature (level 2)

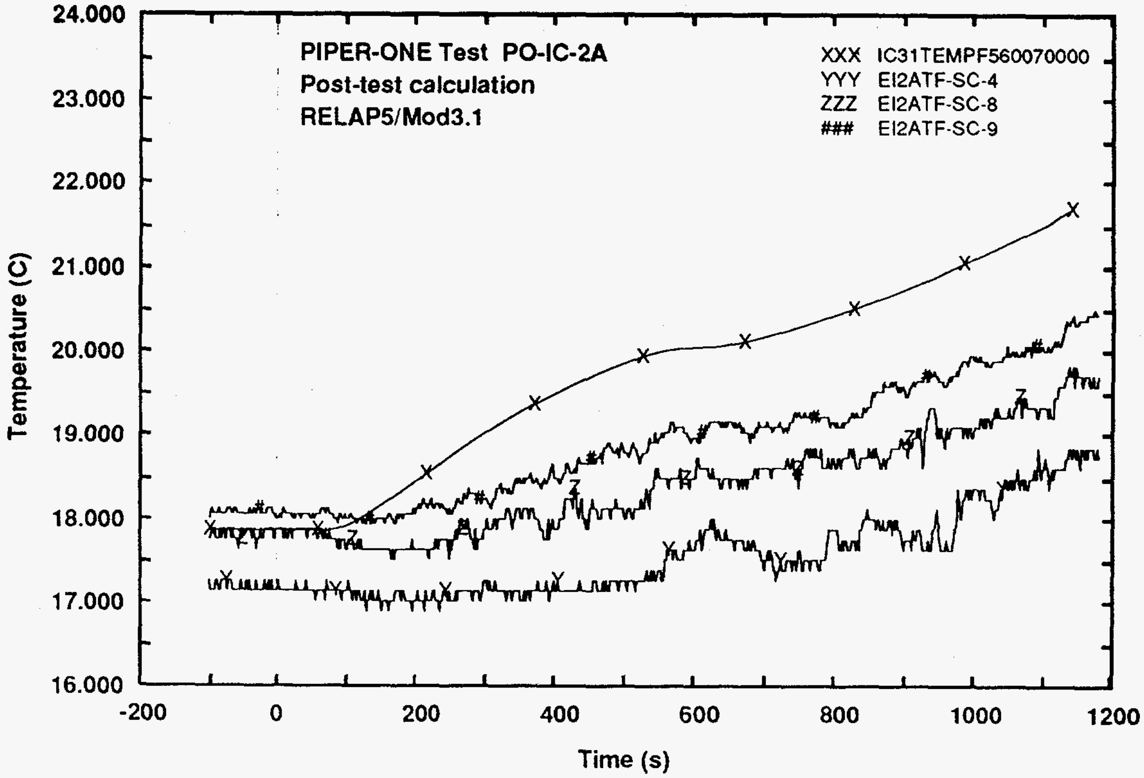

Fig. 21 - Measured and calculated trends of IC internal pool fluid temperature (middle level)

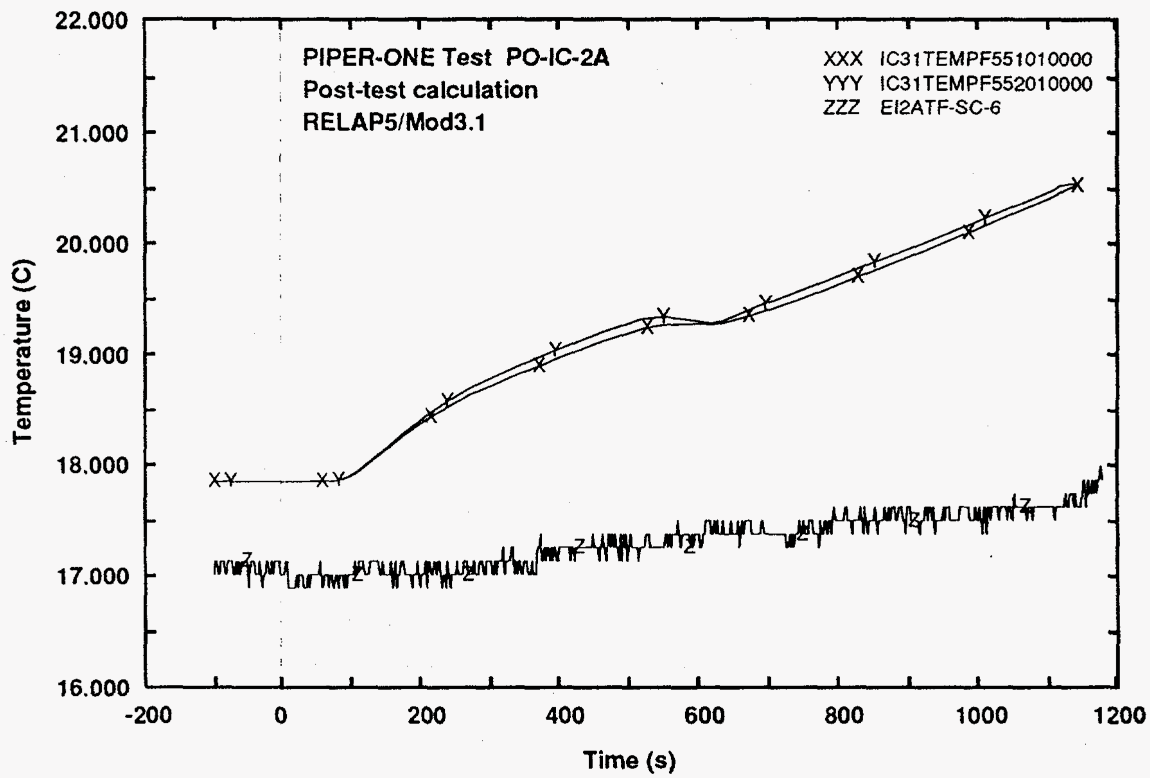

Fig. 22 - Measured and calculated trends of IC internal pool fluid temperature (bottom level)

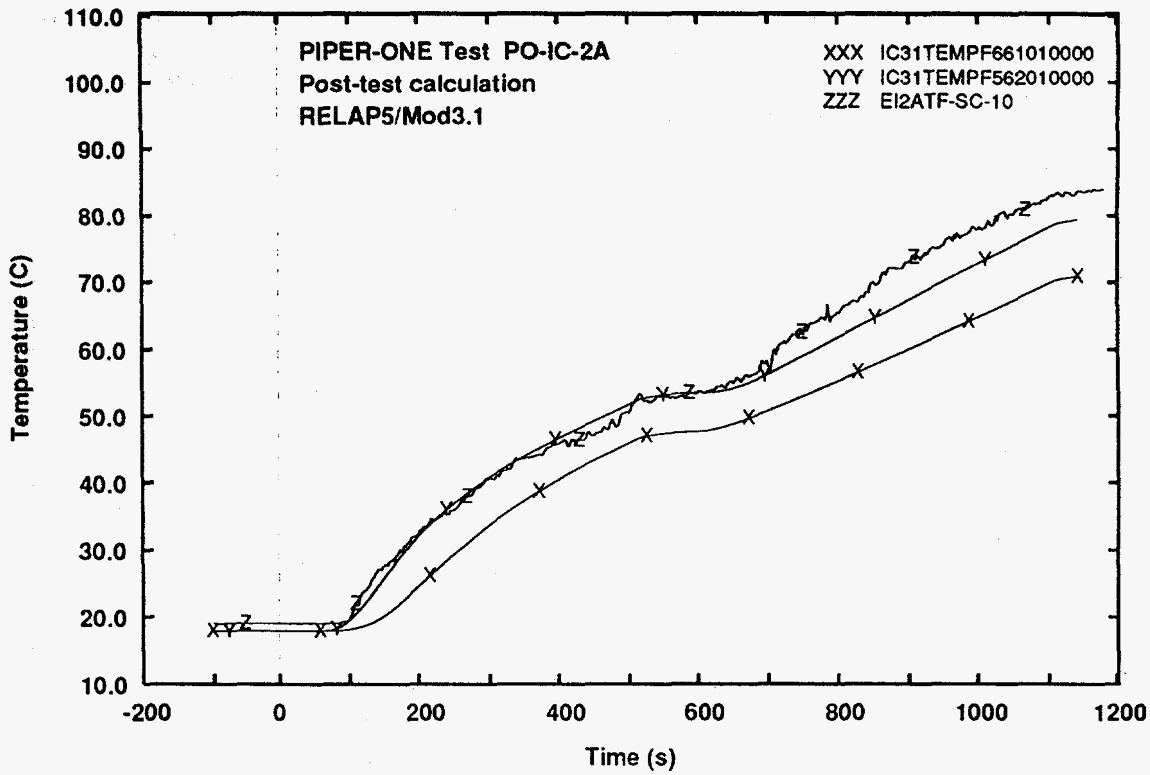

Fig. 23 - Measured and calculated trends of IC external pool fluid temperature (top level)

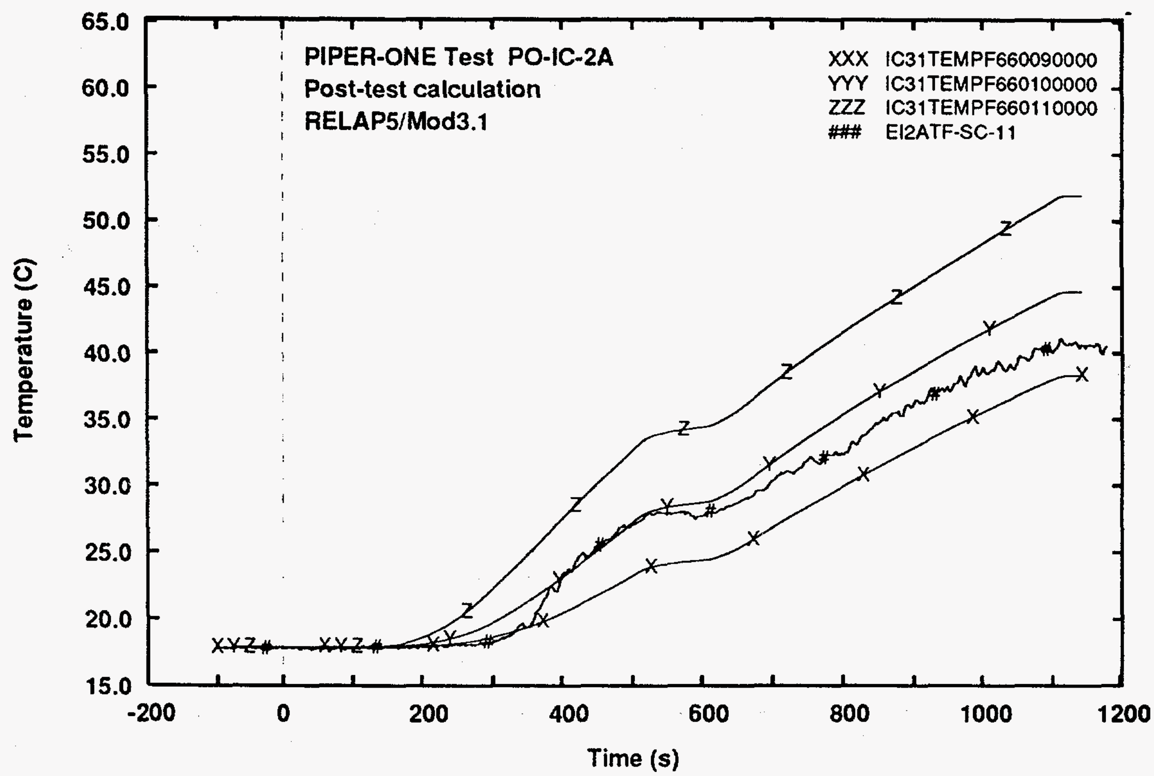

Fig. 24 - Measured and calculated trends of IC external pool fluid temperature (level 11)

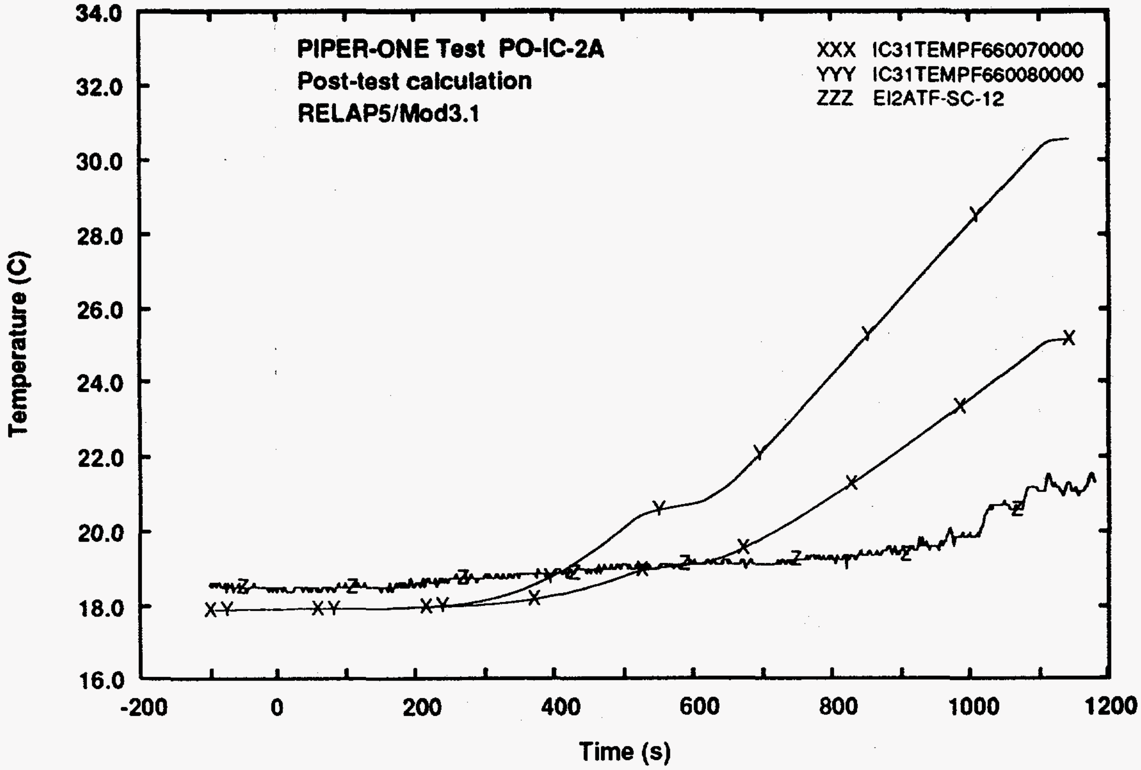

Fig. 25 - Measured and calculated trends of IC external pool fluid temperature (middle level)

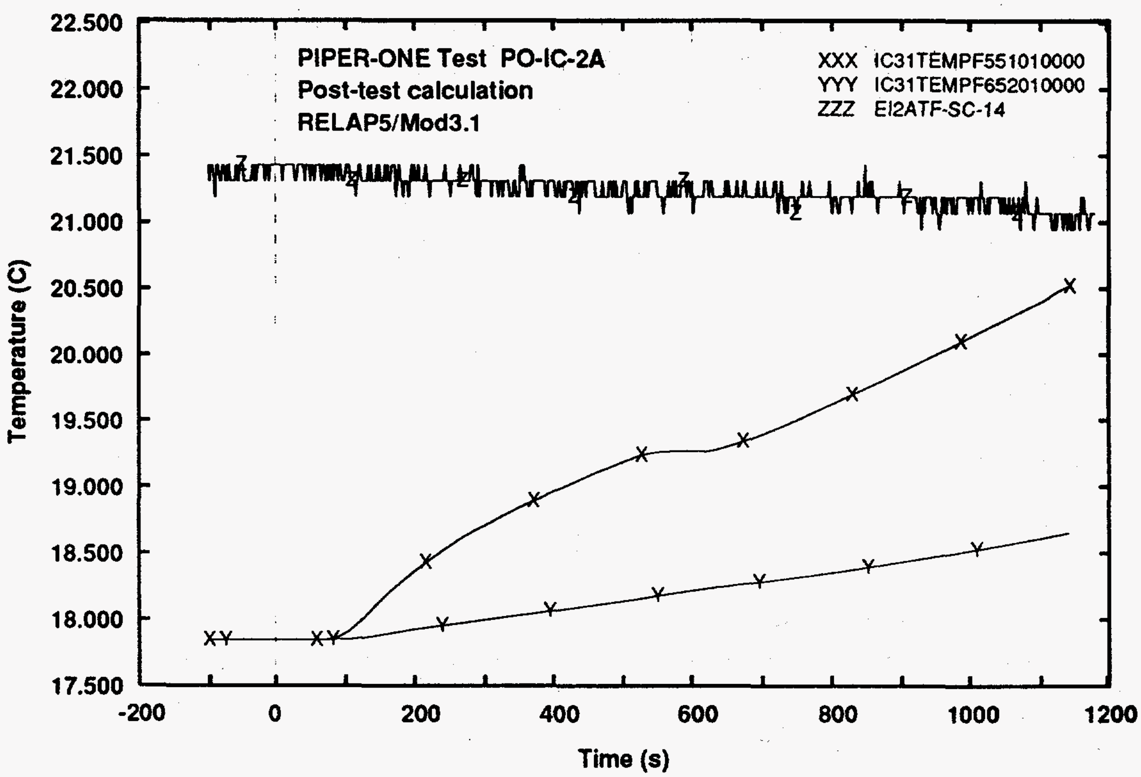

Fig. 26 - Measured and calculated trends of IC external pool fluid temperature (bottom level)

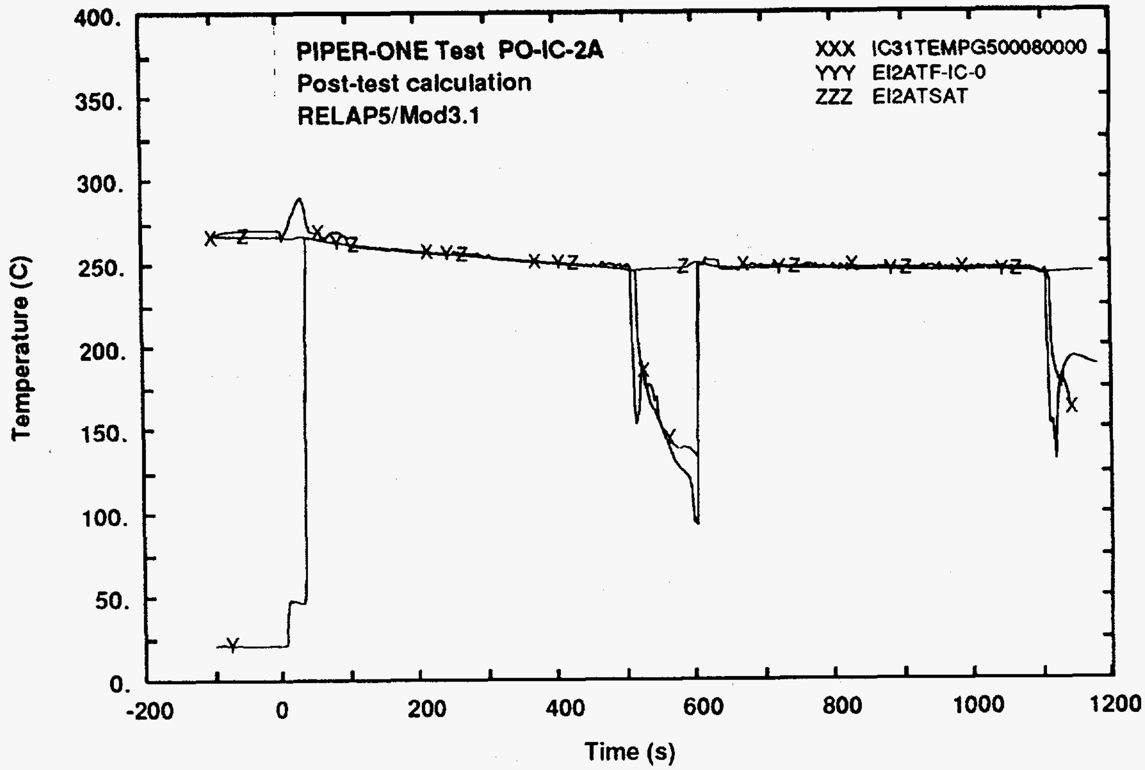

Fig. 27 - Measured and calculated trends of steam temperature at IC inlet compared with experimental saturated temperature

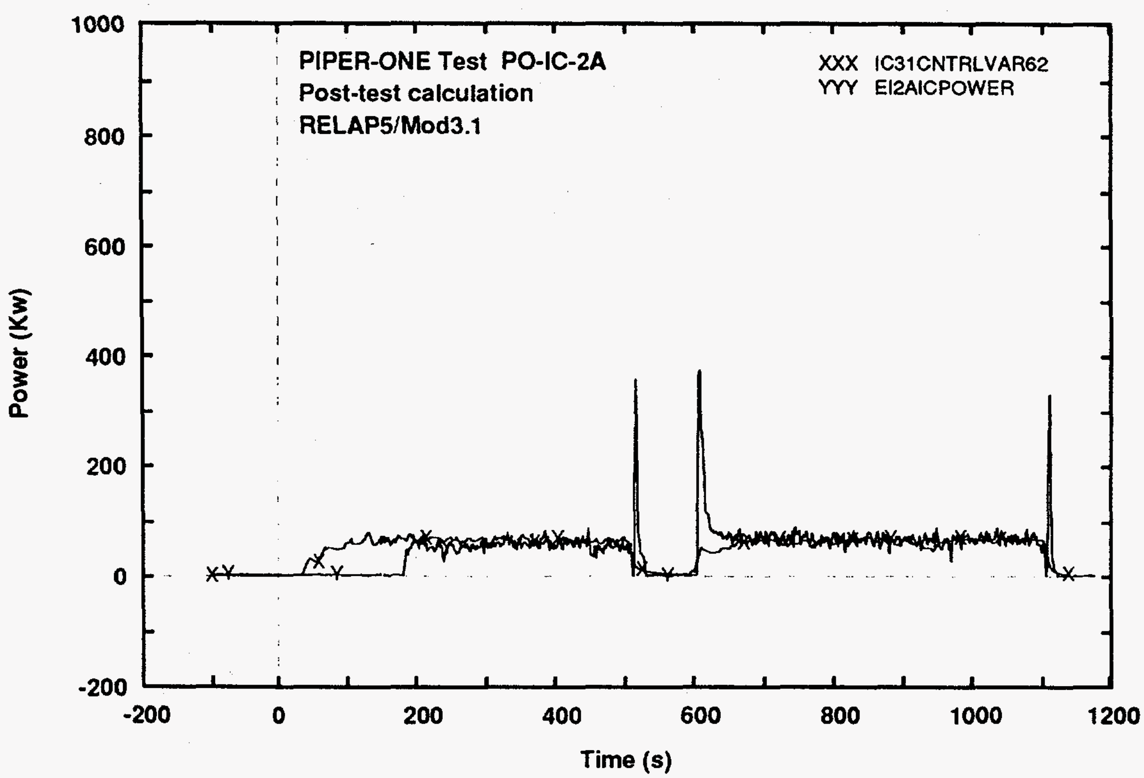

Fig. 28 - Measured and calculated trends of IC exchanged power

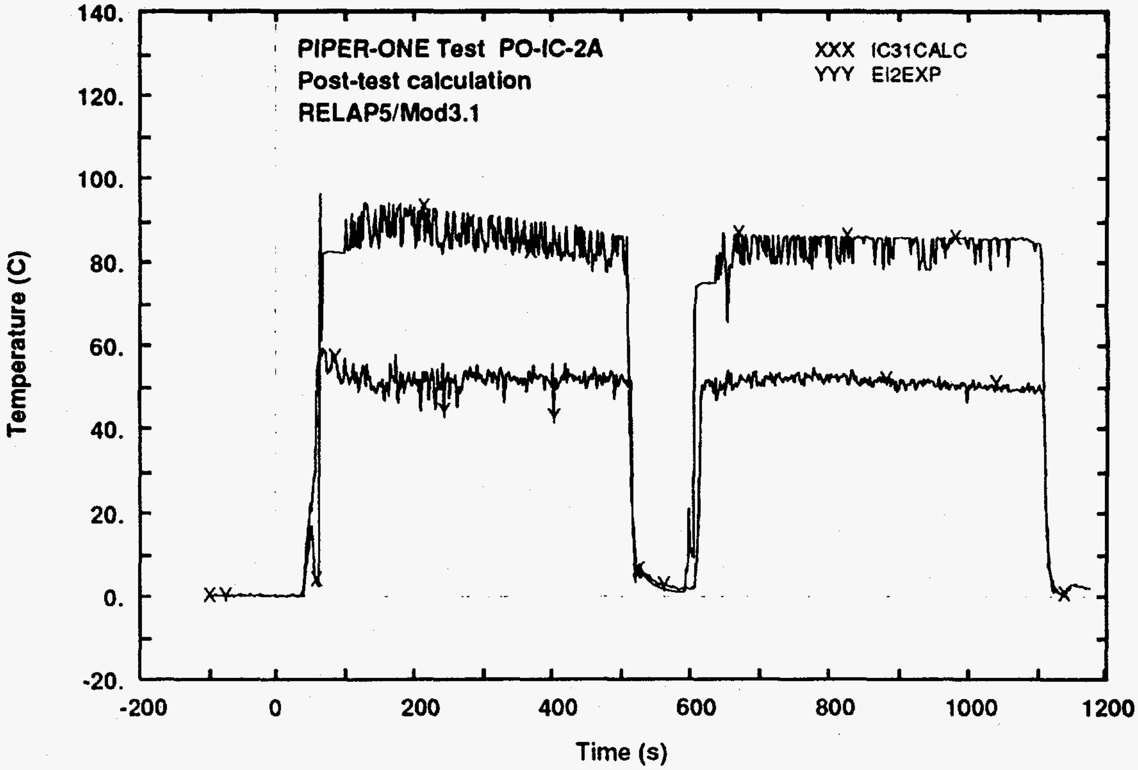

Fig. 29 - Measured and calculated trends of temperature difference between internal and external side of IC tubes wall (top elevation)

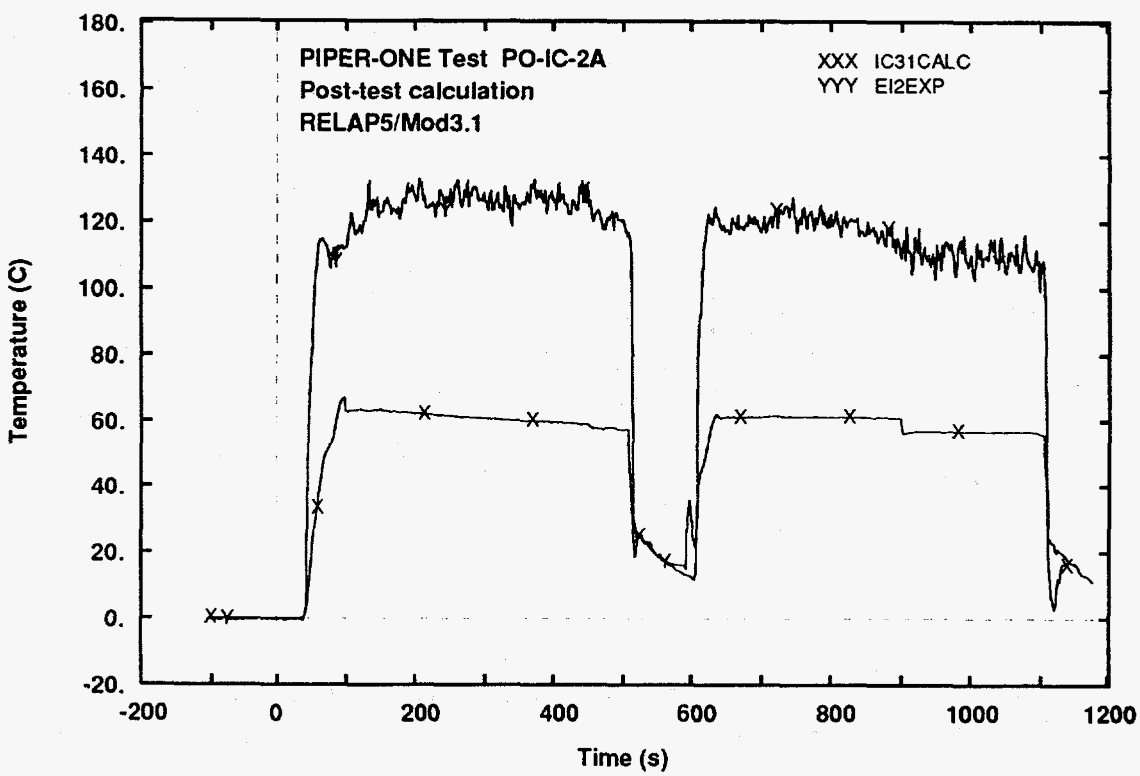

Fig. 30 - Measured and calculated trends of temperature difference between IC fluid and external side of IC tubes wall (middle elevation)

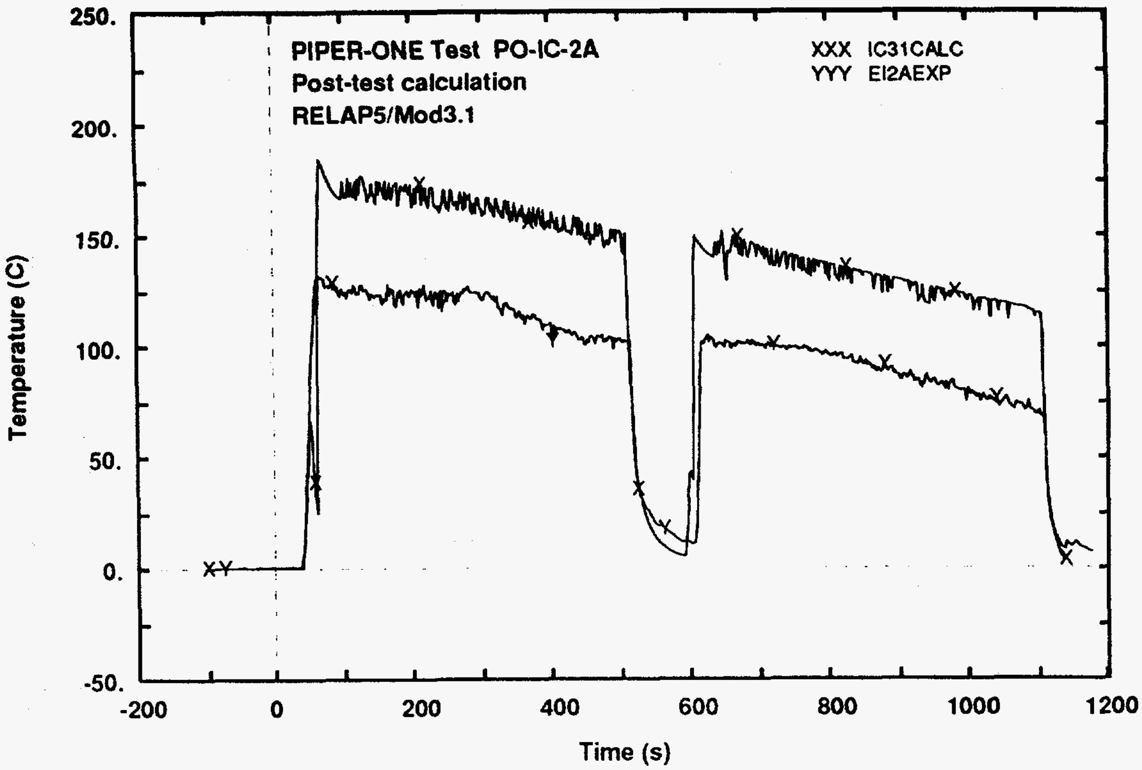

Fig. 31 - Measured and calculated trends of temperature difference between internal side of IC tubes wall and IC pool fluid temperature (top elevation)

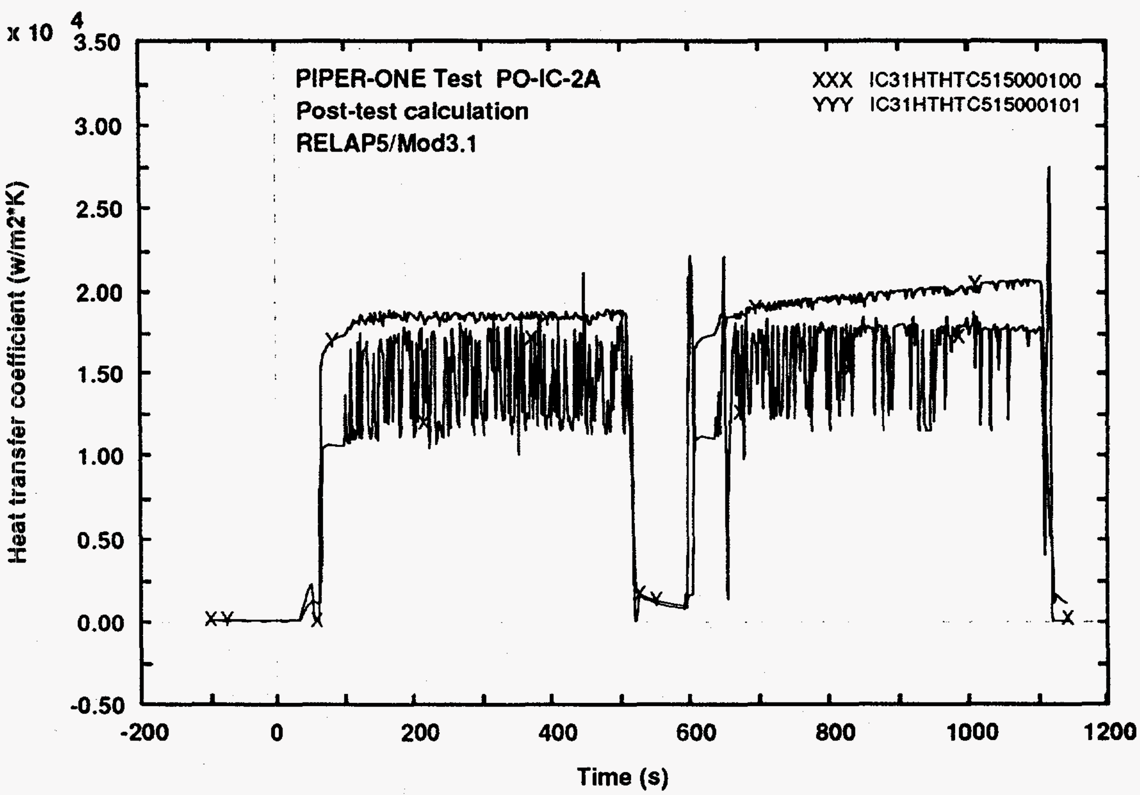

Fig. 32 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (top elevation)

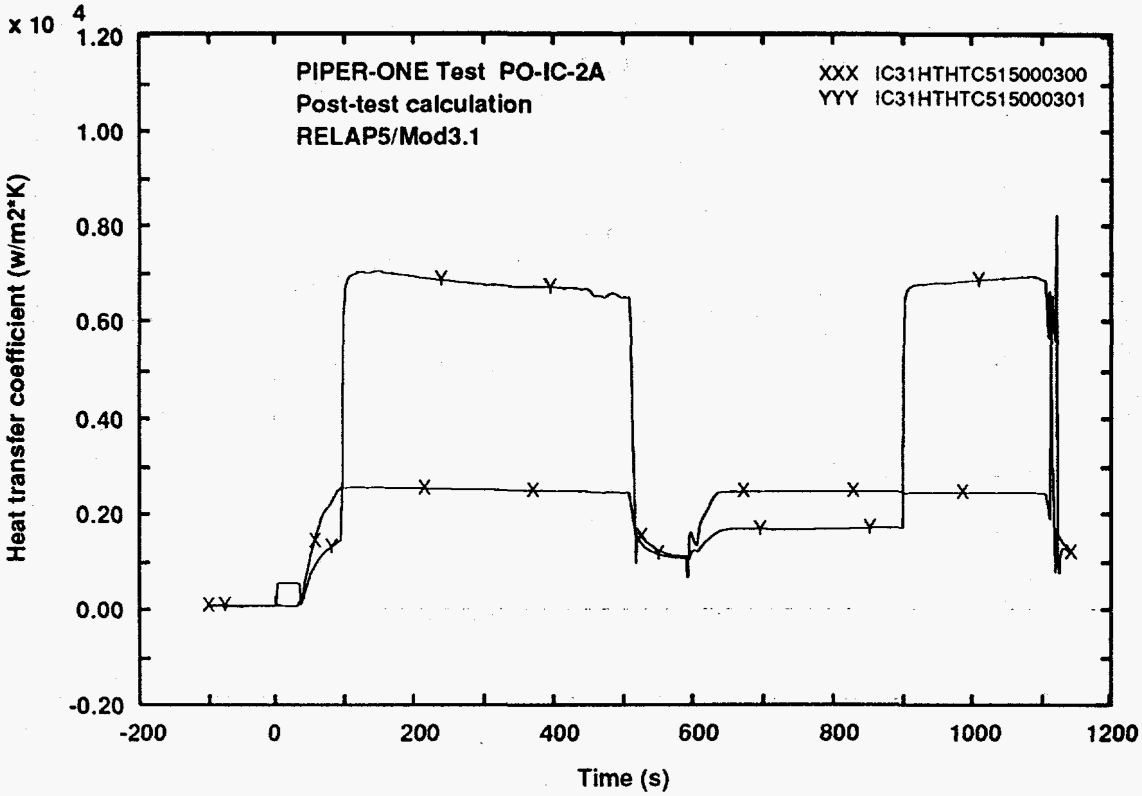

Fig. 33 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (middle elevation)

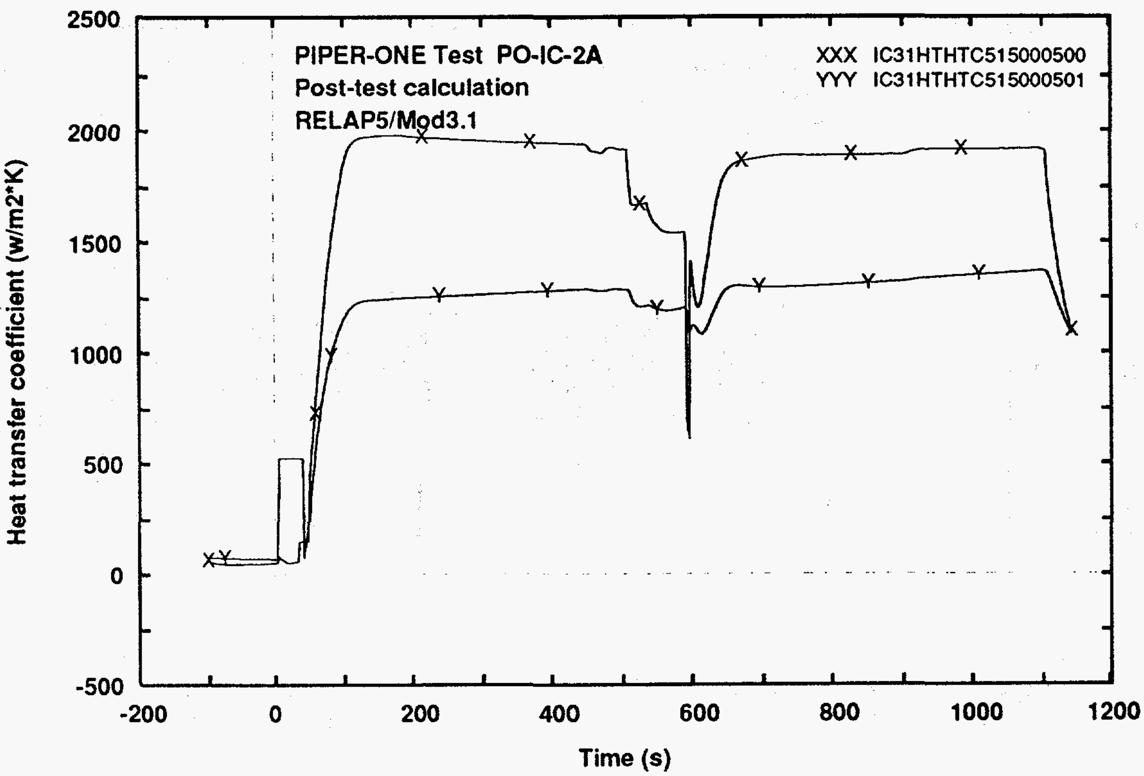

Fig. 34 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (bottom elevation)

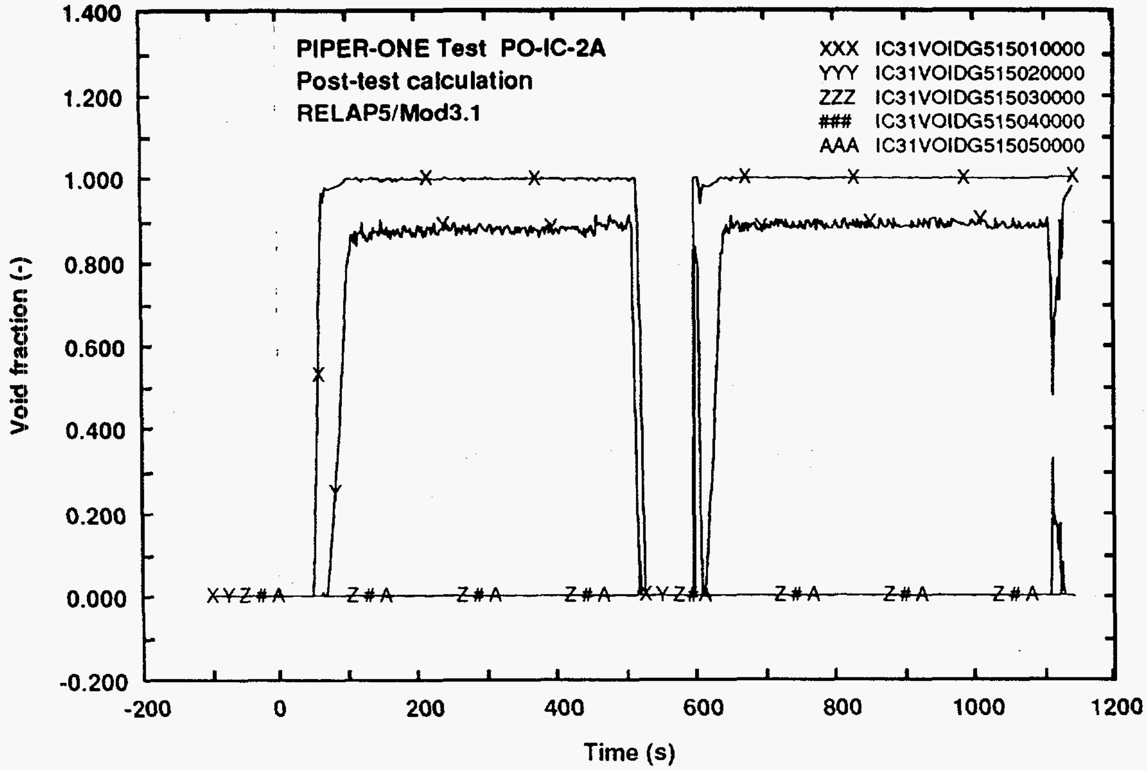

Fig. 35 - Calculated trends of IC tubes void fraction along the axis

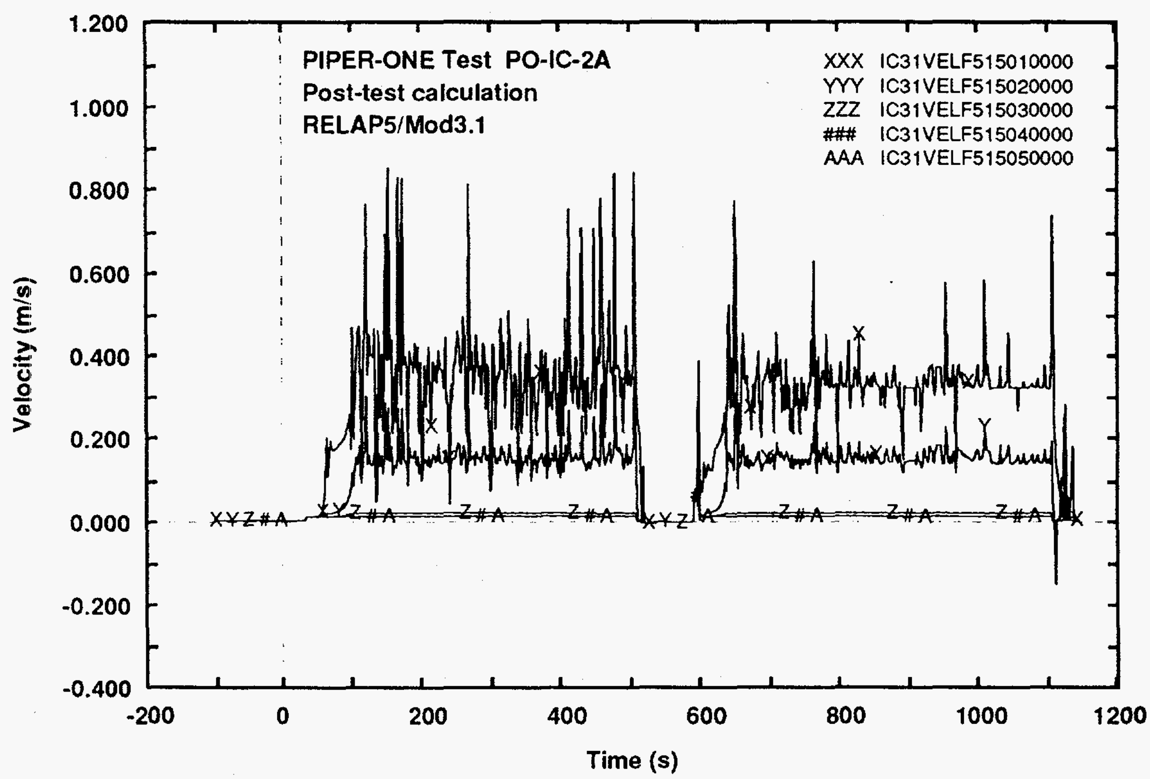

Fig. 36 - Calculated trends of IC tubes liquid velocity along the axis

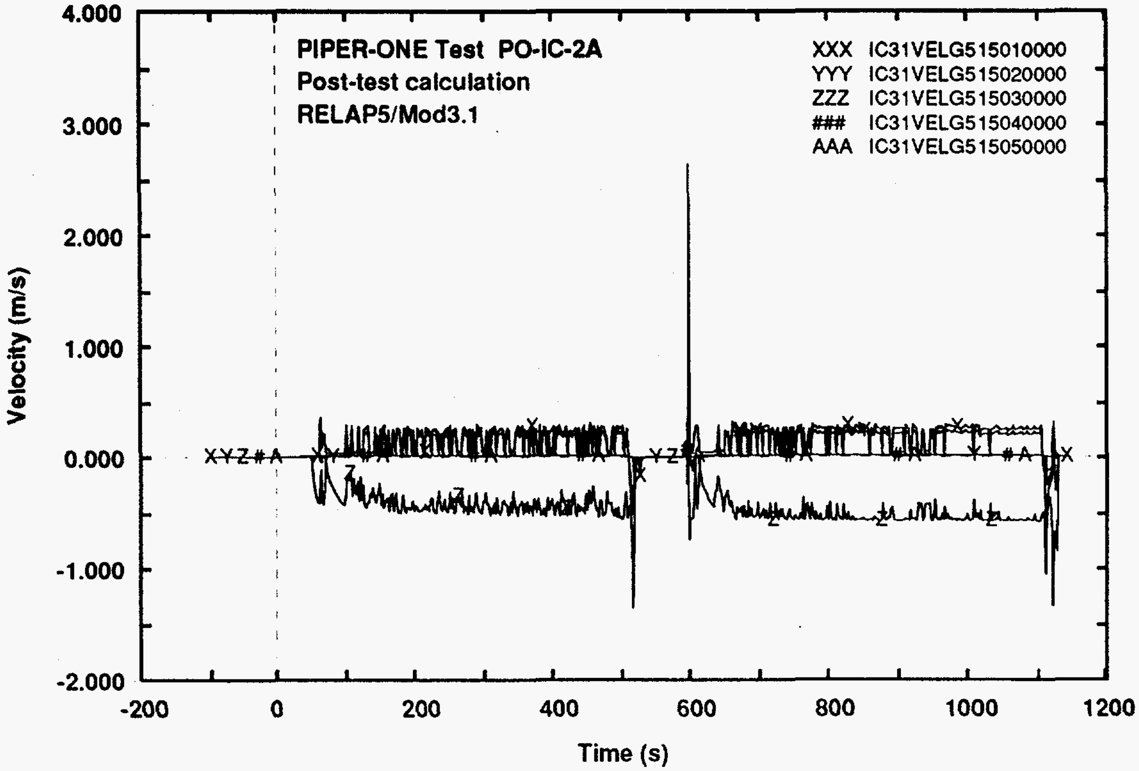

Fig. 37 - Calculated trends of IC tubes steam velocity along the axis

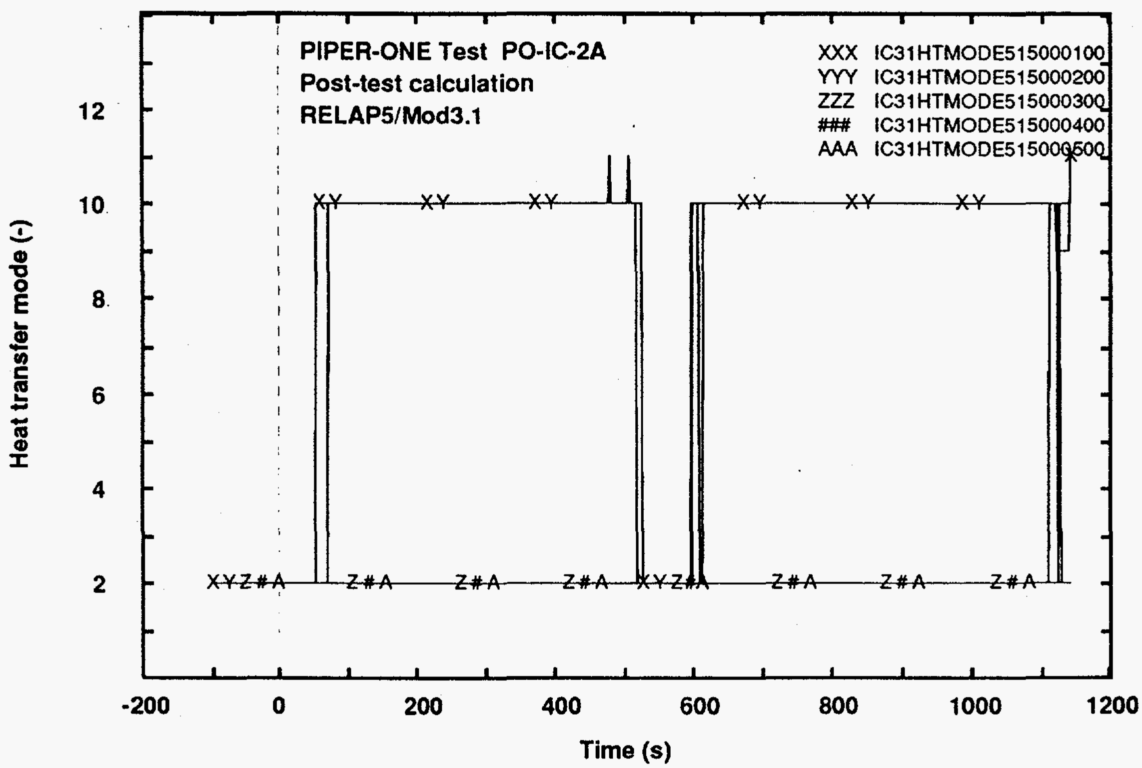

Fig. 38 - Calculated trends of IC tubes heat transfer mode (internal side)

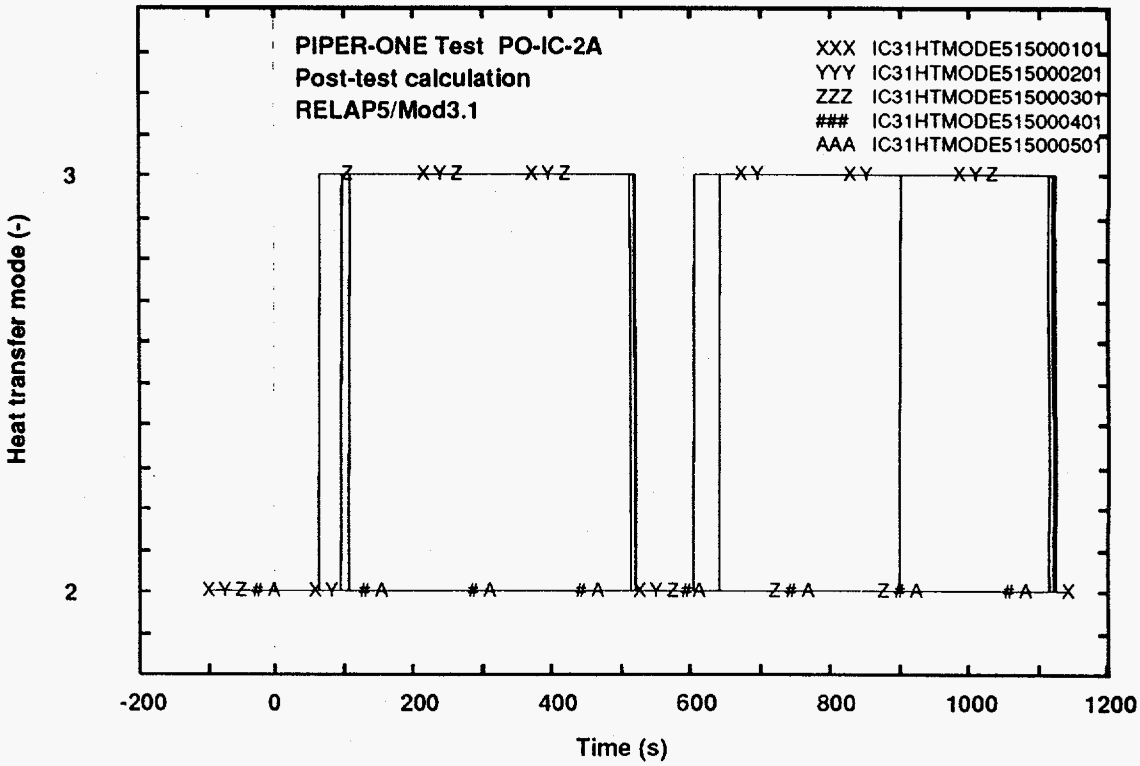

Fig. 39 - Calculated trends of IC tubes heat transfer mode (external side)

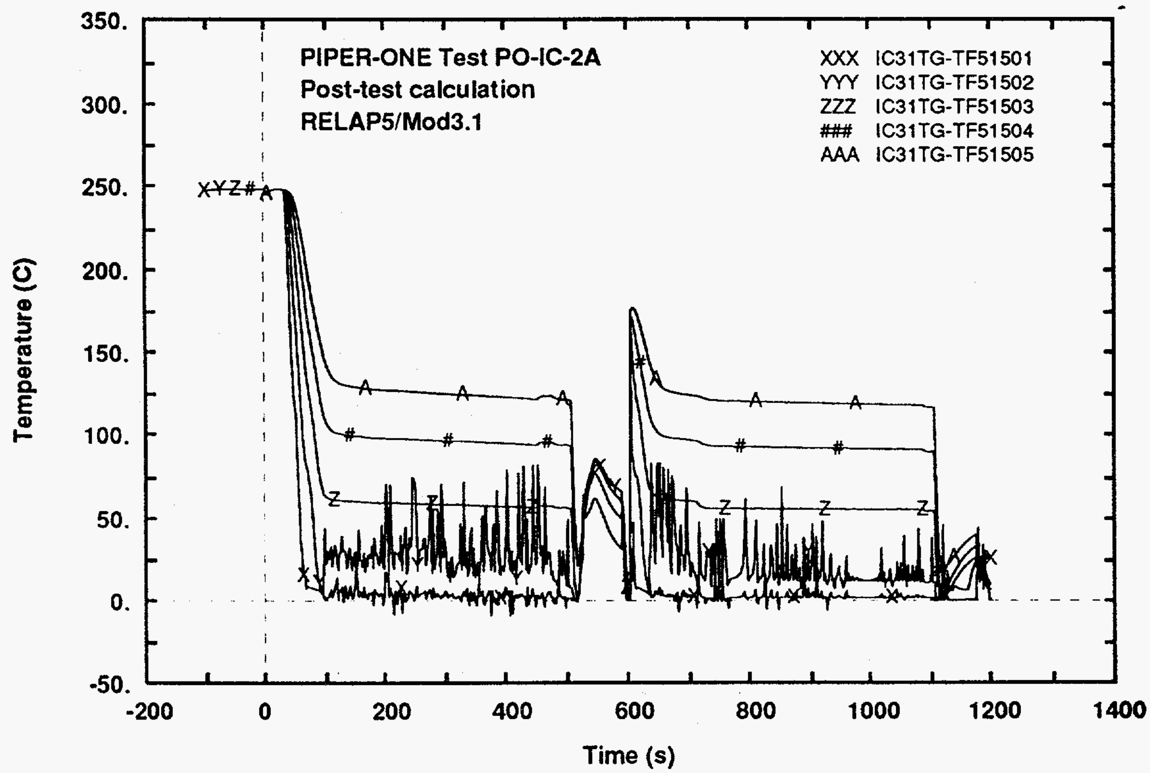

Fig. 40 - Calculated trends of subcooling degree inside IC tubes

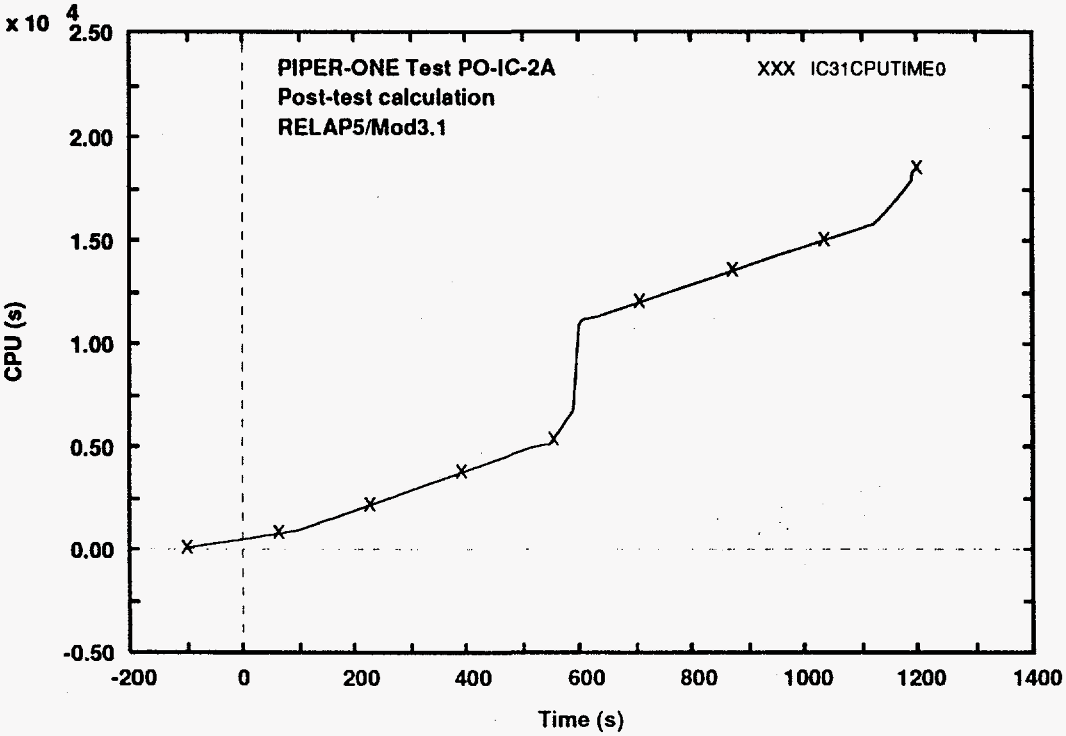

Fig. 41 - CPU versus transient time

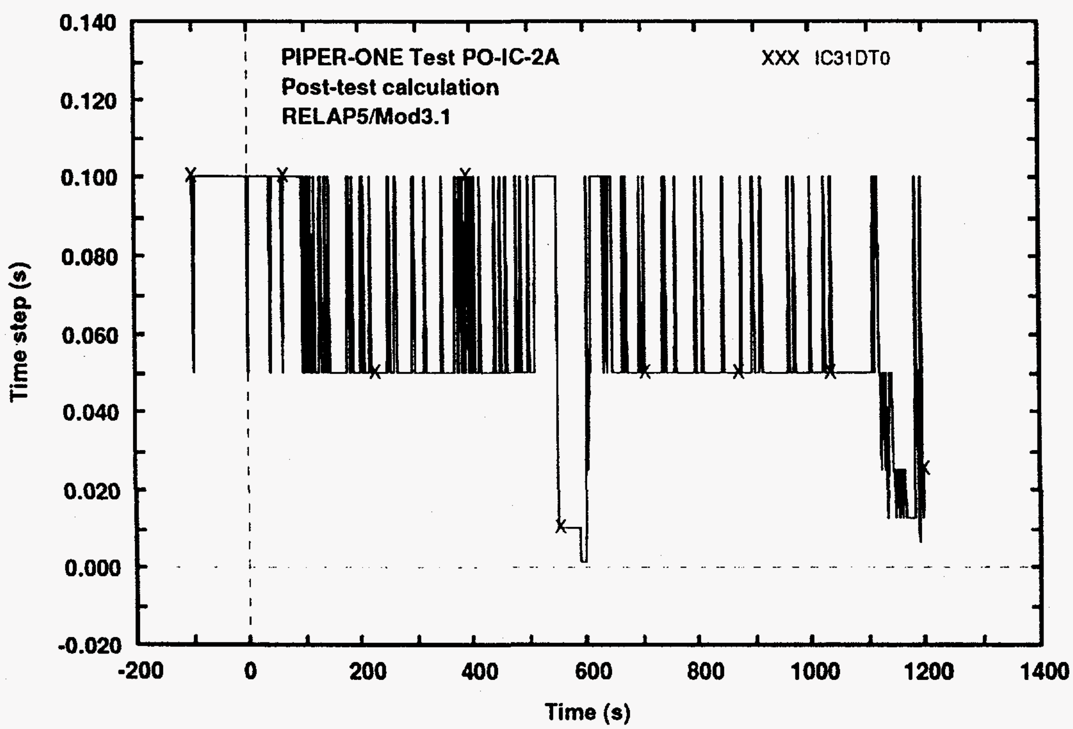

Fig. 42 - Time step versus transient time

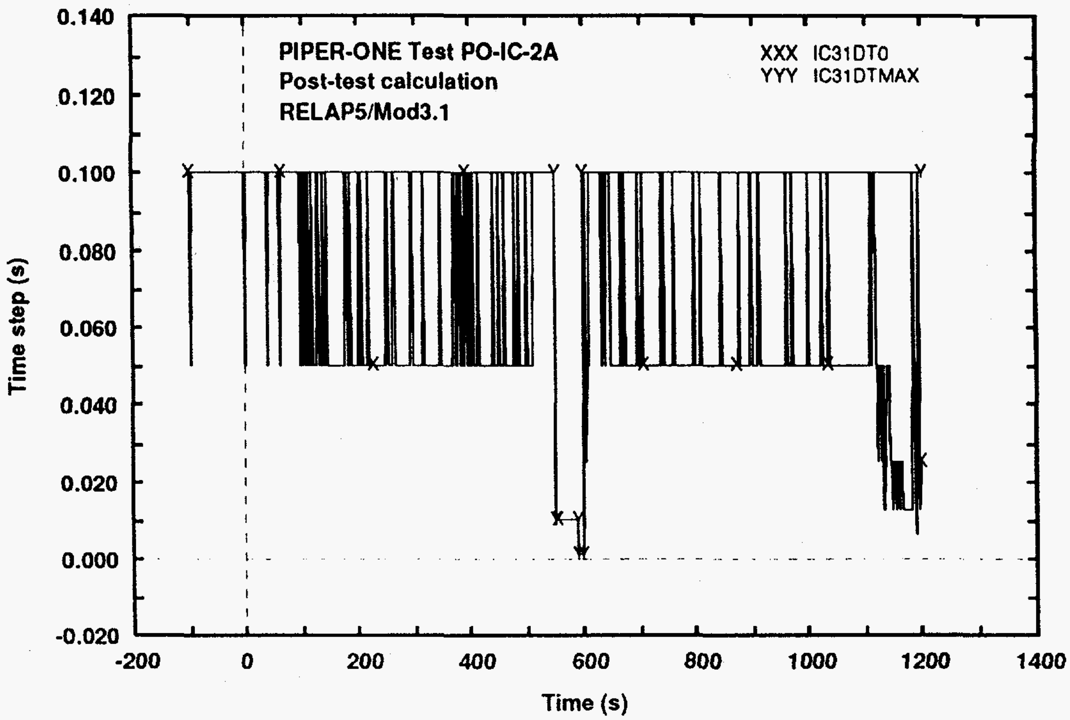

Fig. 43 - Time step and specified maximum time step versus transient time

APPENDIX 2:

IC 36 Results

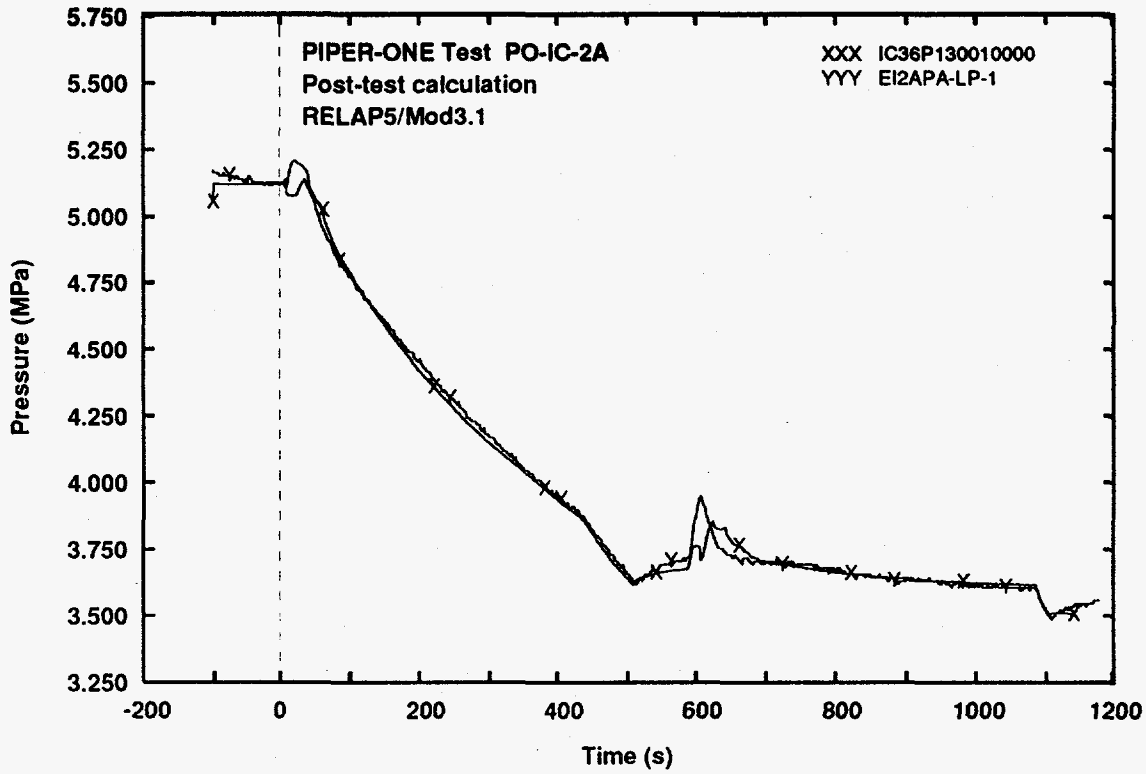

Fig. 1 - Measured and predicted trends of lower plenum pressure

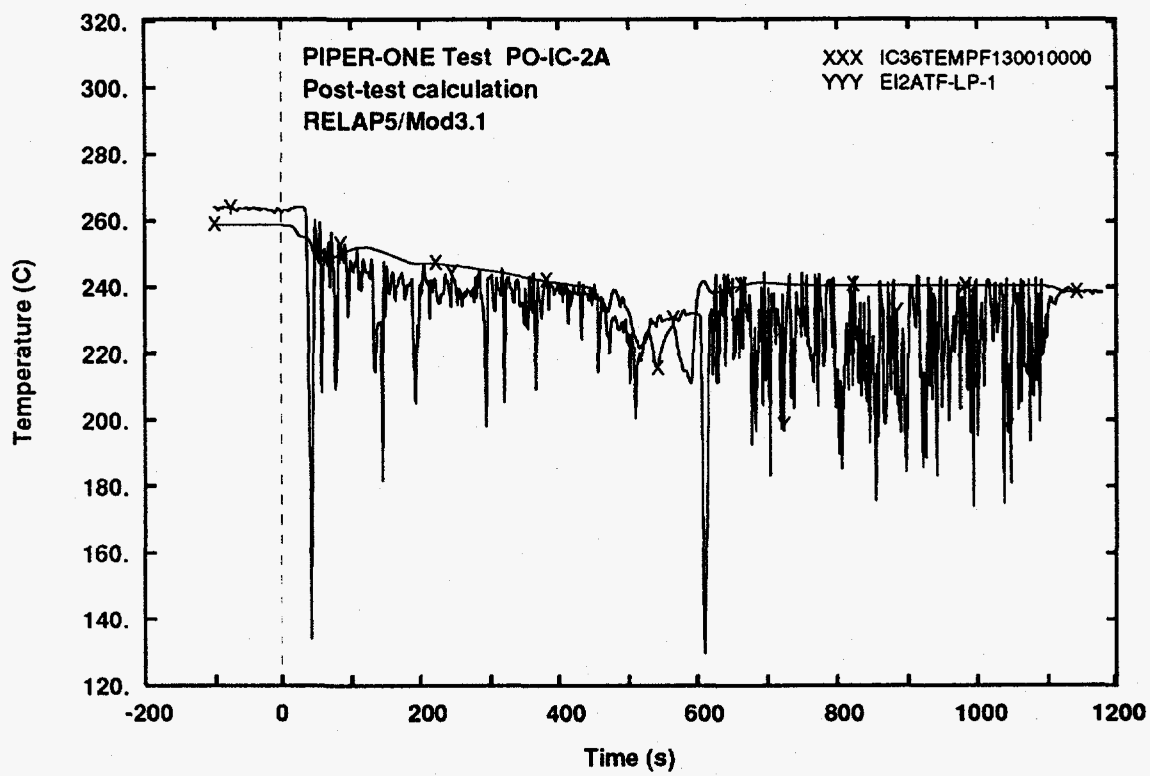

Fig. 2 - Measured and calculated trends of lower plenum temperature

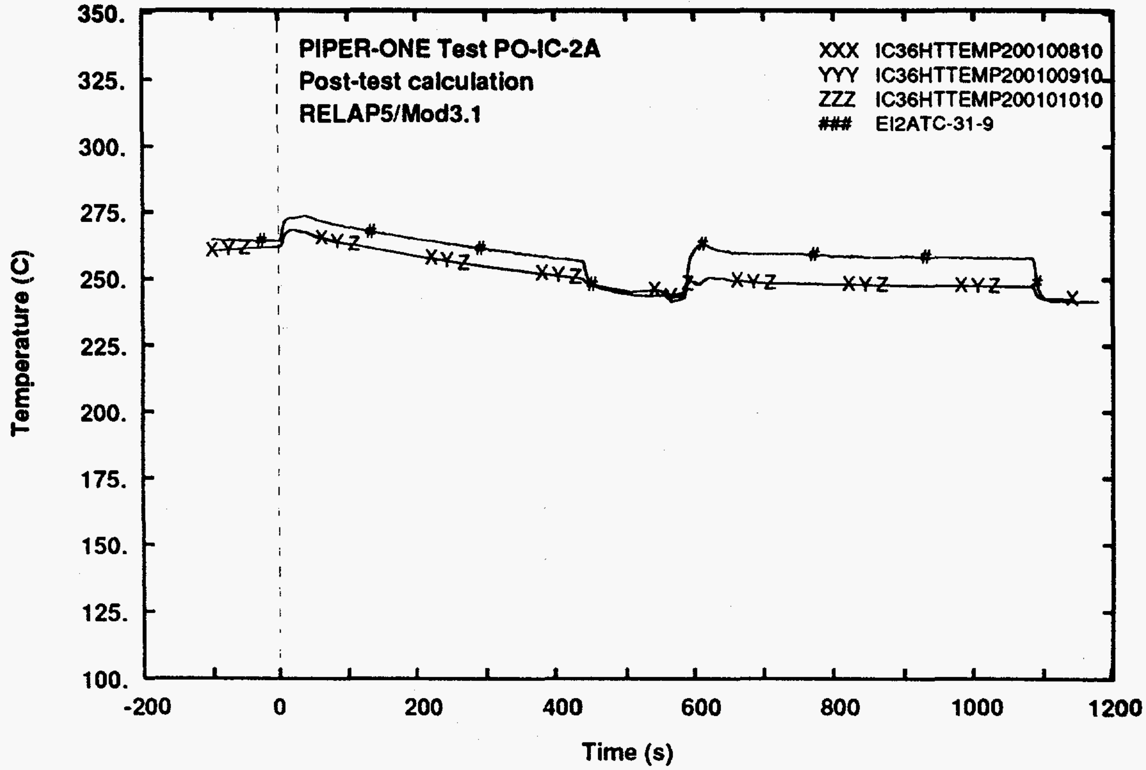

Fig. 3 - Measured and calculated trends of rod surface temperature (level 9)

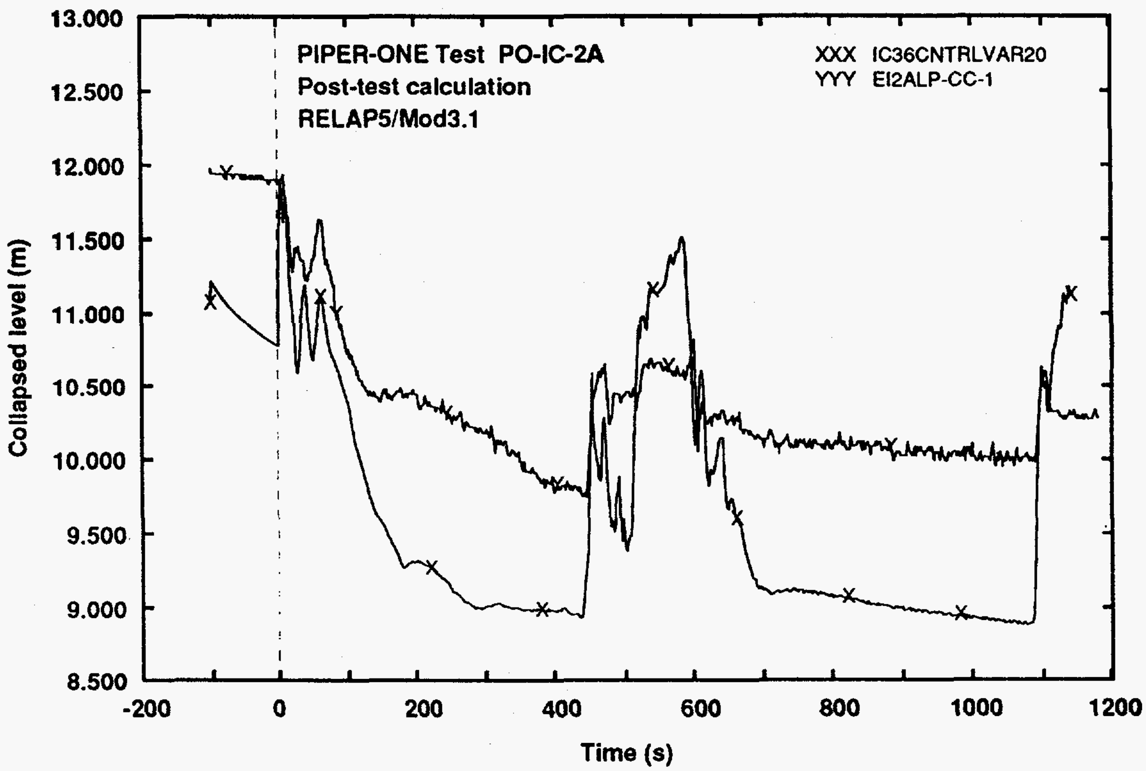

Fig. 4 - Measured and calculated trends of core level

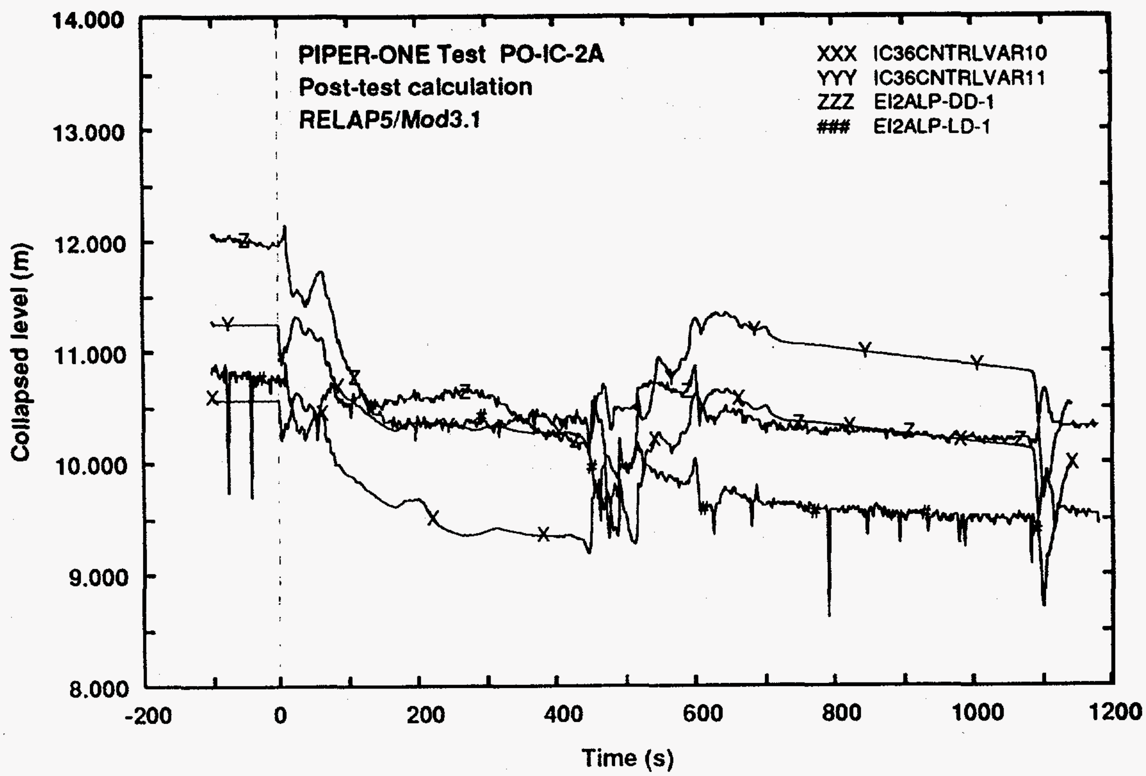

Fig. 5 - Measured and calculated trends of downcomer level

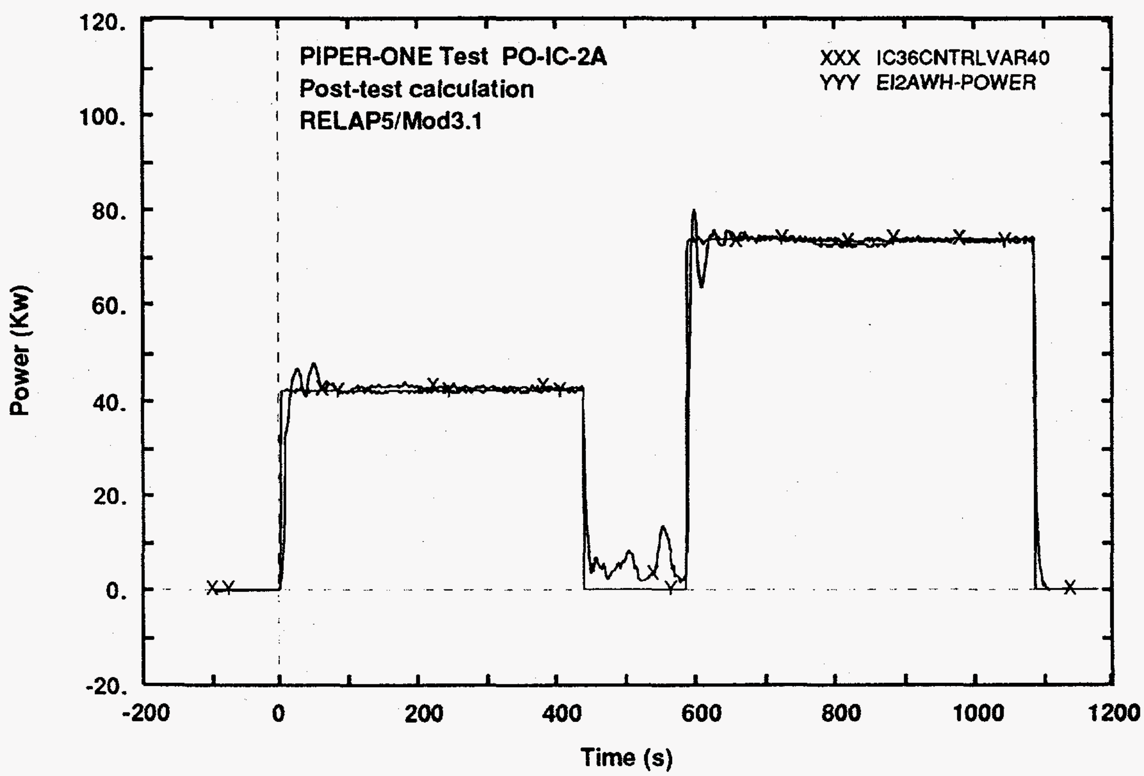

Fig. 6 - Measured and calculated trends of core power

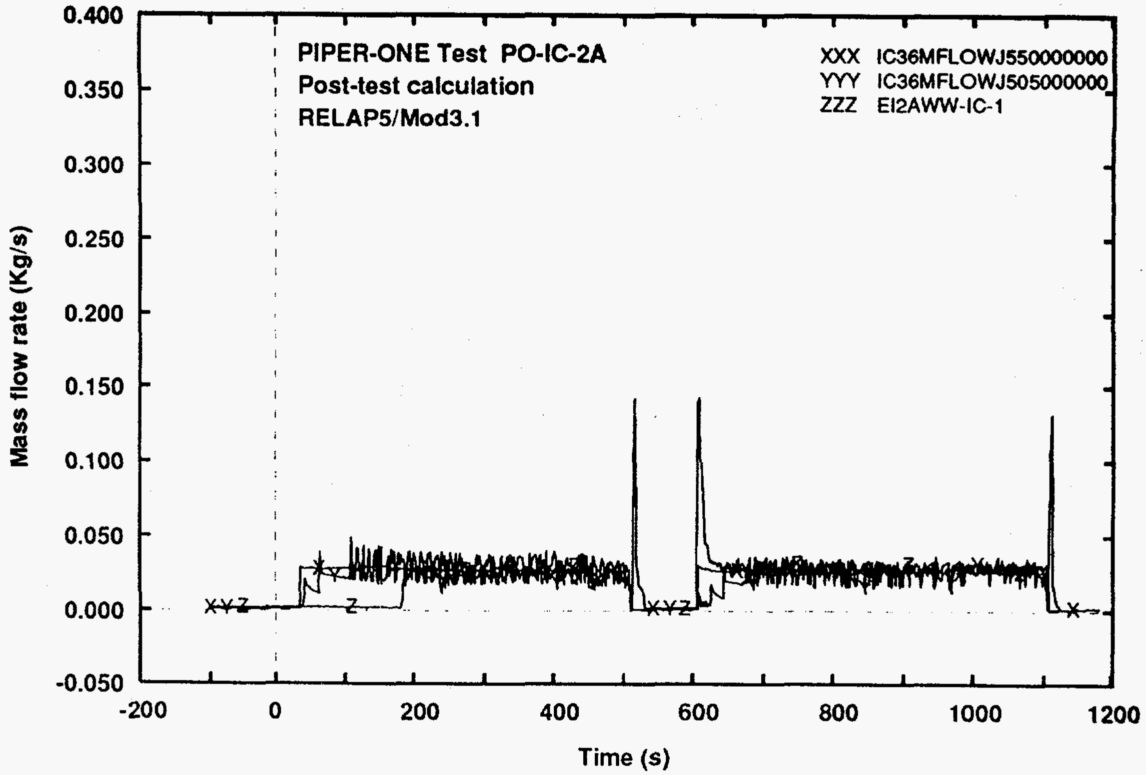

Fig. 7 - Measured and calculated trends of IC mass flow rate

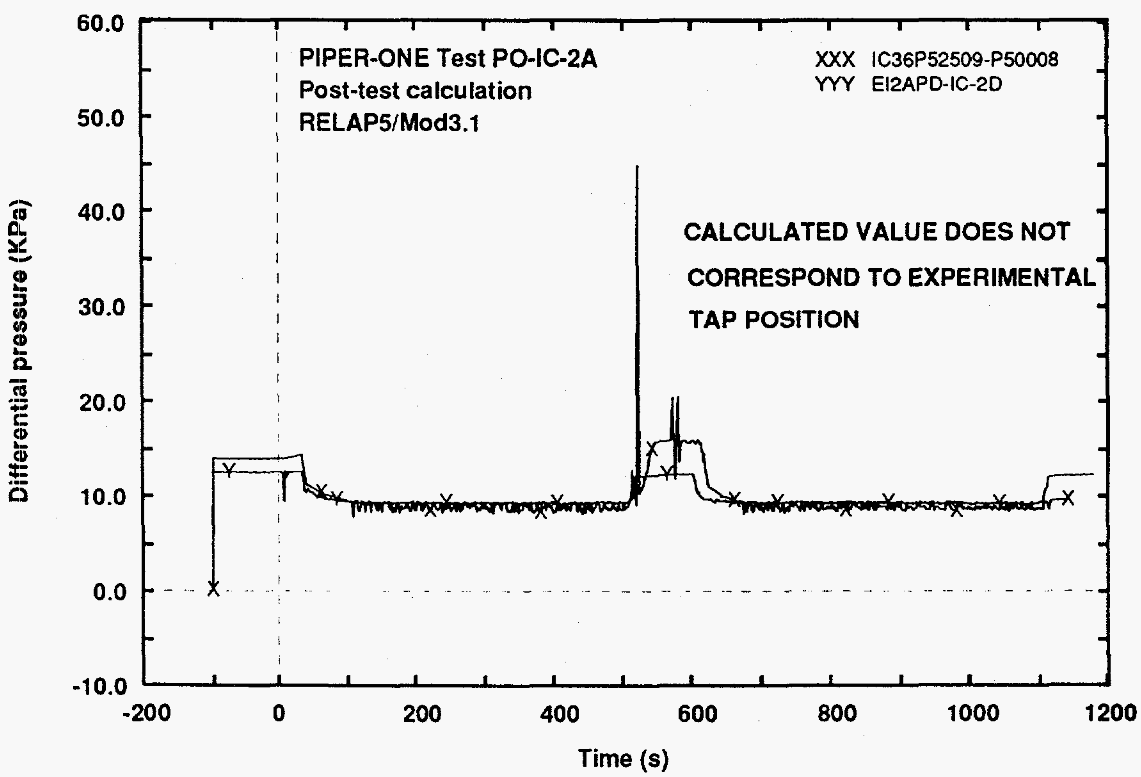

Fig. 8 - Measured and calculated trends of IC differential pressure

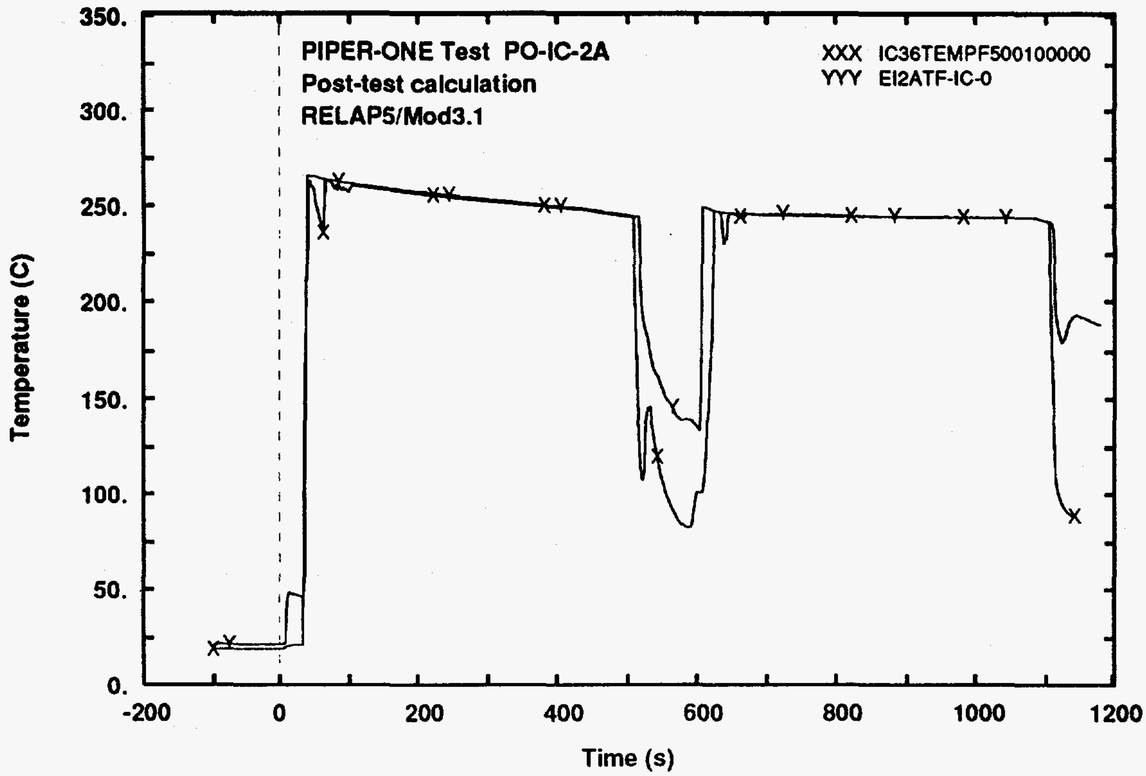

Fig. 9 - Measured and calculated trends of IC inlet fluid temperature

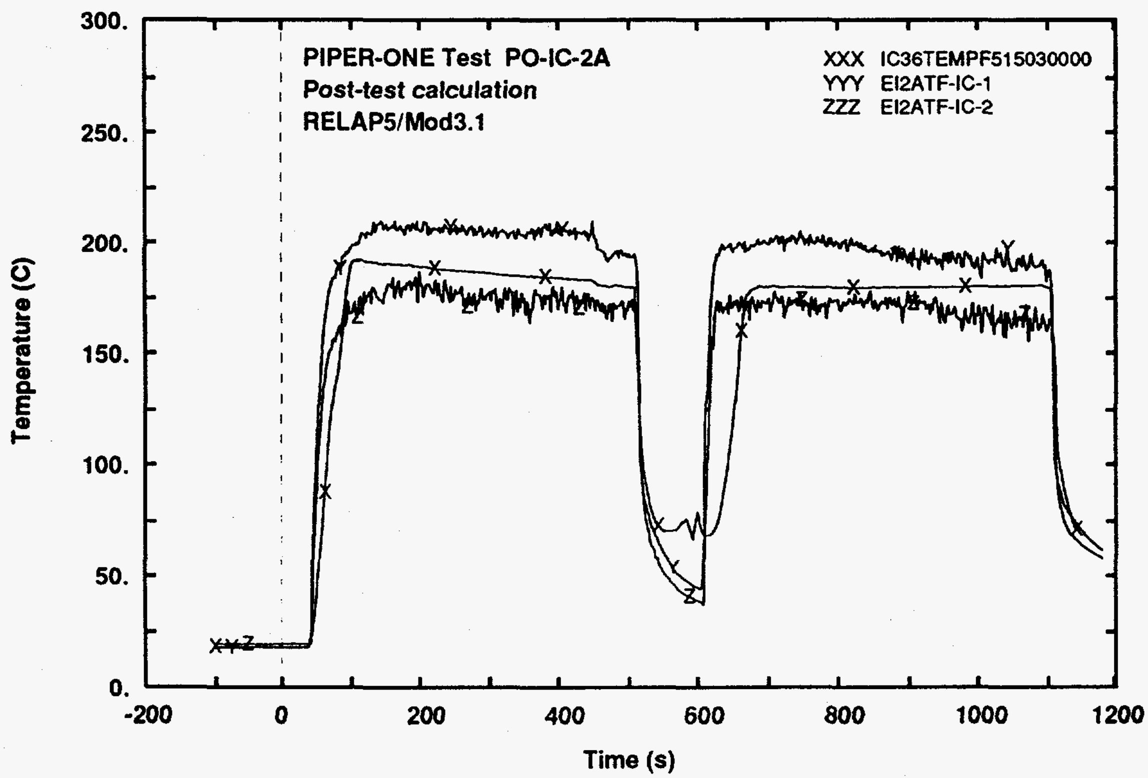

Fig. 10 - Measured and calculated trends of IC tubes fluid temperature
(middle elevation)

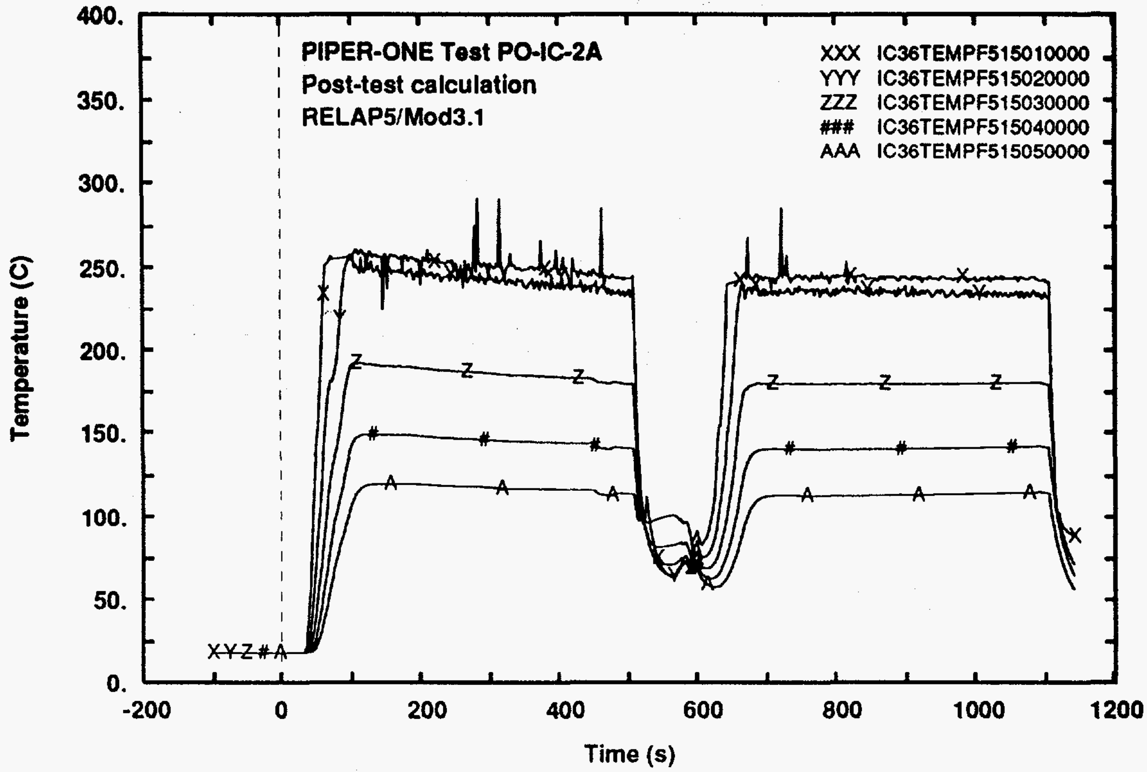

Fig. 11 - Calculated trends of IC tubes fluid temperature along the axis

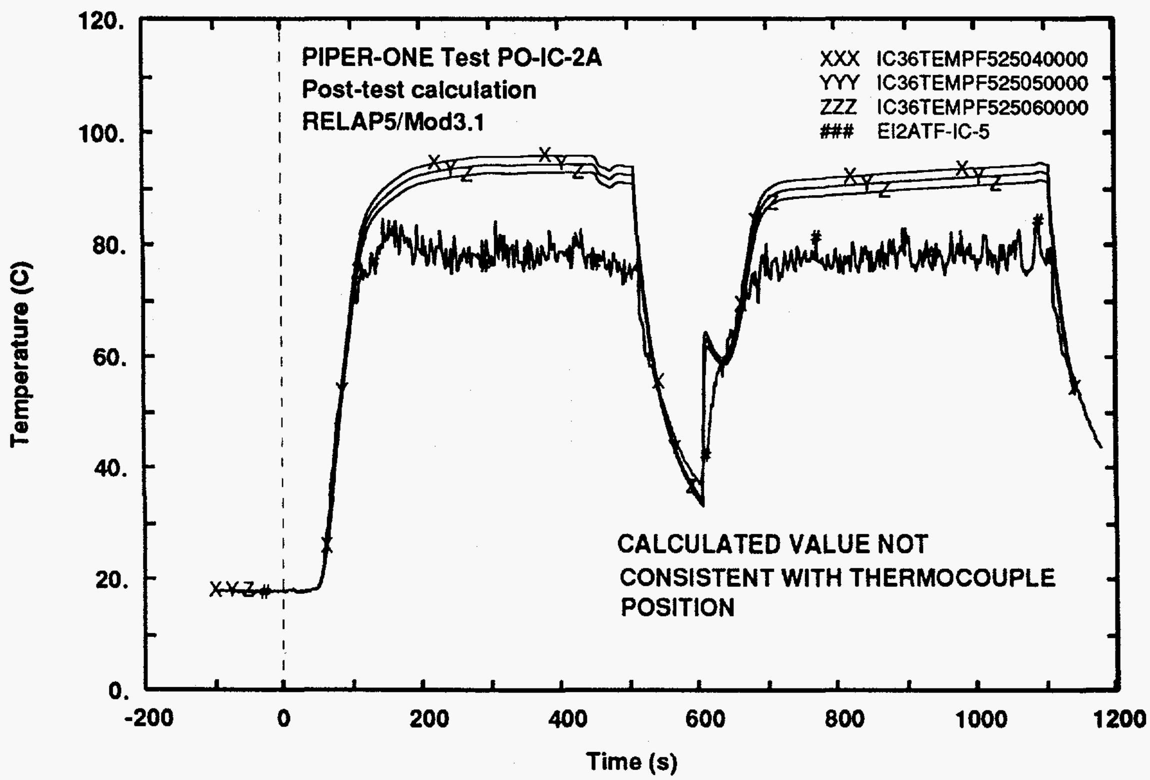

Fig. 12 - Measured and calculated trends of IC outlet fluid temperature

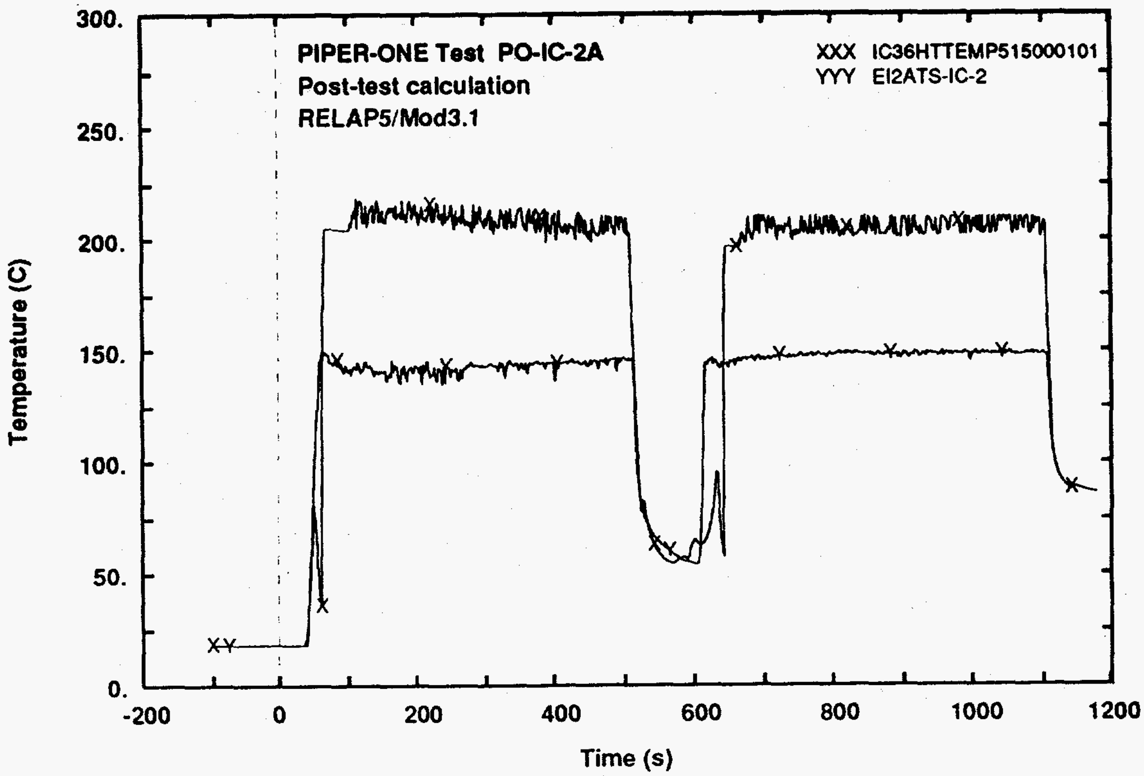

Fig. 13 - Measured and calculated trends of IC tubes wall surface temperature (internal side top elevation)

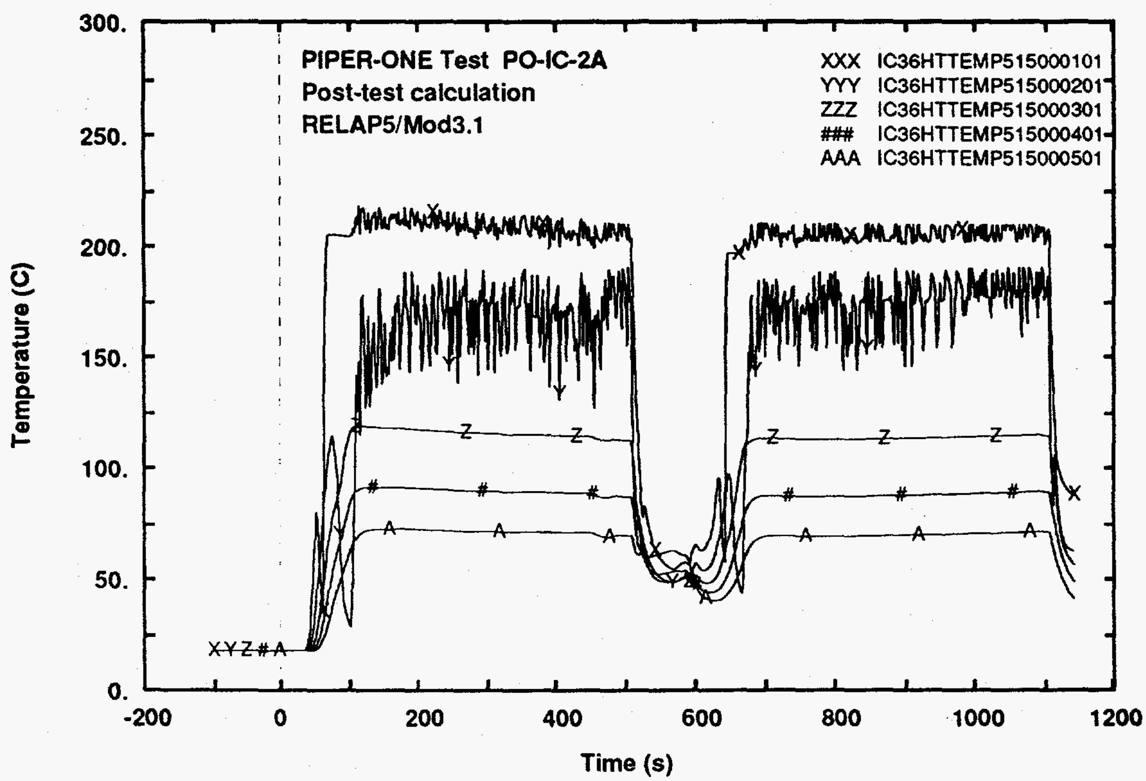

Fig. 14 - Calculated trends of IC tubes wall surface temperature along the axis (internal side)

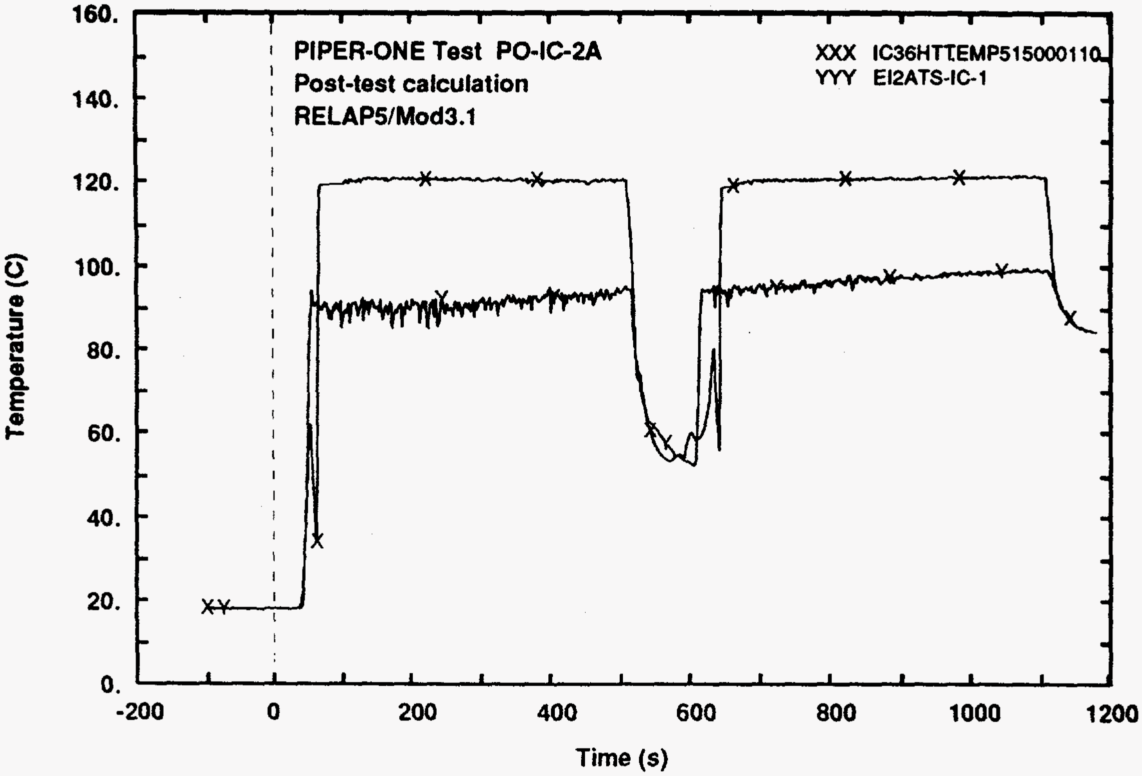

Fig. 15 - Measured and calculated trends of IC tubes wall surface temperature (external side top elevation)

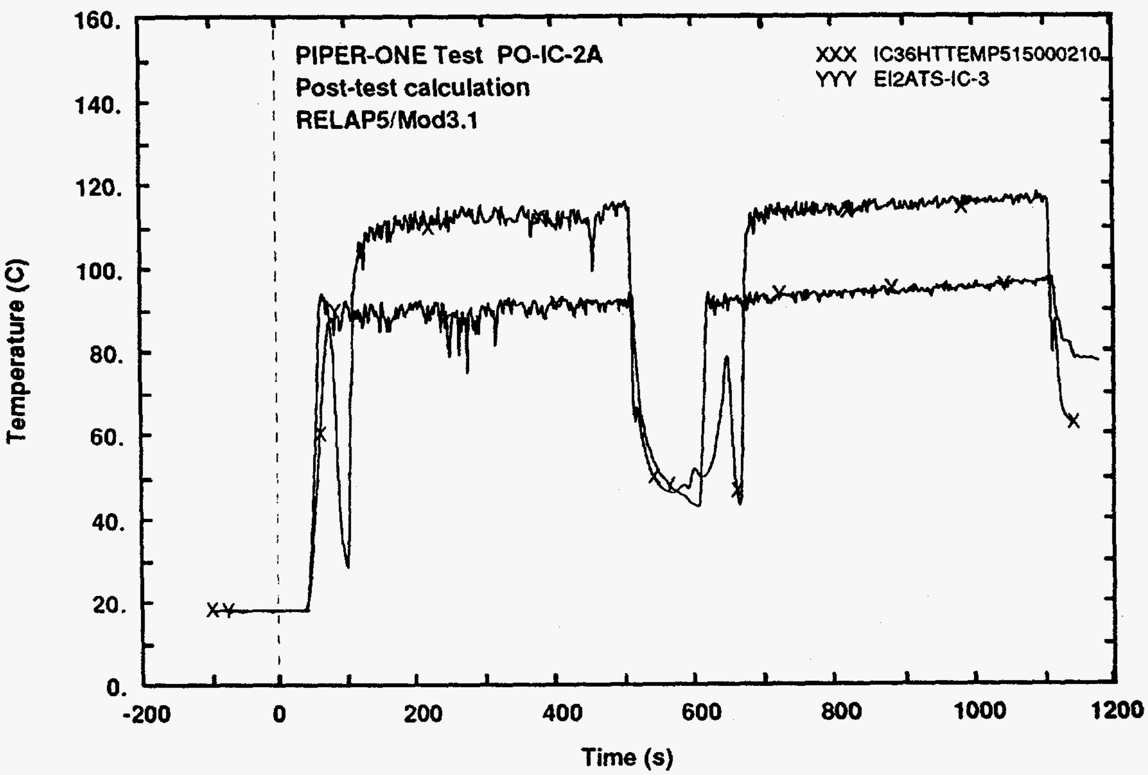

Fig. 16 - Measured and calculated trends of IC tubes wall surface temperature (external side level 3)

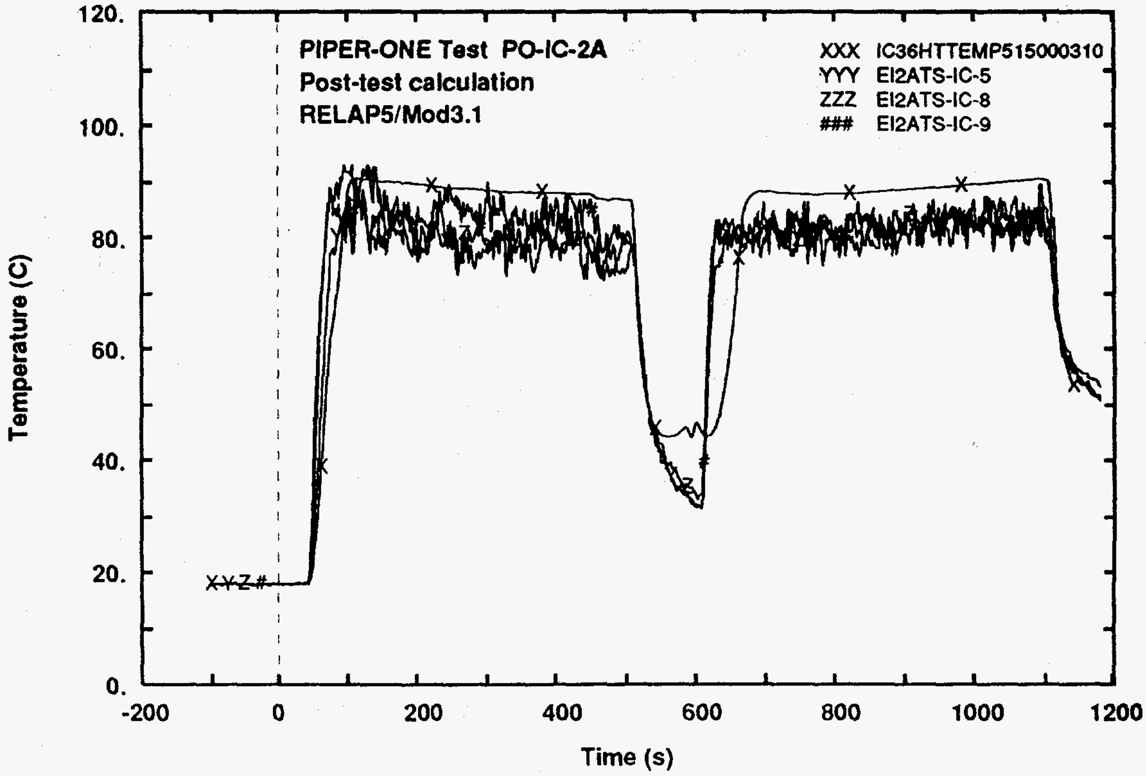

Fig. 17 - Measured and calculated trends of IC tubes wall surface temperature (external side middle elevation)

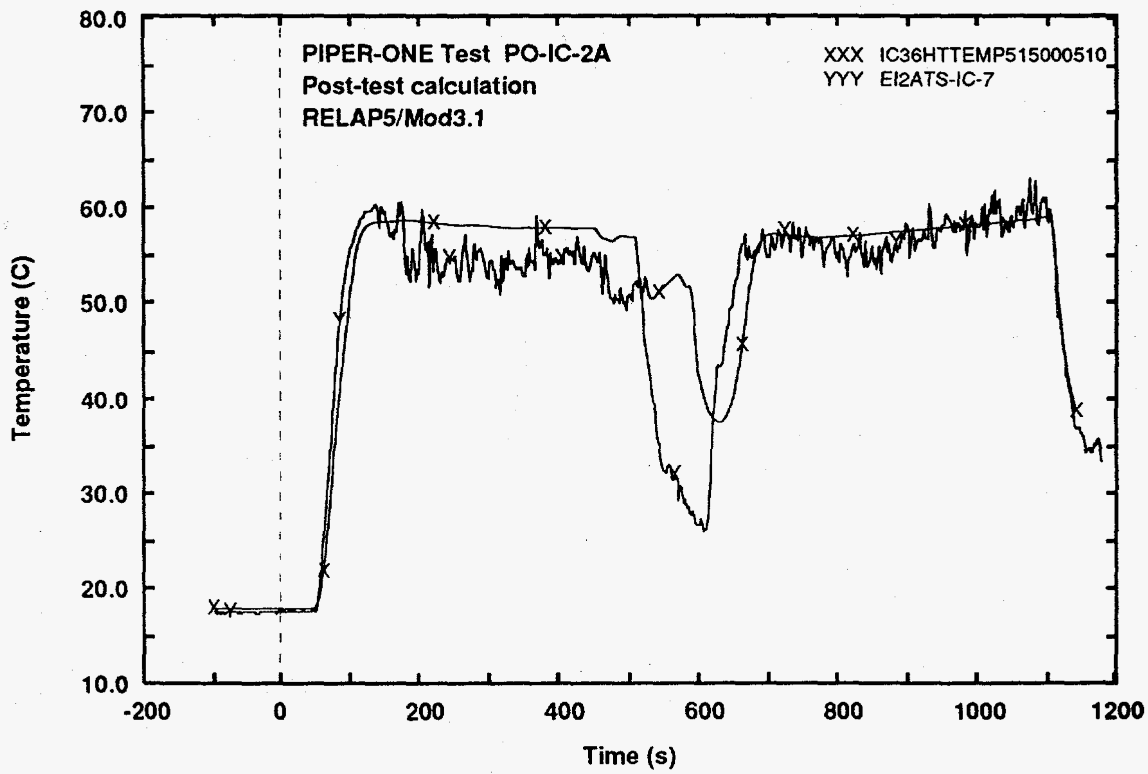

Fig. 18 - Measured and calculated trends of IC tubes wall surface temperature (external side bottom elevation)

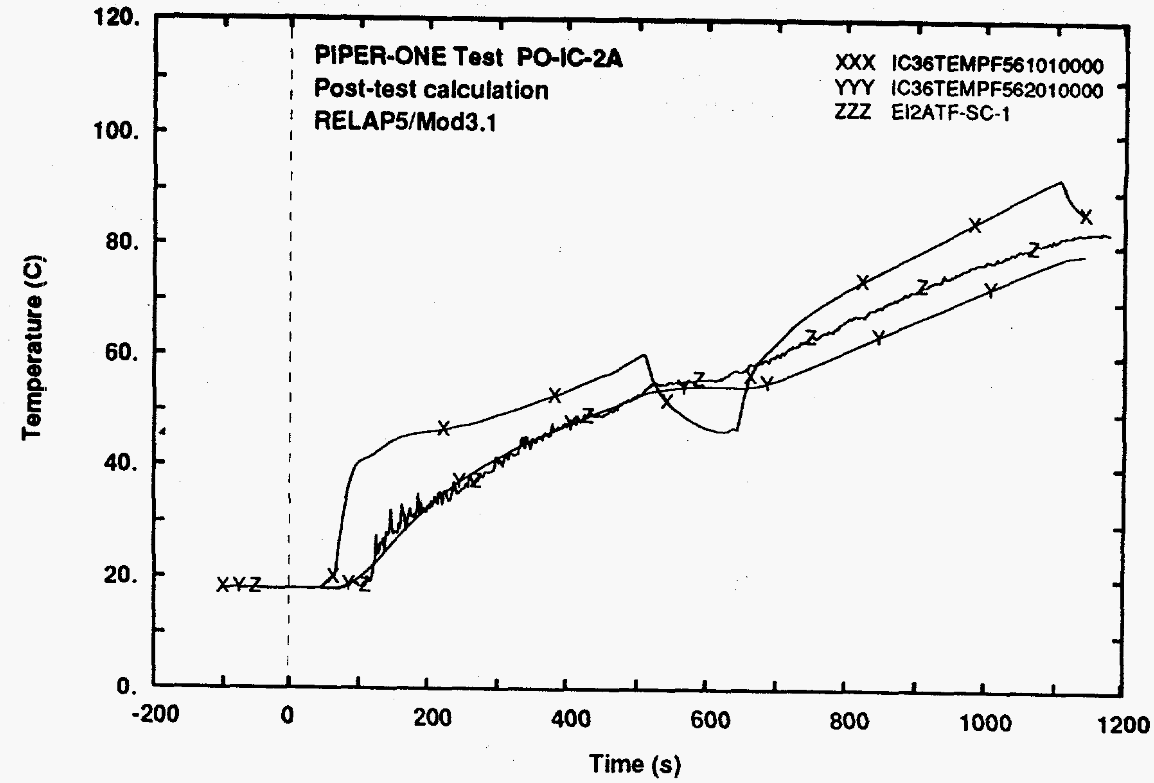

Fig. 19 - Measured and calculated trends of IC internal pool fluid temperature (top level)

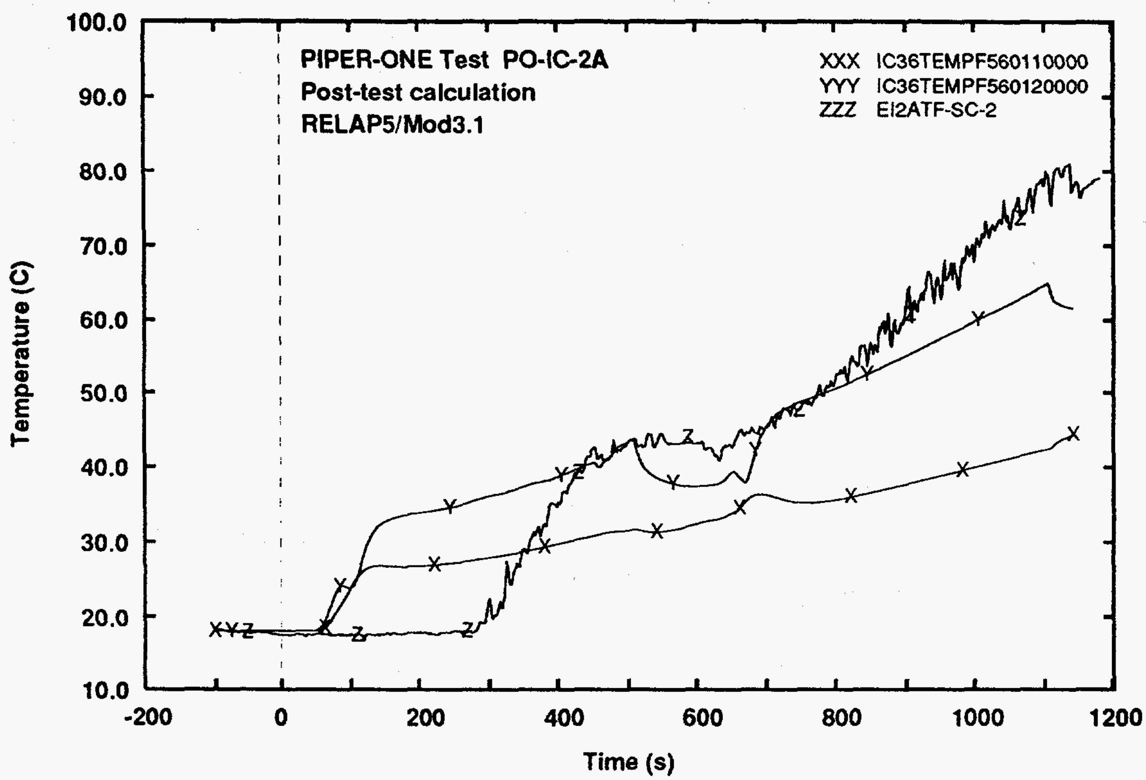

Fig. 20 - Measured and calculated trends of IC internal pool fluid temperature (level 2)

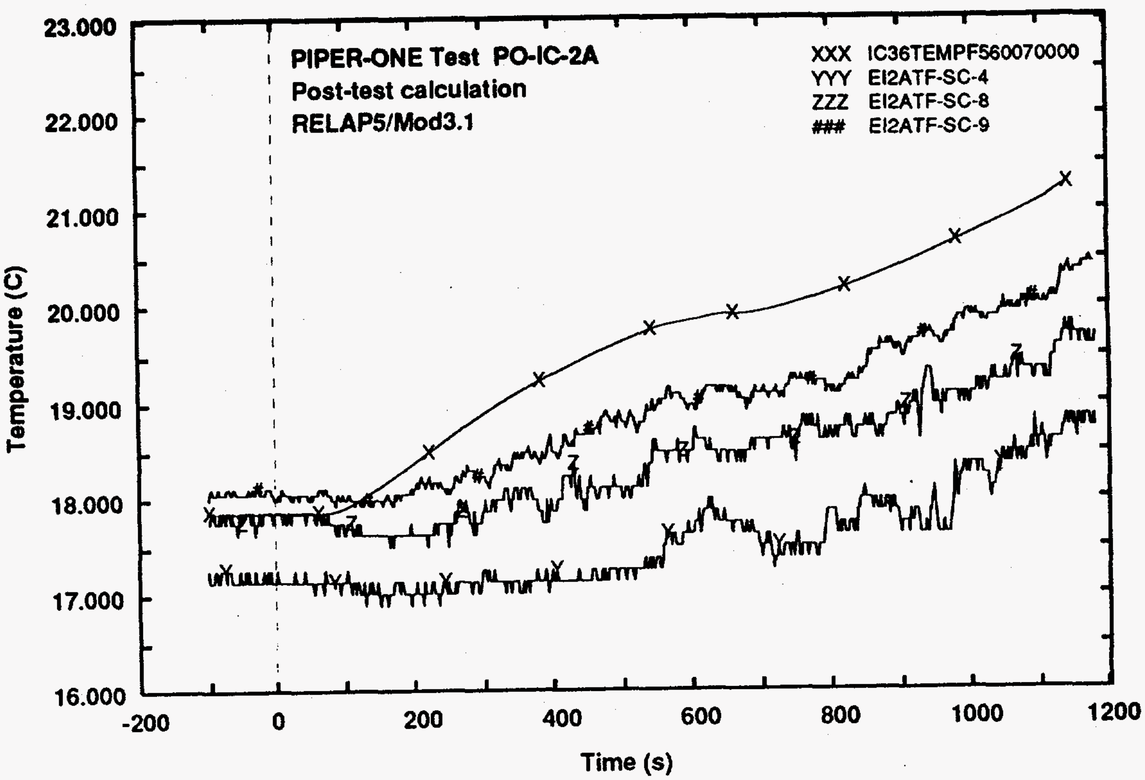

Fig. 21 - Measured and calculated trends of IC internal pool fluid temperature (middle level)

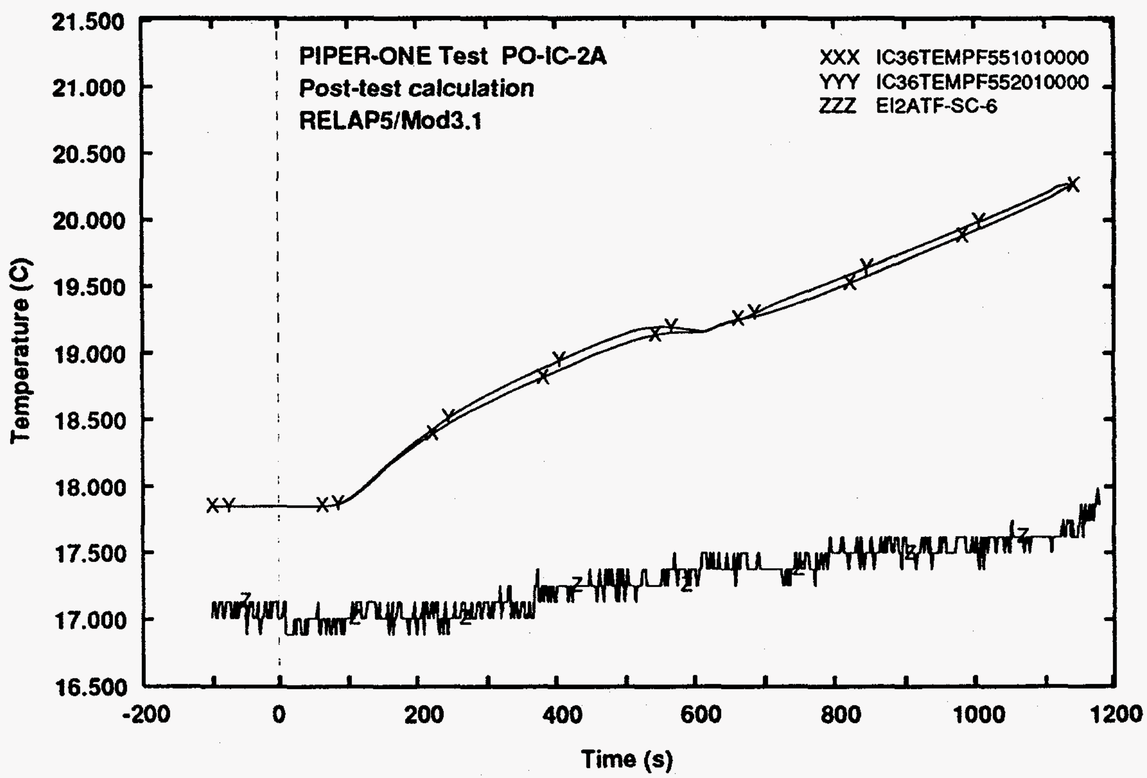

Fig. 22 - Measured and calculated trends of IC internal pool fluid temperature (bottom level)

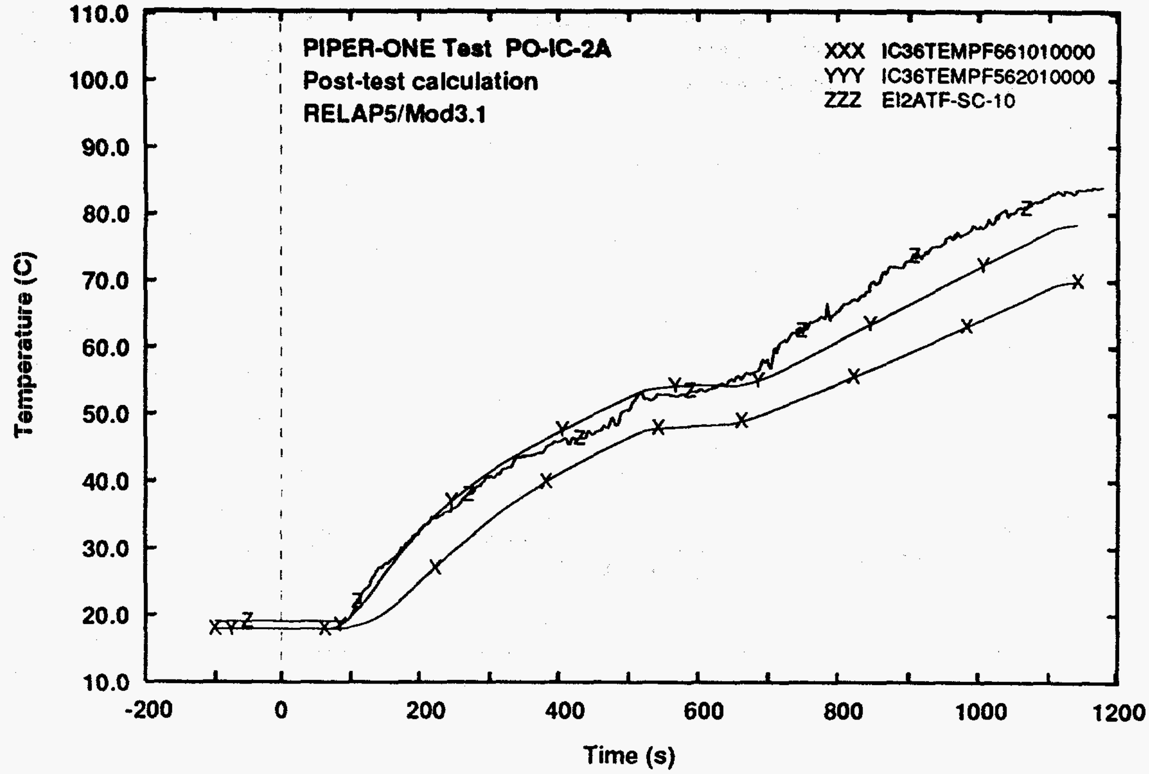

Fig. 23 - Measured and calculated trends of IC external pool fluid temperature (top level)

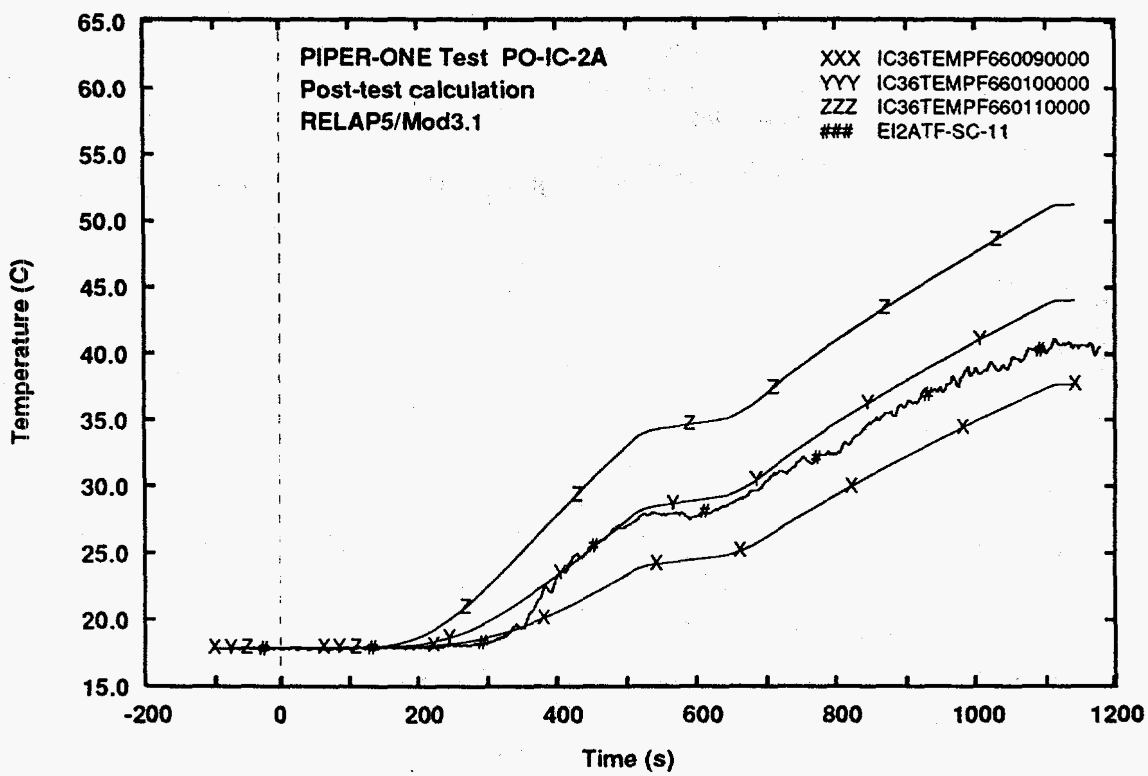

Fig. 24 - Measured and calculated trends of IC external pool fluid temperature (level 11)

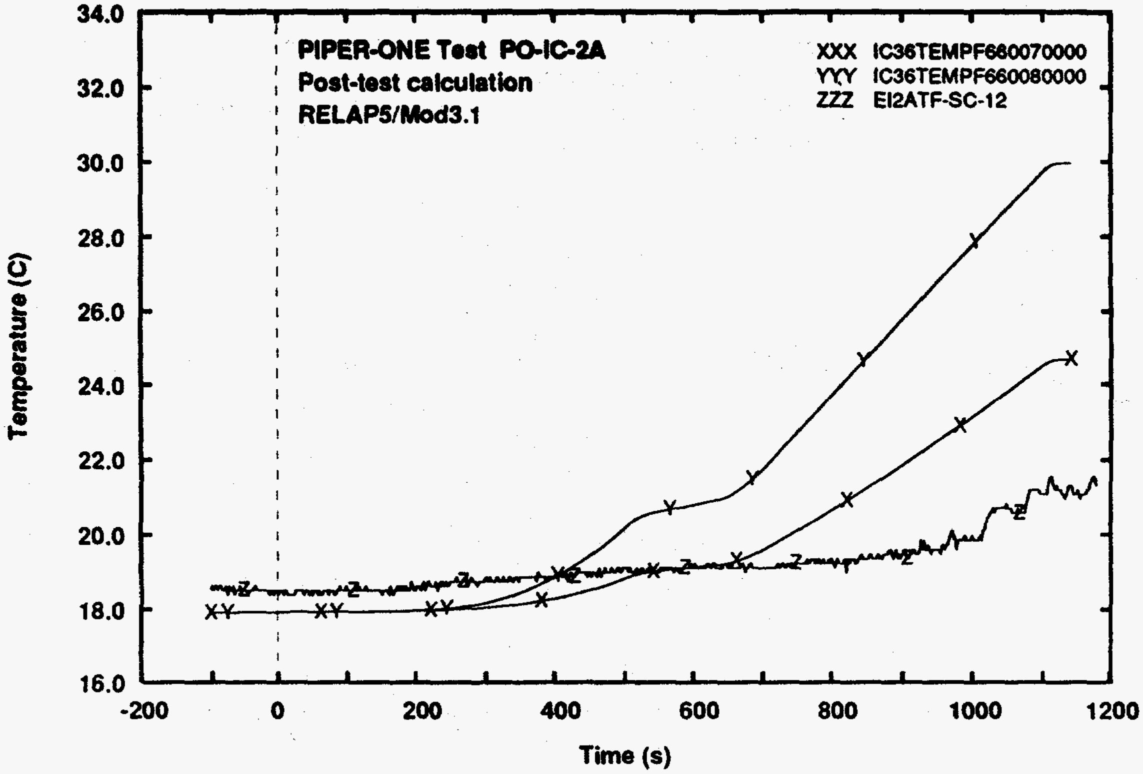

Fig. 25 - Measured and calculated trends of IC external pool fluid temperature (middle level)

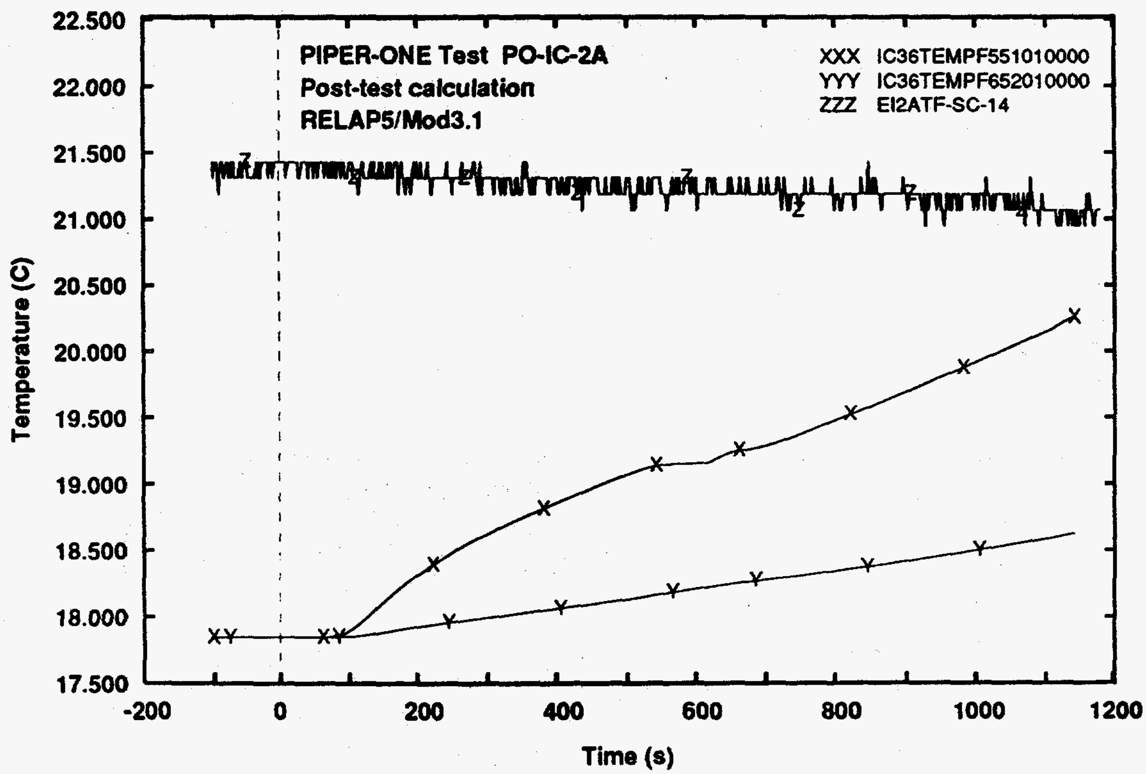

Fig. 26 - Measured and calculated trends of IC external pool fluid temperature (bottom level)

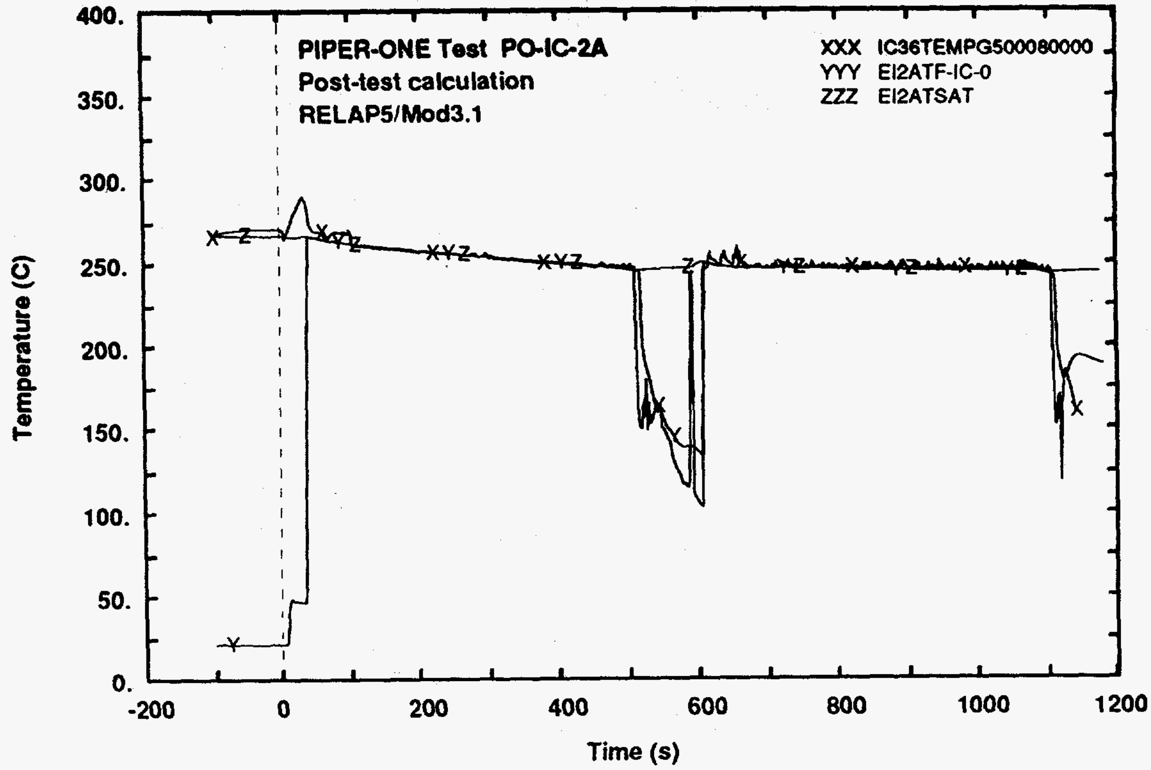

Fig. 27 - Measured and calculated trends of steam temperature at IC inlet compared with experimental saturated temperature

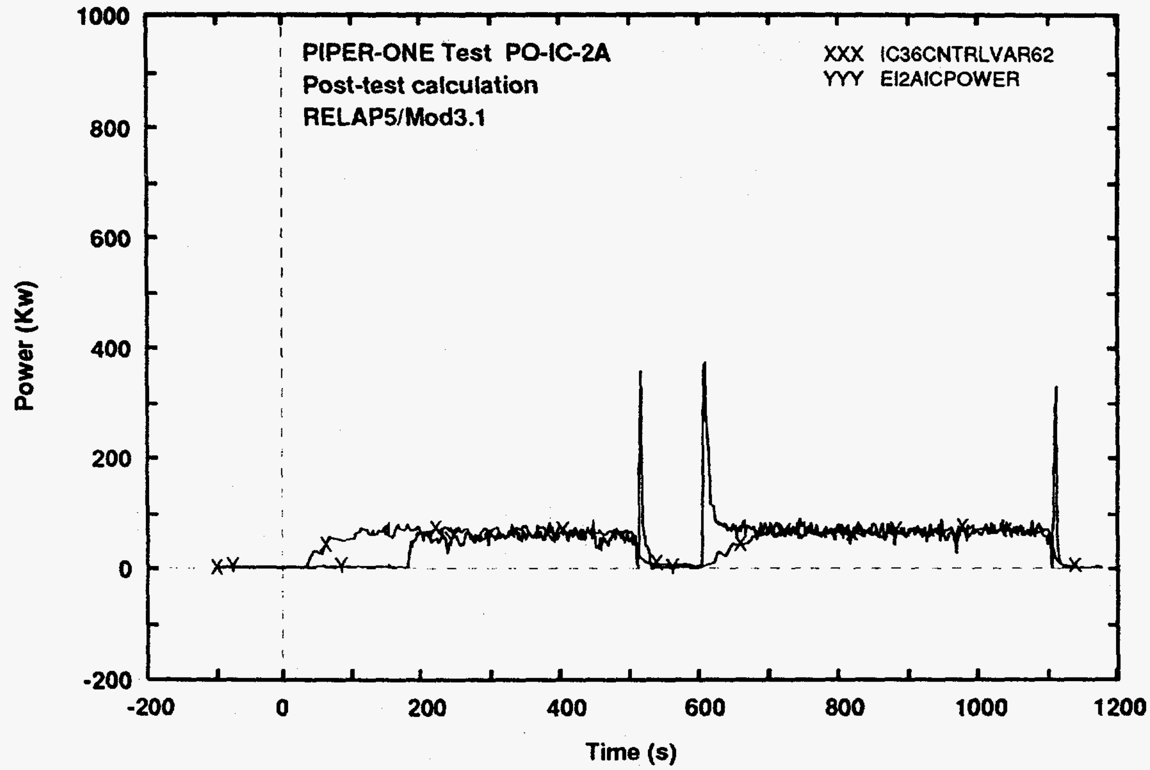

Fig. 28 - Measured and calculated trends of IC exchanged power

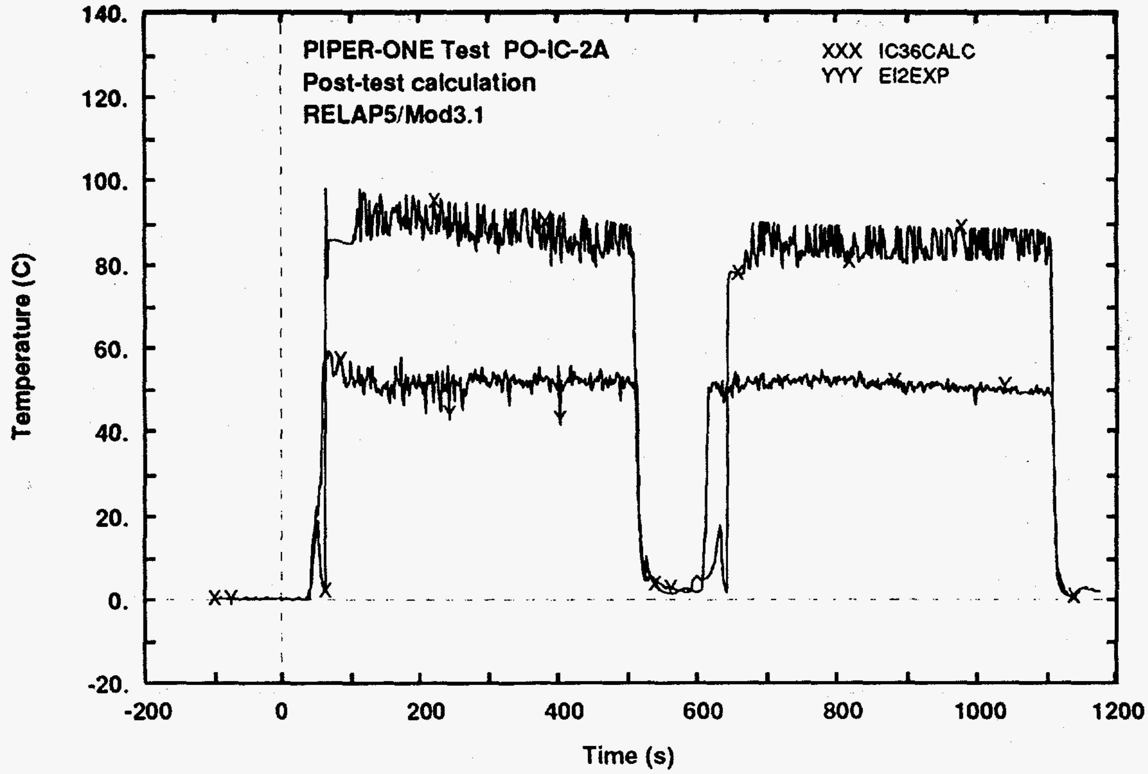

Fig. 29 - Measured and calculated trends of temperature difference between internal and external side of IC tubes wall (top elevation)

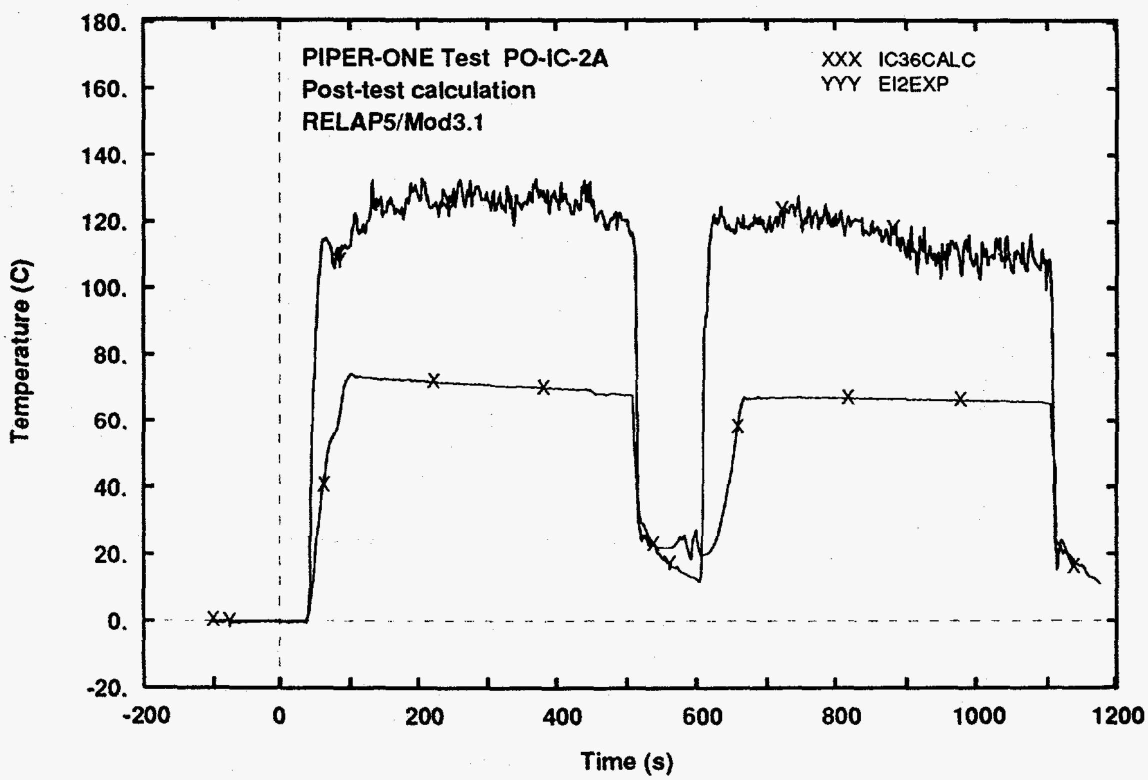

Fig. 30 - Measured and calculated trends of temperature difference between IC fluid and external side of IC tubes wall (middle elevation)

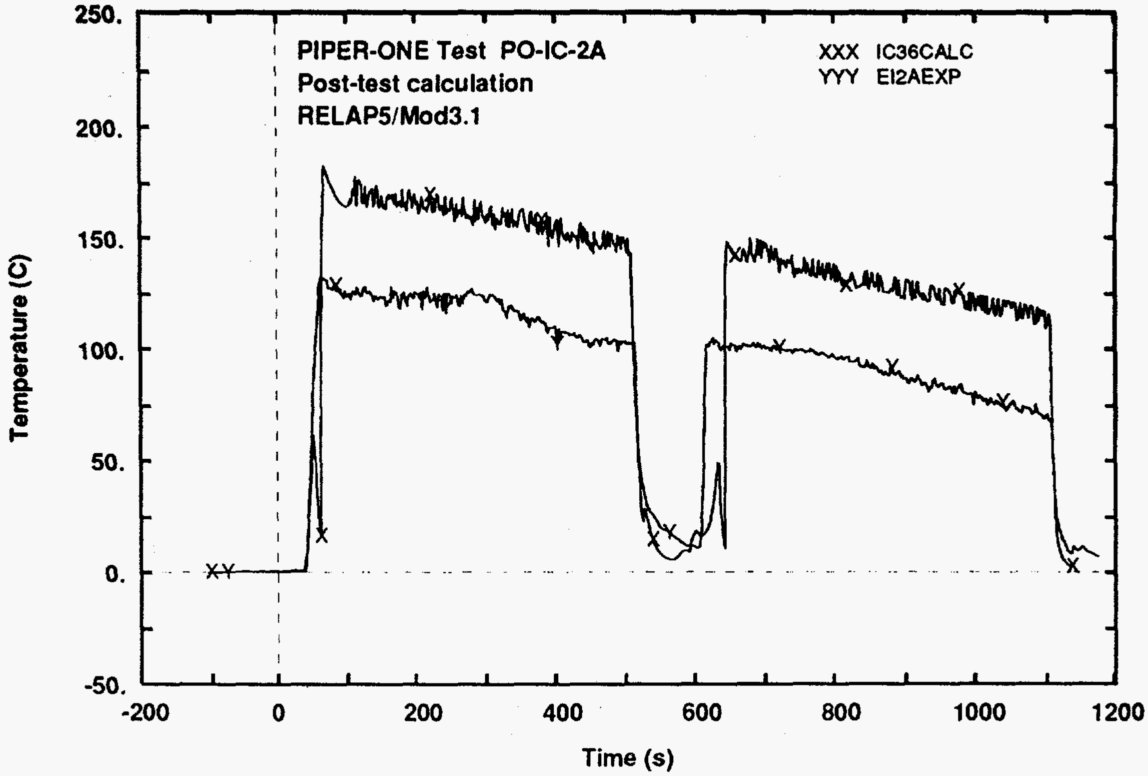

Fig. 31 - Measured and calculated trends of temperature difference between internal side of IC tubes wall and IC pool fluid temperature (top elevation)

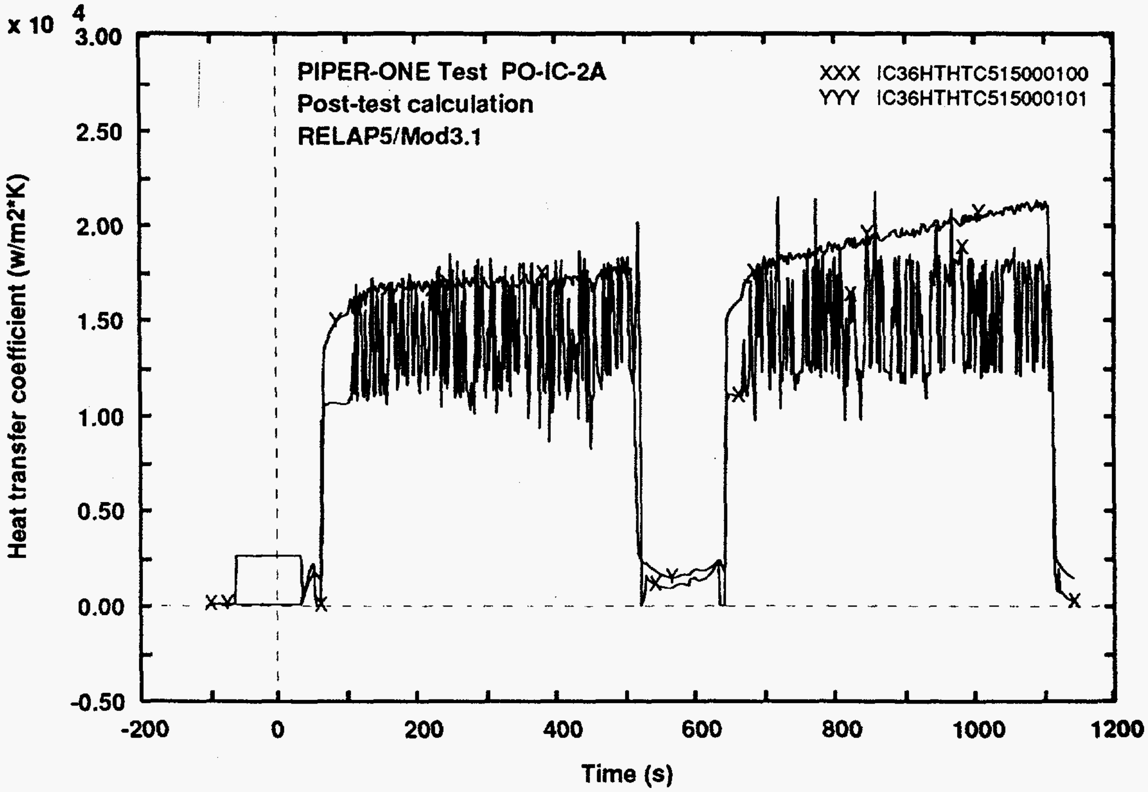

Fig. 32 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (top elevation)

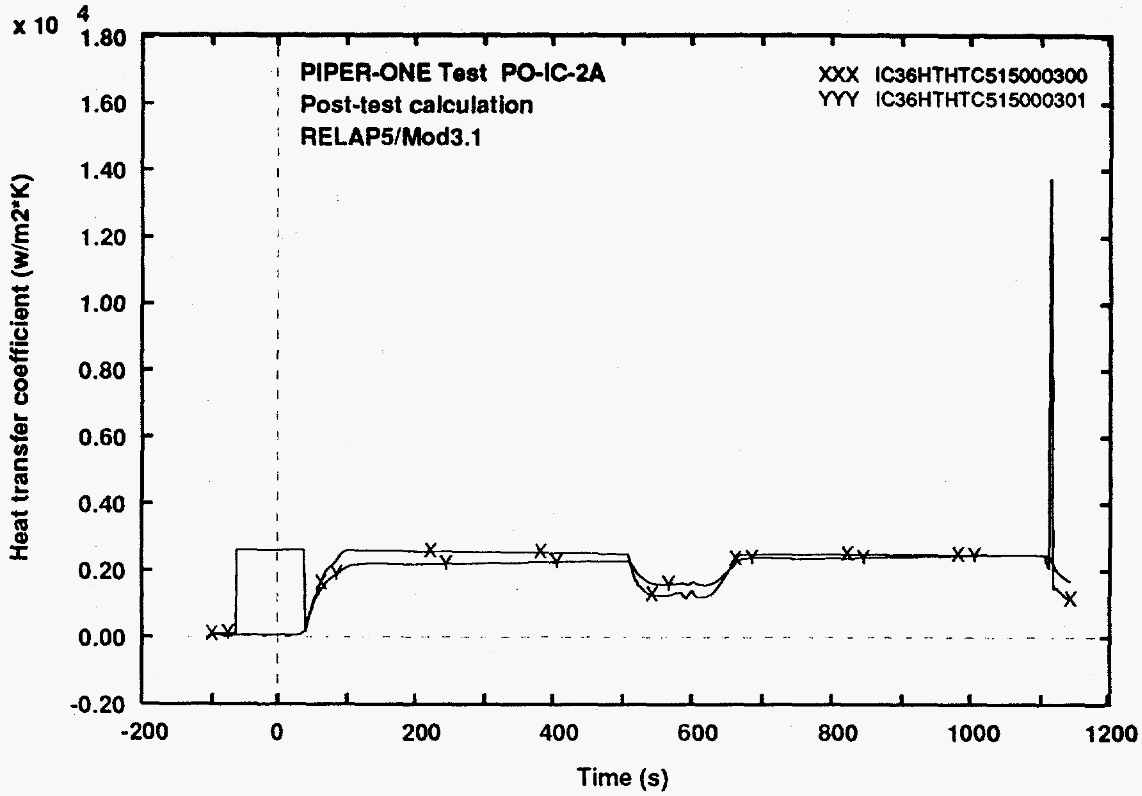

Fig. 33 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (middle elevation)

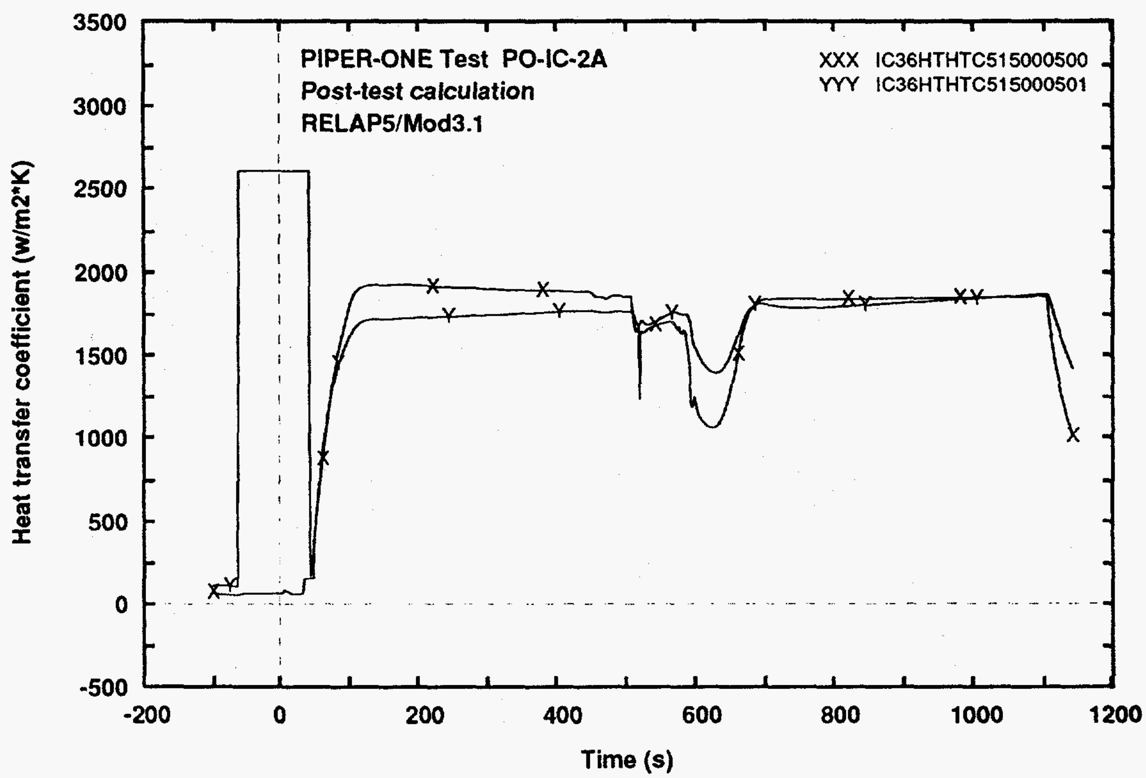

Fig. 34 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (bottom elevation)

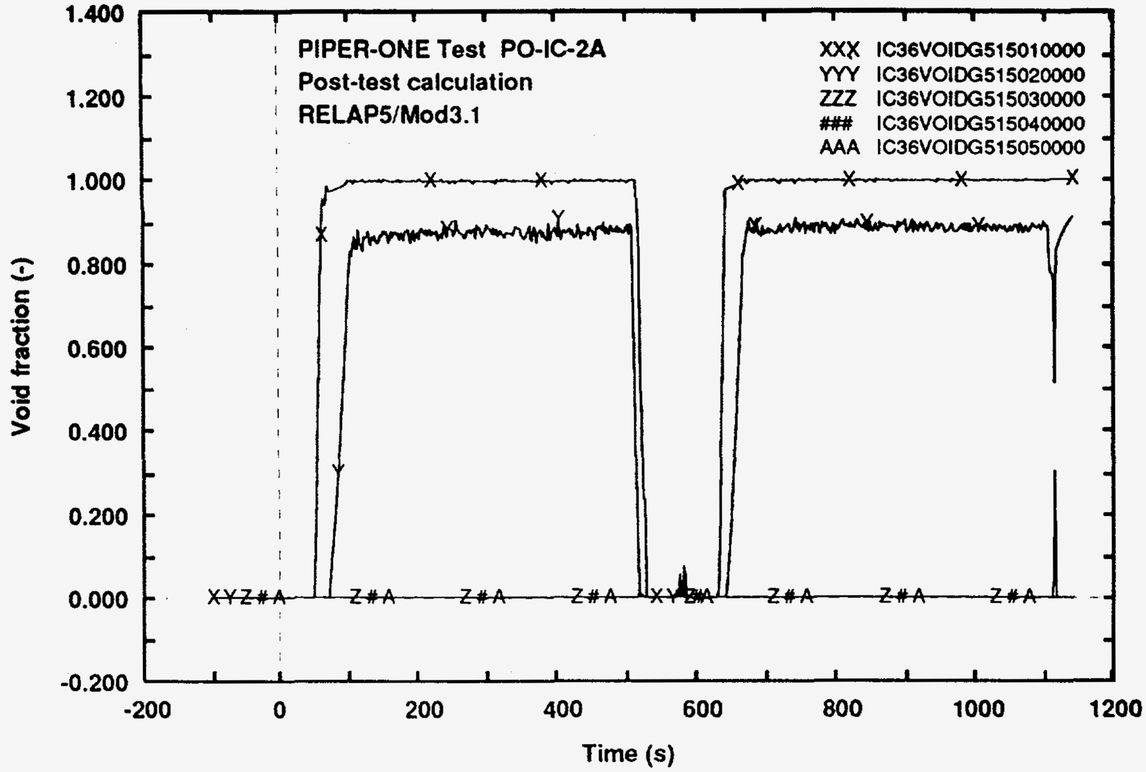

Fig. 35 - Calculated trends of IC tubes void fraction along the axis

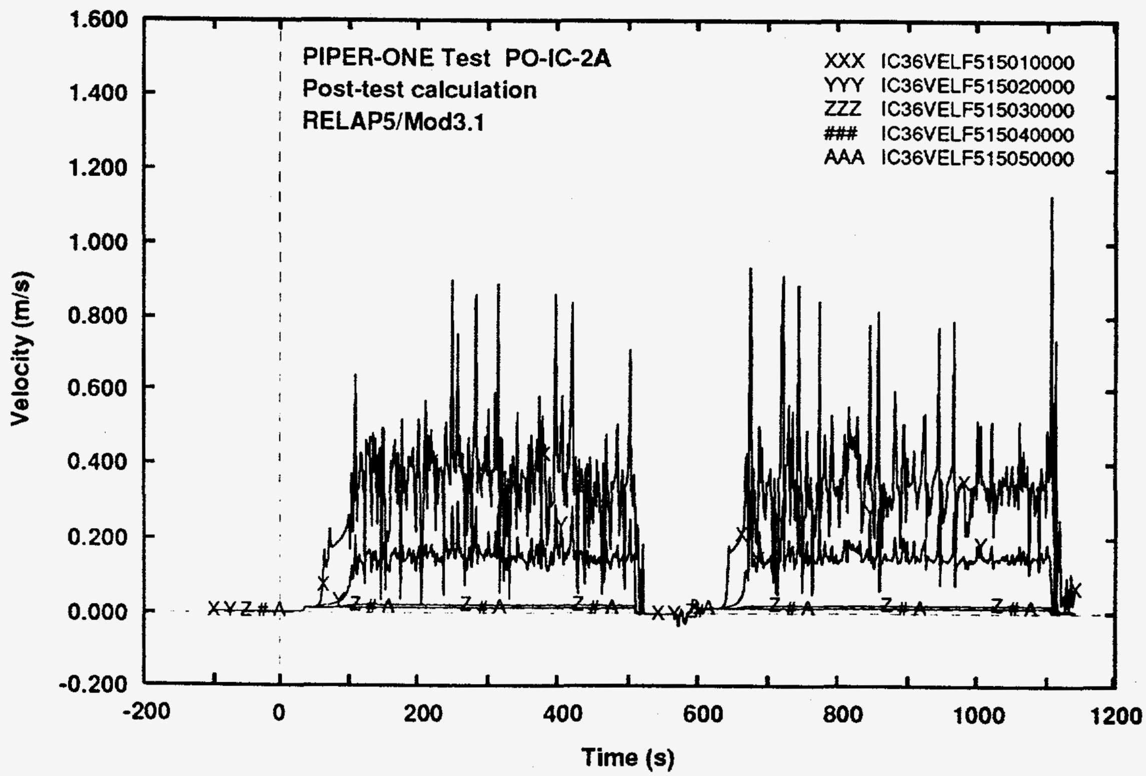

Fig. 36 - Calculated trends of IC tubes liquid velocity along the axis

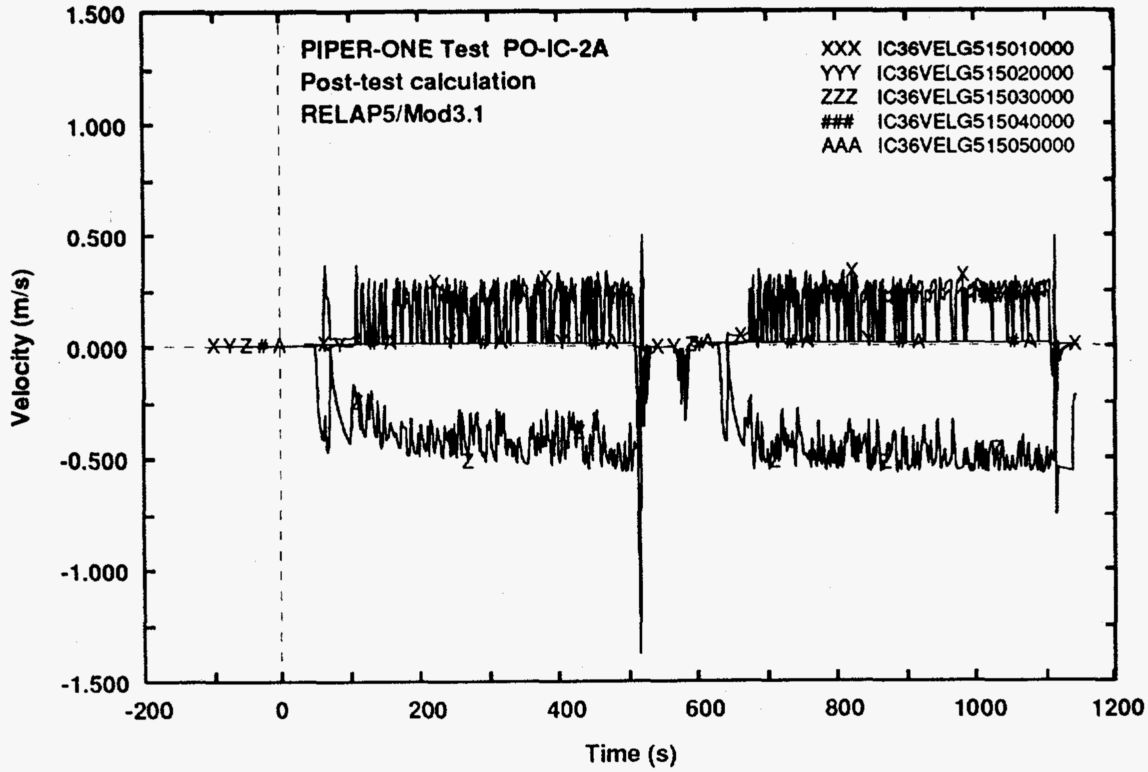

Fig. 37 - Calculated trends of IC tubes steam velocity along the axis

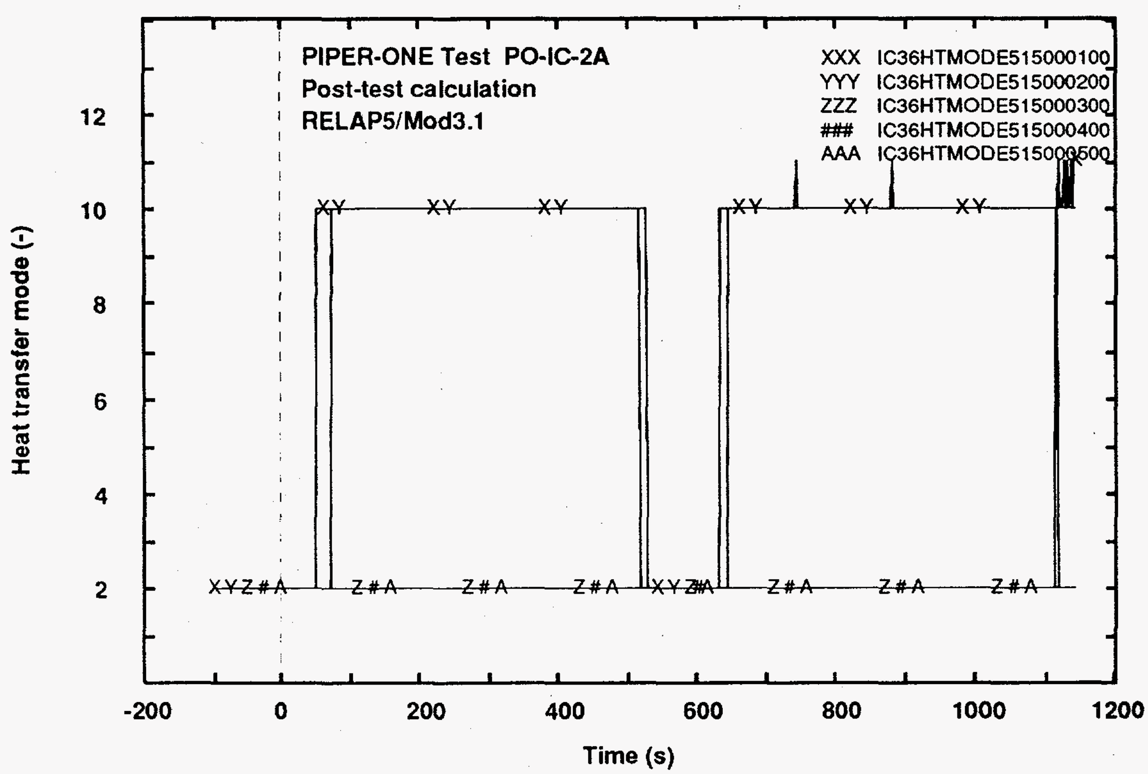

Fig. 38 - Calculated trends of IC tubes heat transfer mode (internal side)

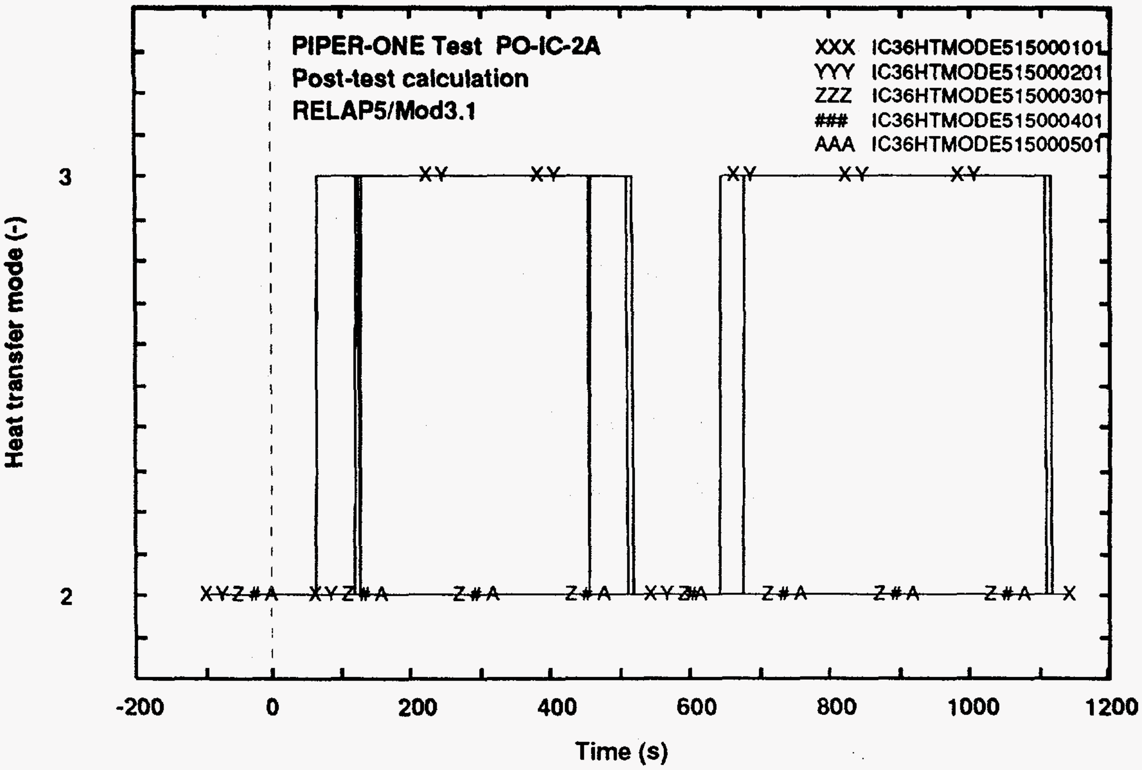

Fig. 39 - Calculated trends of IC tubes heat transfer mode (external side)

APPENDIX 3:

IC 37 Results

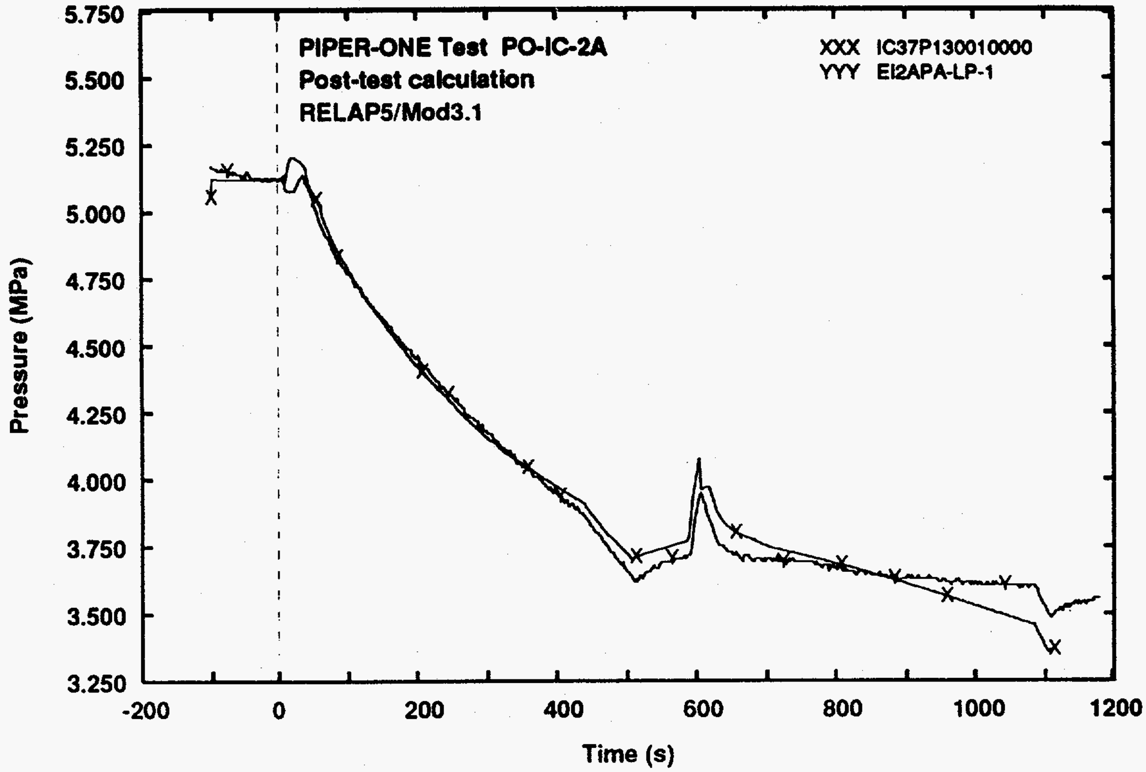

Fig. 1 - Measured and predicted trends of lower plenum pressure

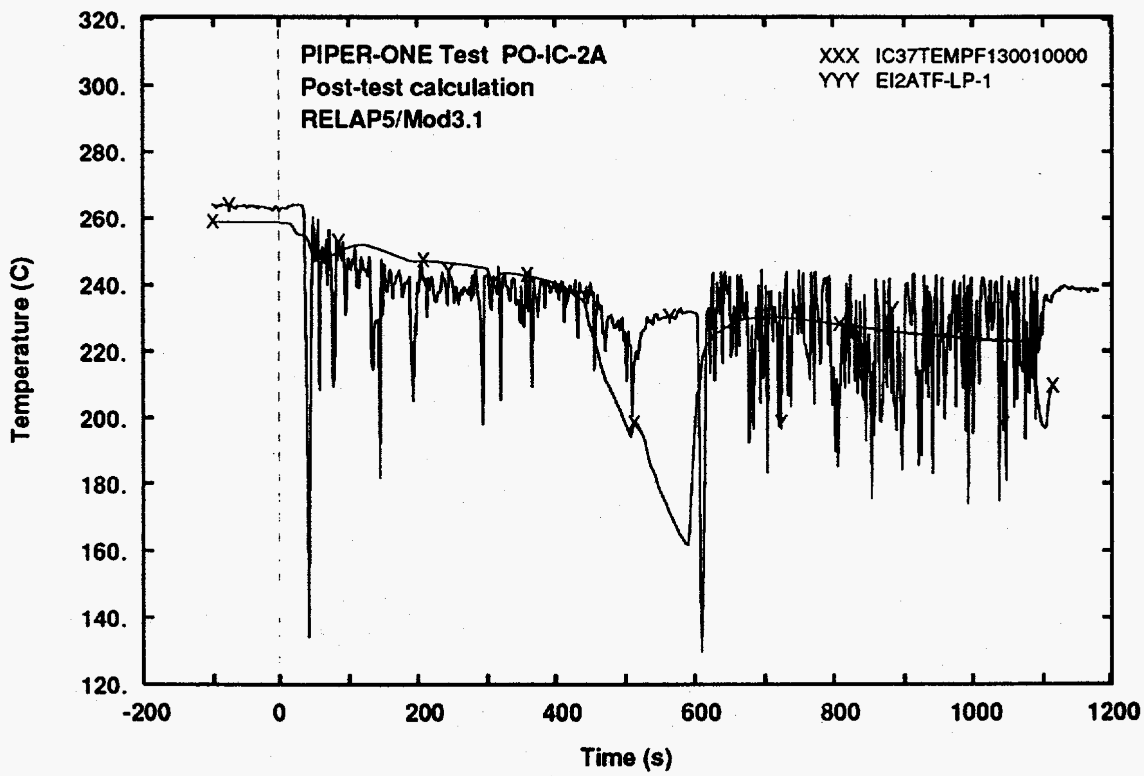

Fig. 2 - Measured and calculated trends of lower plenum temperature

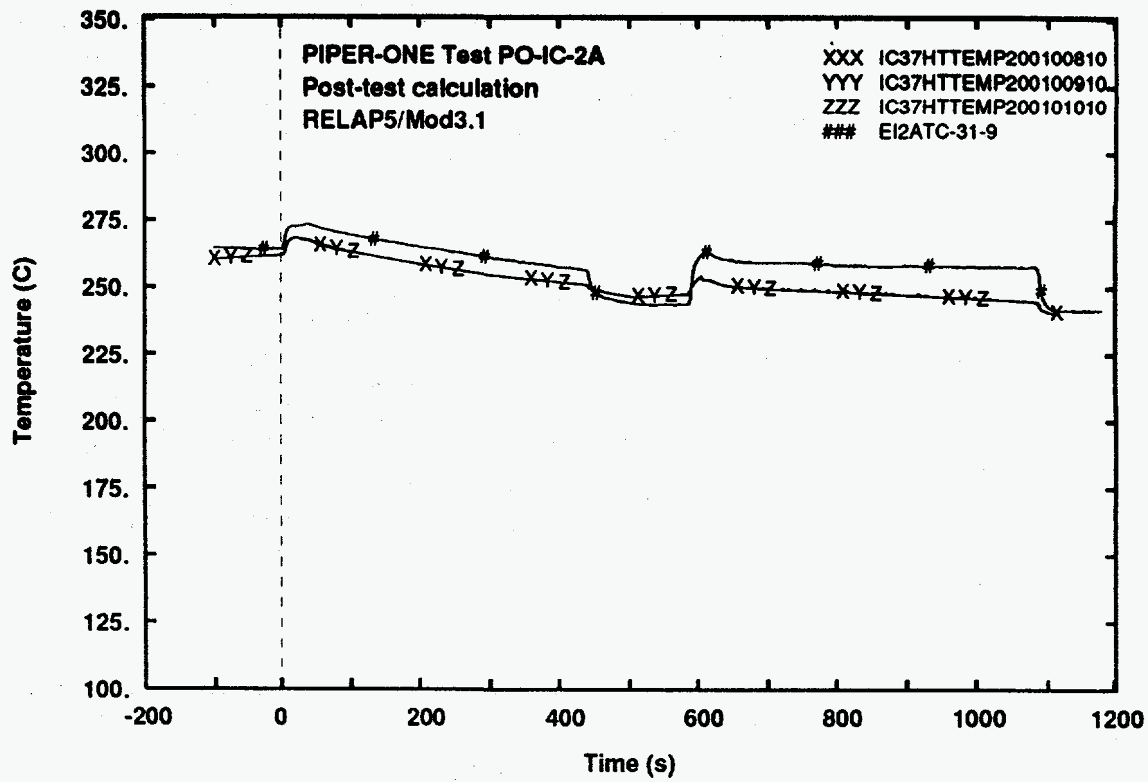

Fig. 3 - Measured and calculated trends of rod surface temperature (level 9)

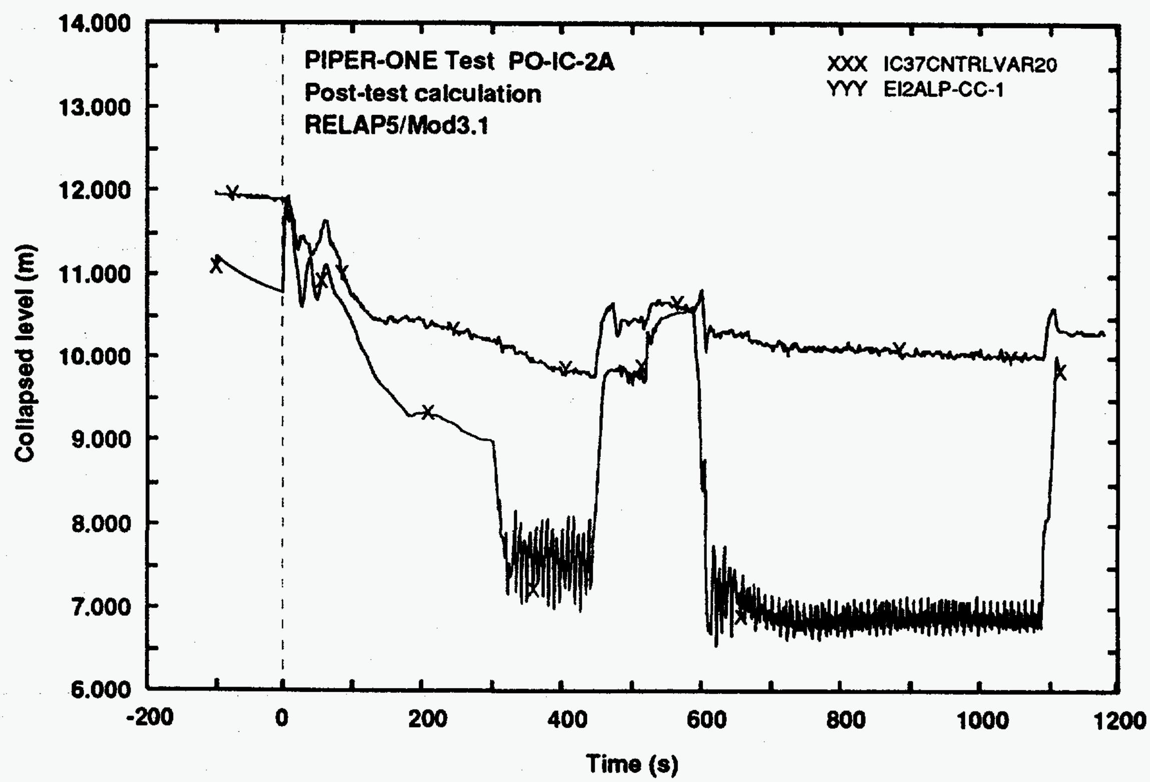

Fig. 4 - Measured and calculated trends of core level

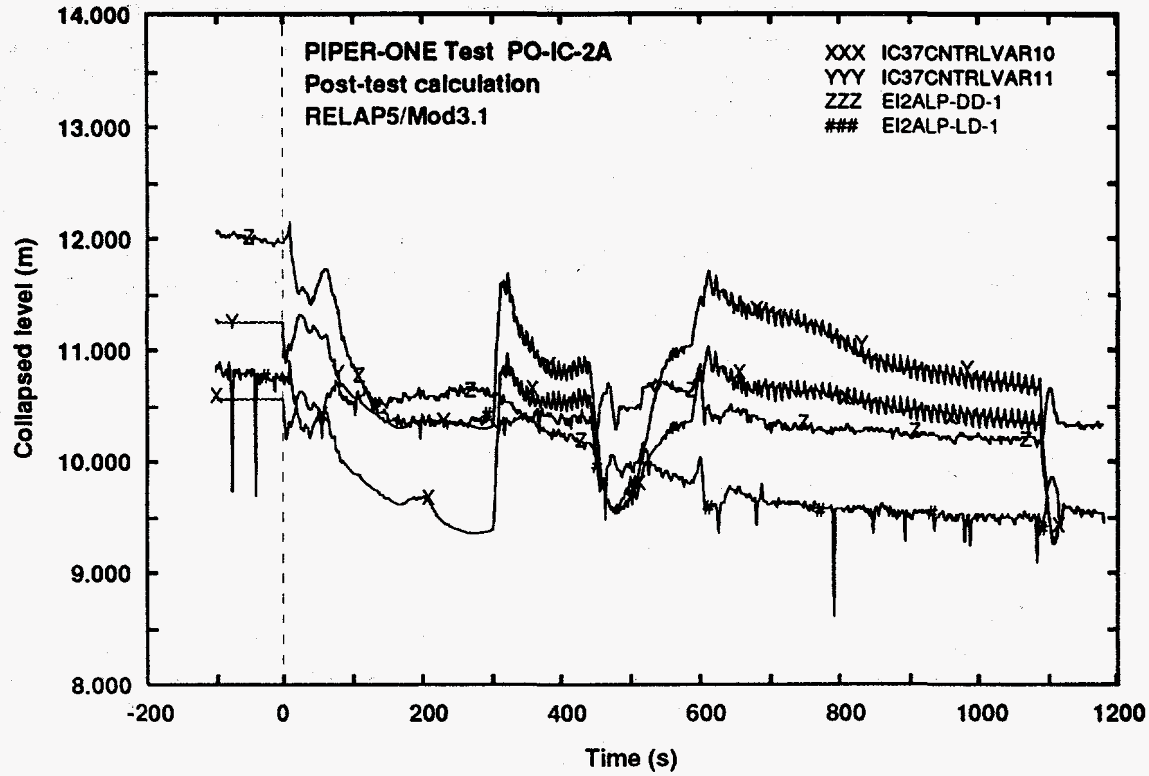

Fig. 5 - Measured and calculated trends of downcomer level

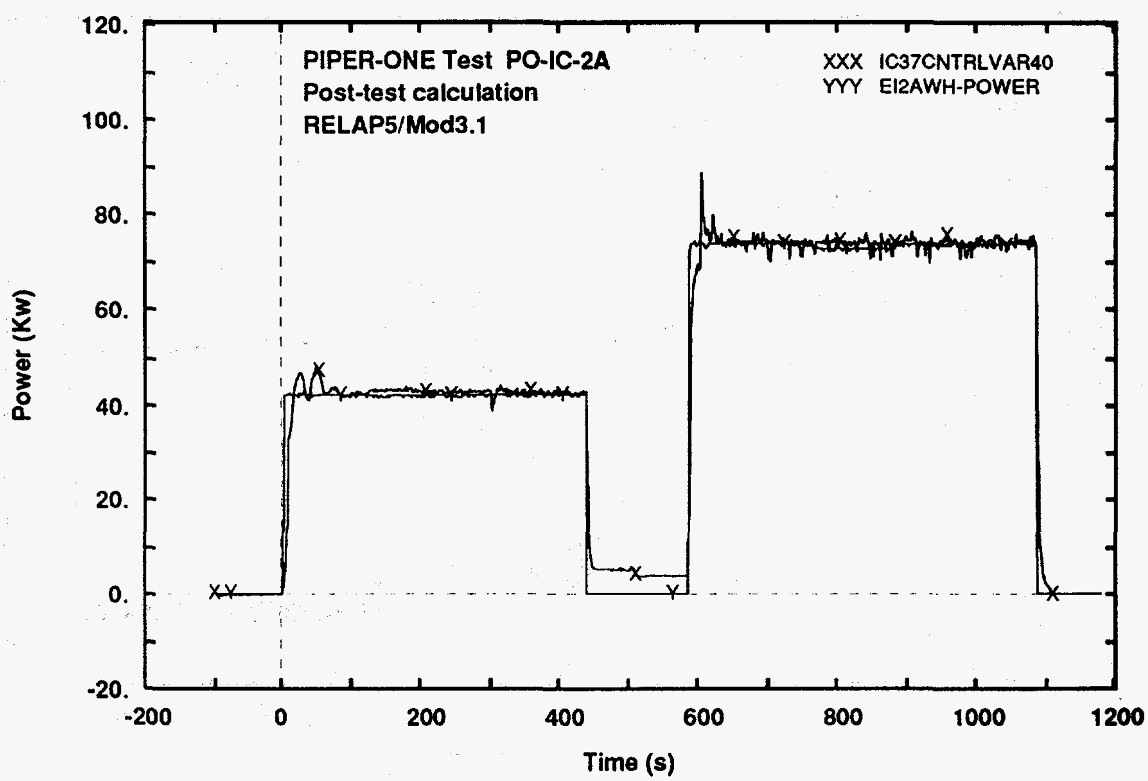

Fig. 6 - Measured and calculated trends of core power

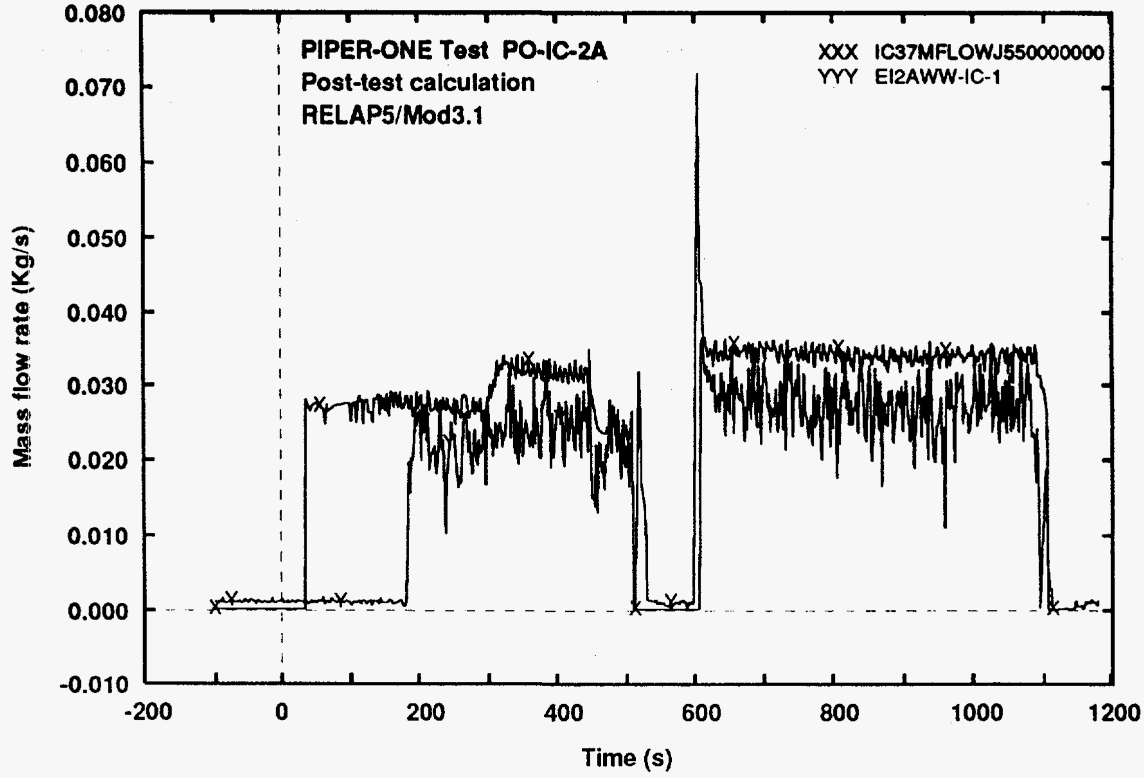

Fig. 7 - Measured and calculated trends of IC mass flow rate

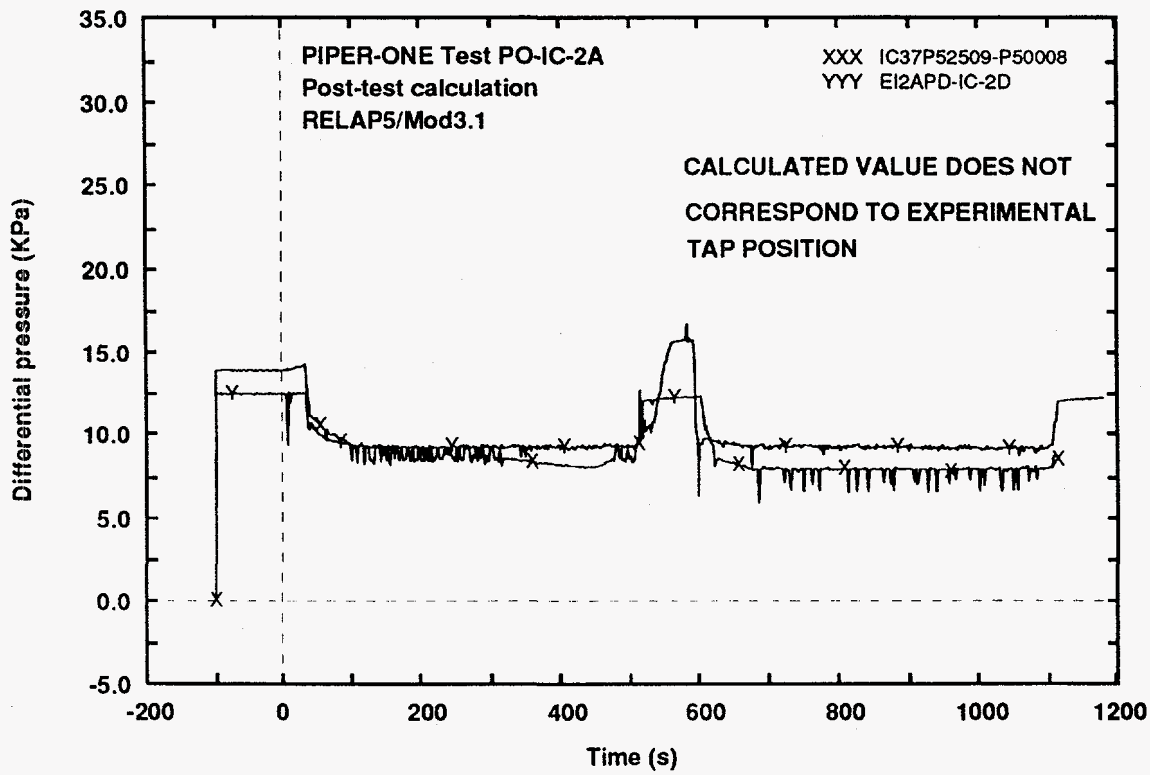

Fig. 8 - Measured and calculated trends of IC differential pressure

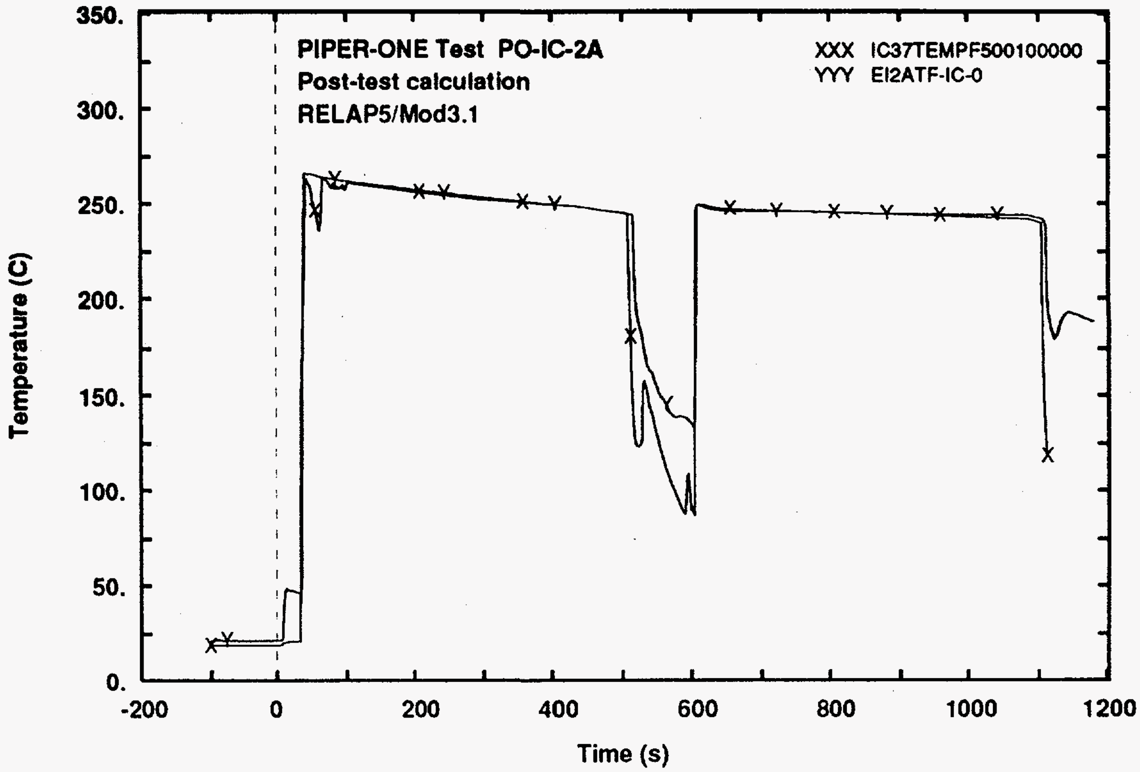

Fig. 9 - Measured and calculated trends of IC inlet fluid temperature

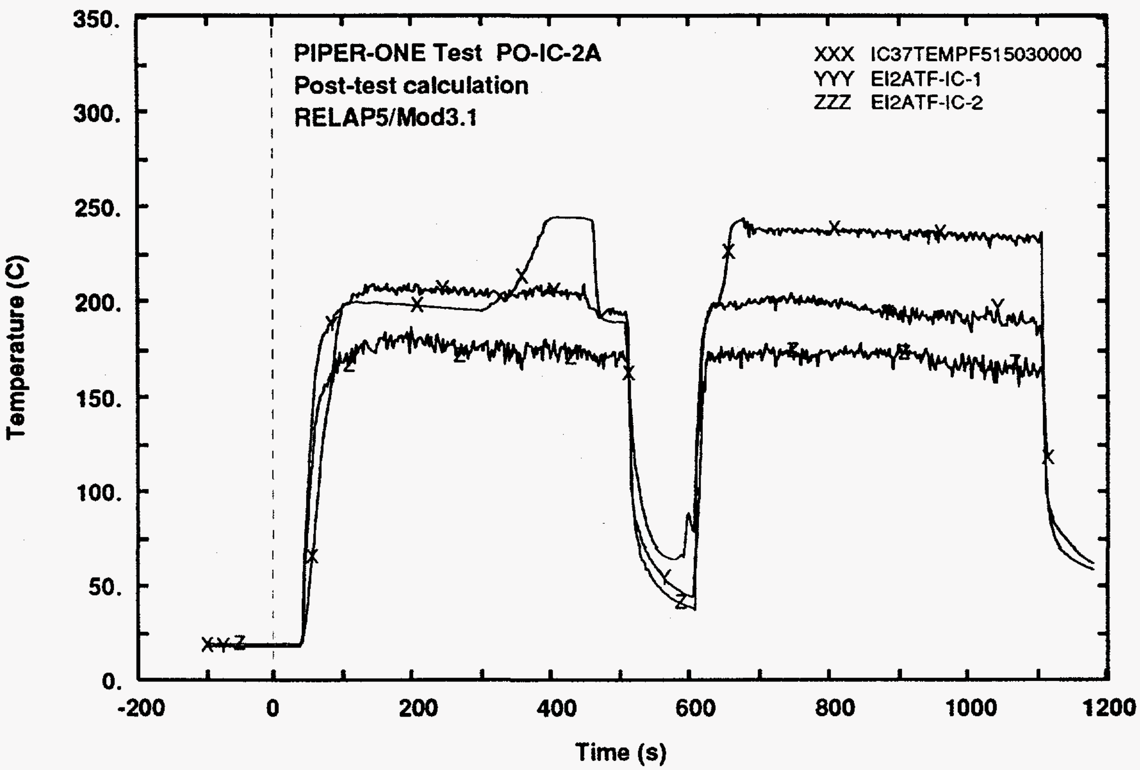

Fig. 10 - Measured and calculated trends of IC tubes fluid temperature (middle elevation)

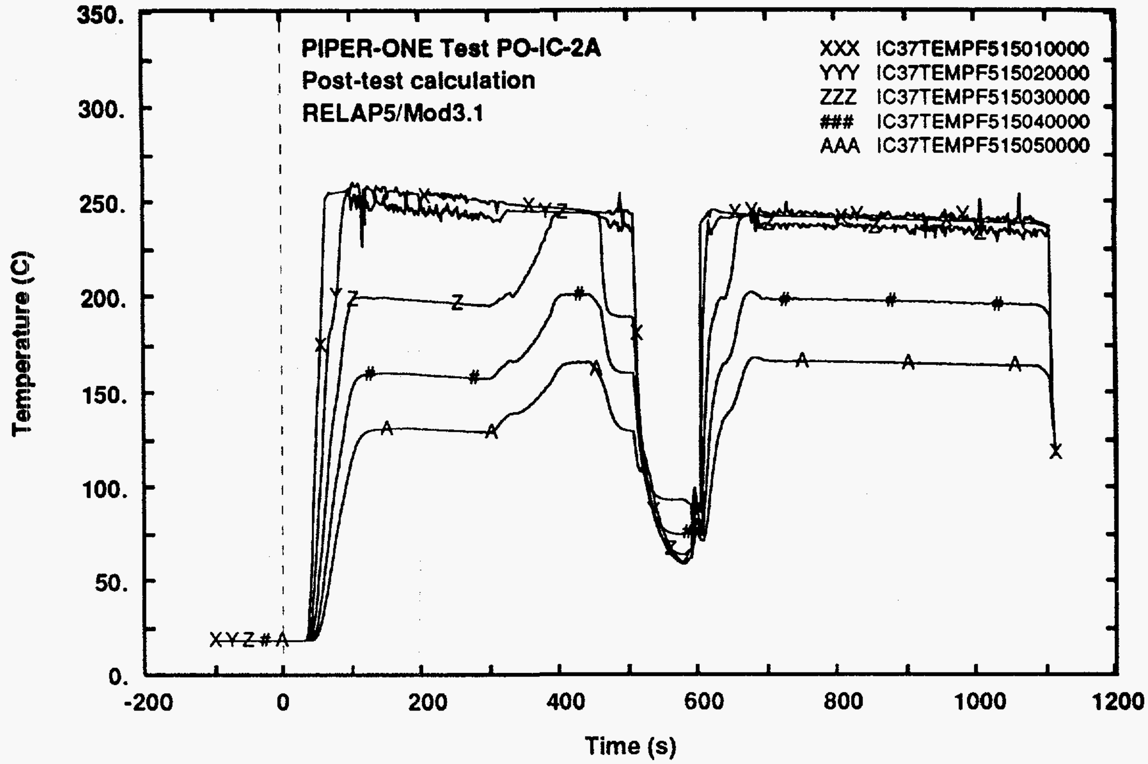

Fig. 11 - Calculated trends of IC tubes fluid temperature along the axis

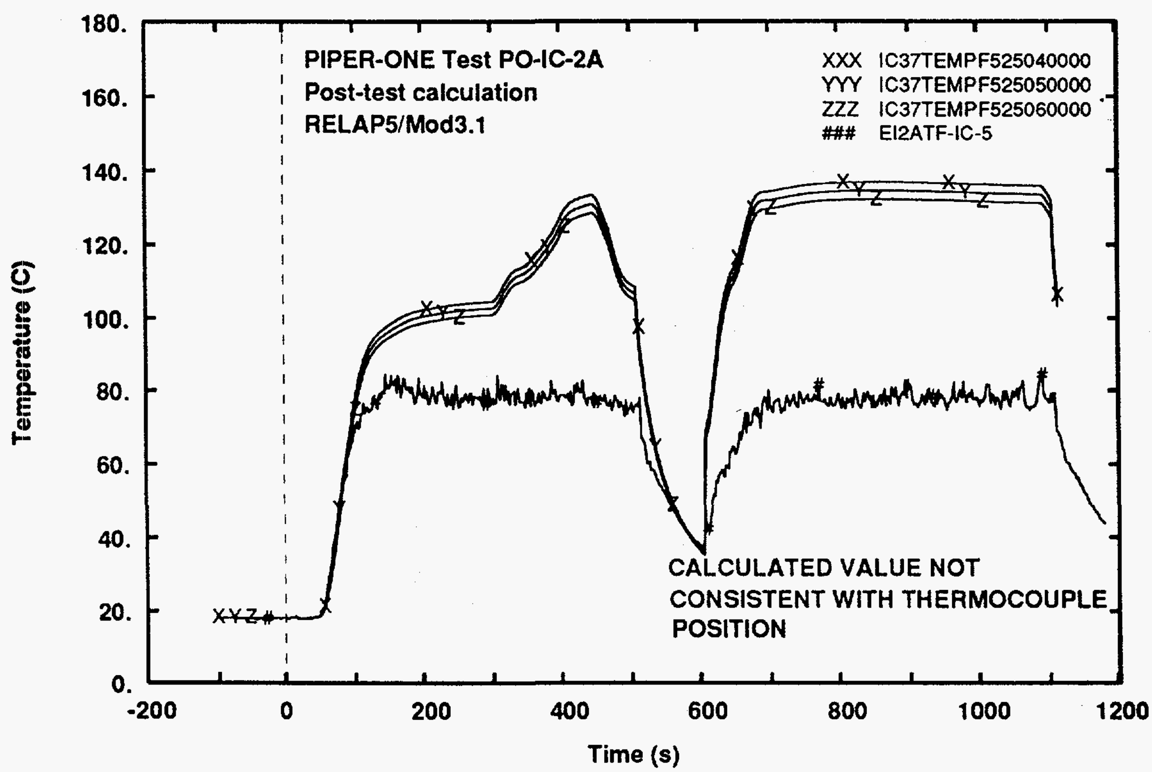

Fig. 12 - Measured and calculated trends of IC outlet fluid temperature

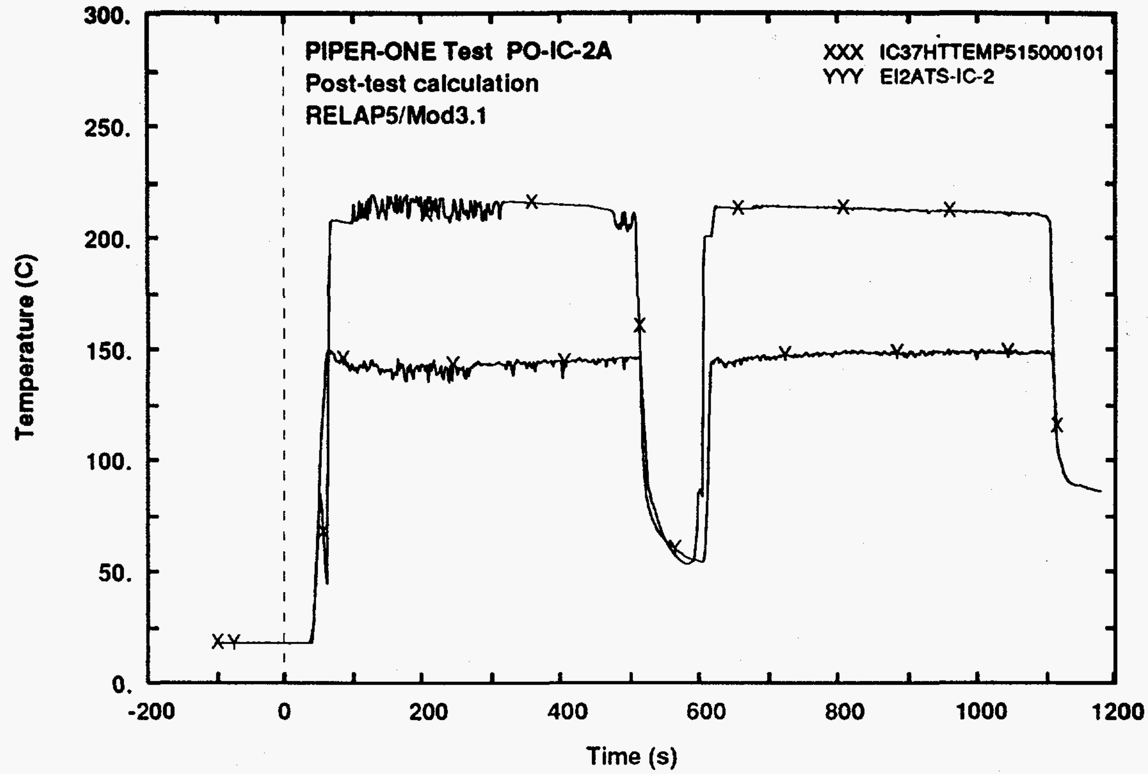

Fig. 13 - Measured and calculated trends of IC tubes wall surface temperature (internal side top elevation)

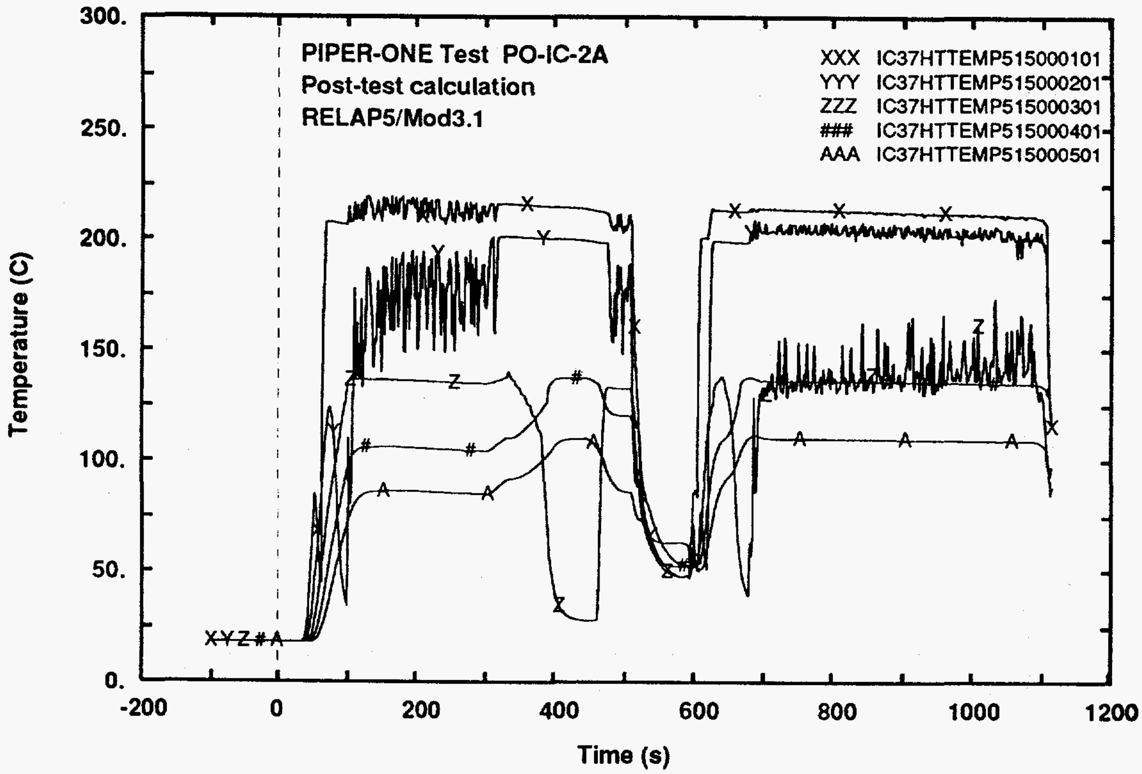

Fig. 14 - Calculated trends of IC tubes wall surface temperature along the axis (internal side)

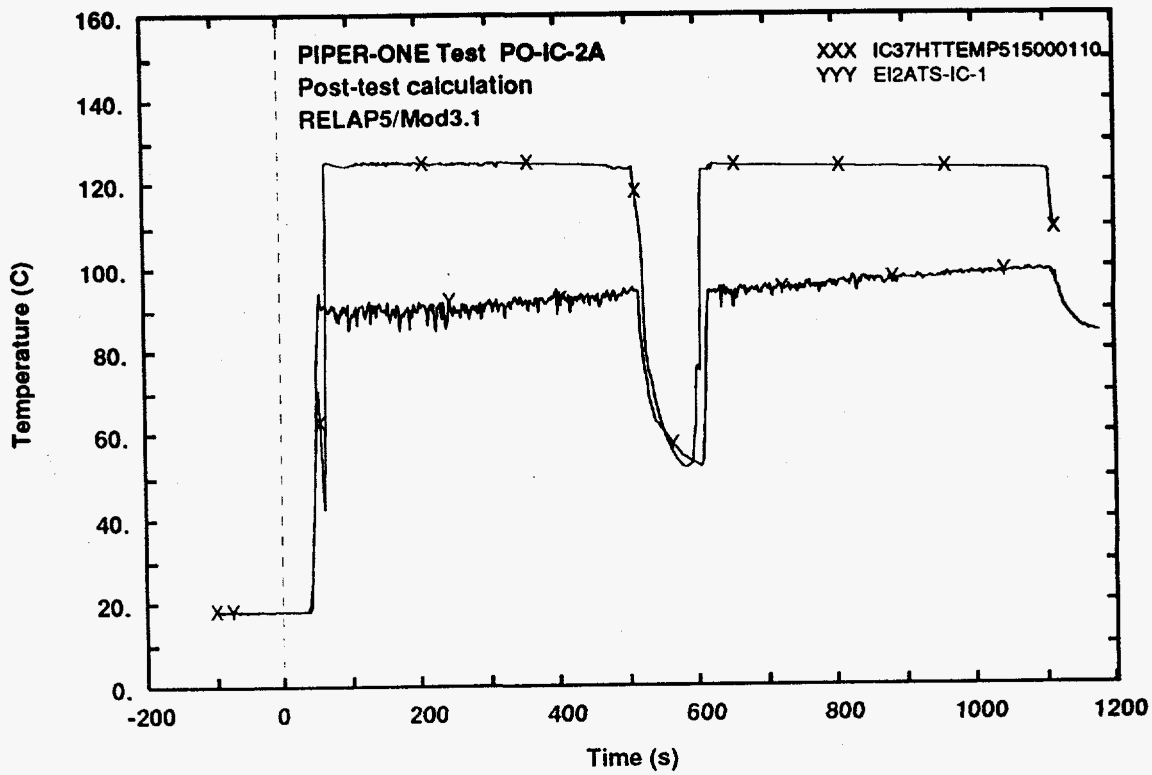

Fig. 15 - Measured and calculated trends of IC tubes wall surface temperature (external side top elevation)

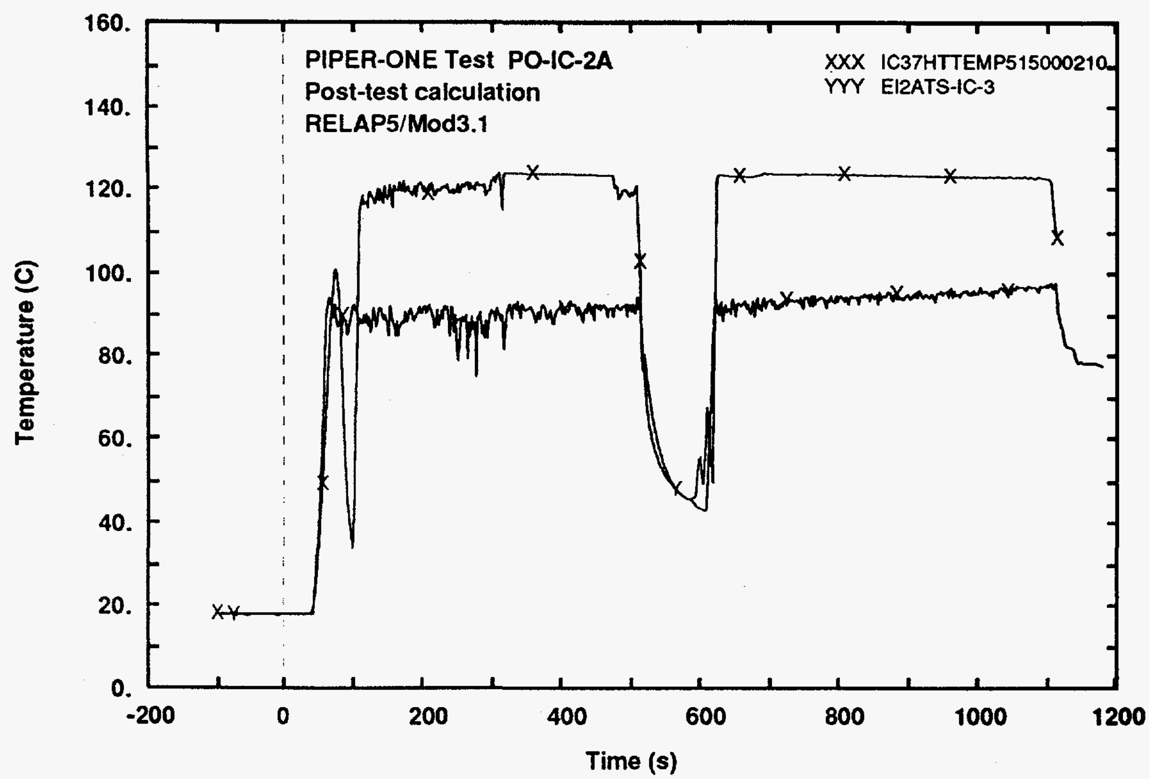

Fig. 16 - Measured and calculated trends of IC tubes wall surface temperature (external side level 3)

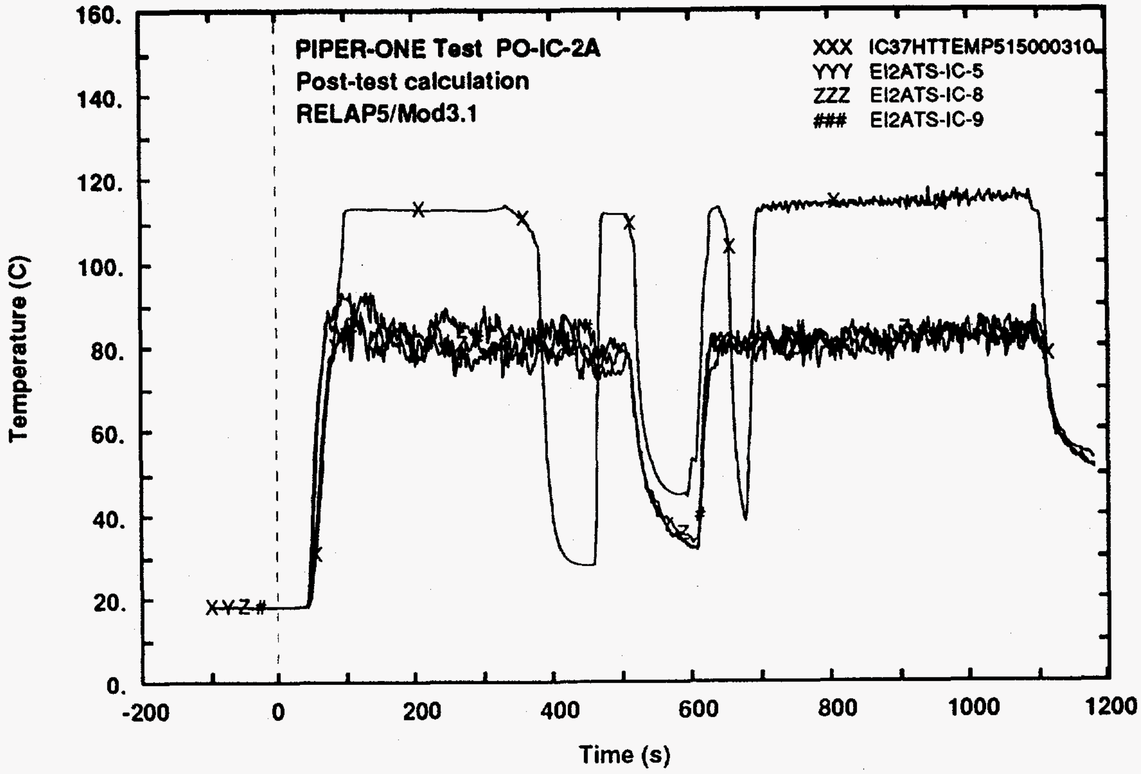

Fig. 17 - Measured and calculated trends of IC tubes wall surface temperature (external side middle elevation)

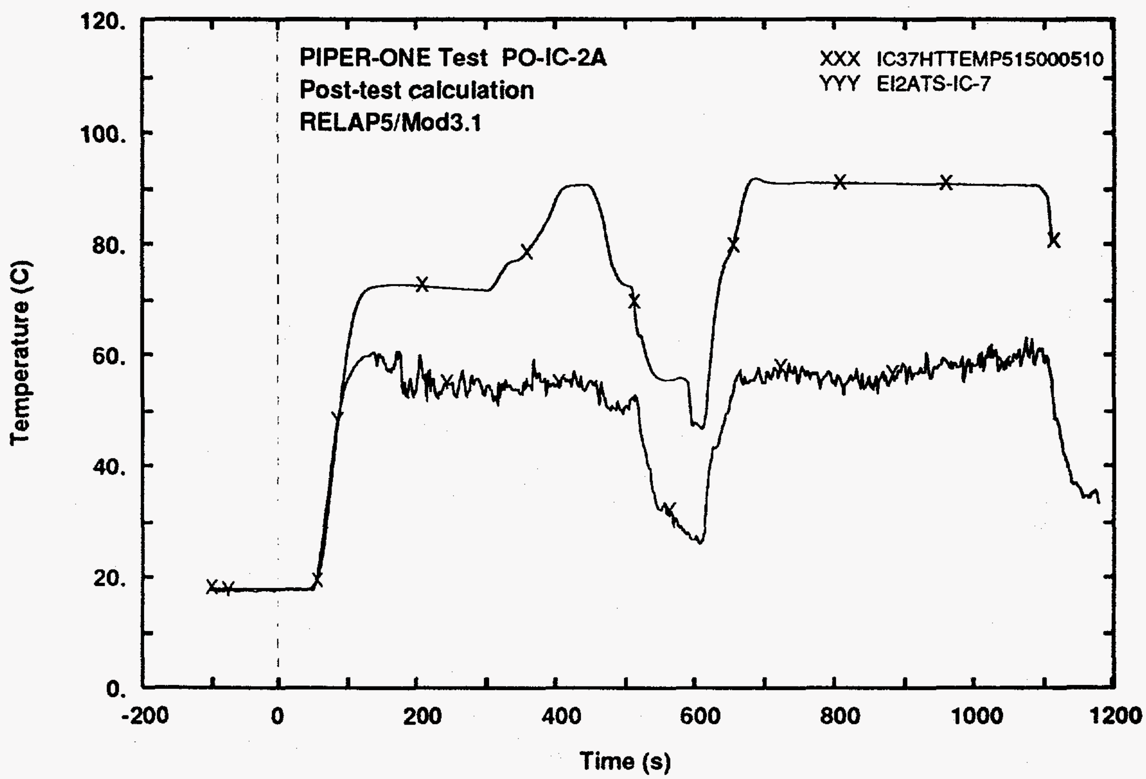

Fig. 18 - Measured and calculated trends of IC tubes wall surface temperature (external side bottom elevation)

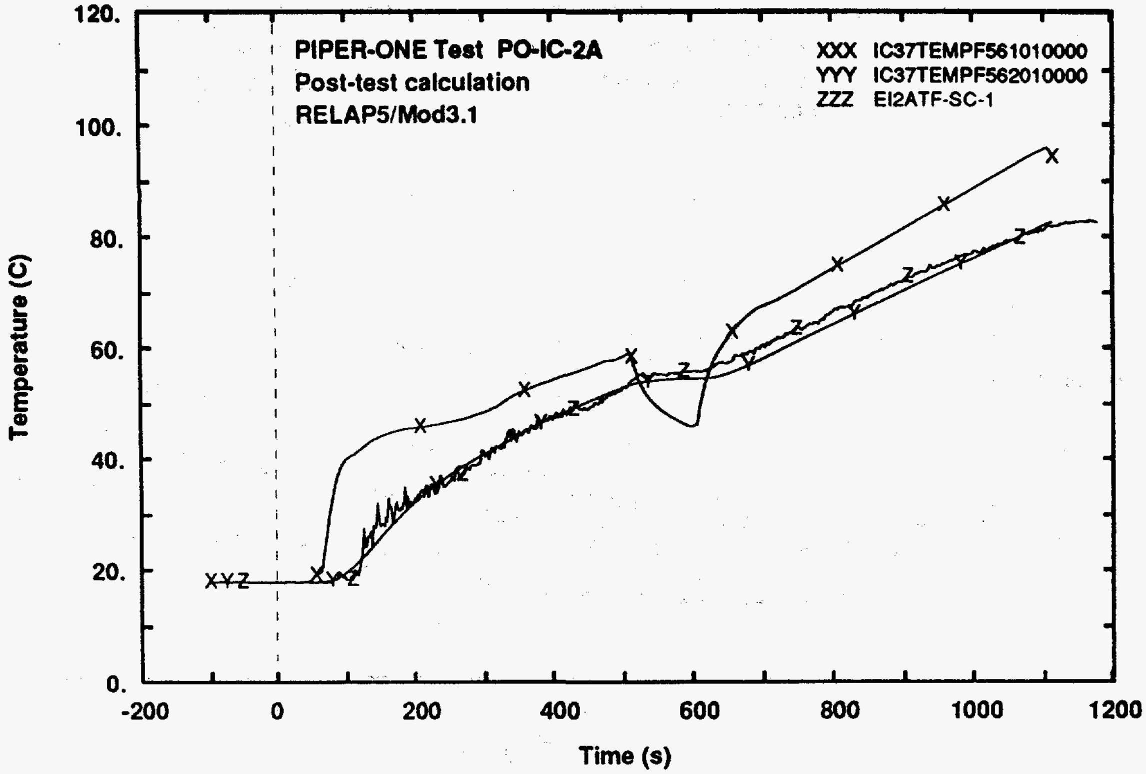

Fig. 19 - Measured and calculated trends of IC internal pool fluid temperature (top level)

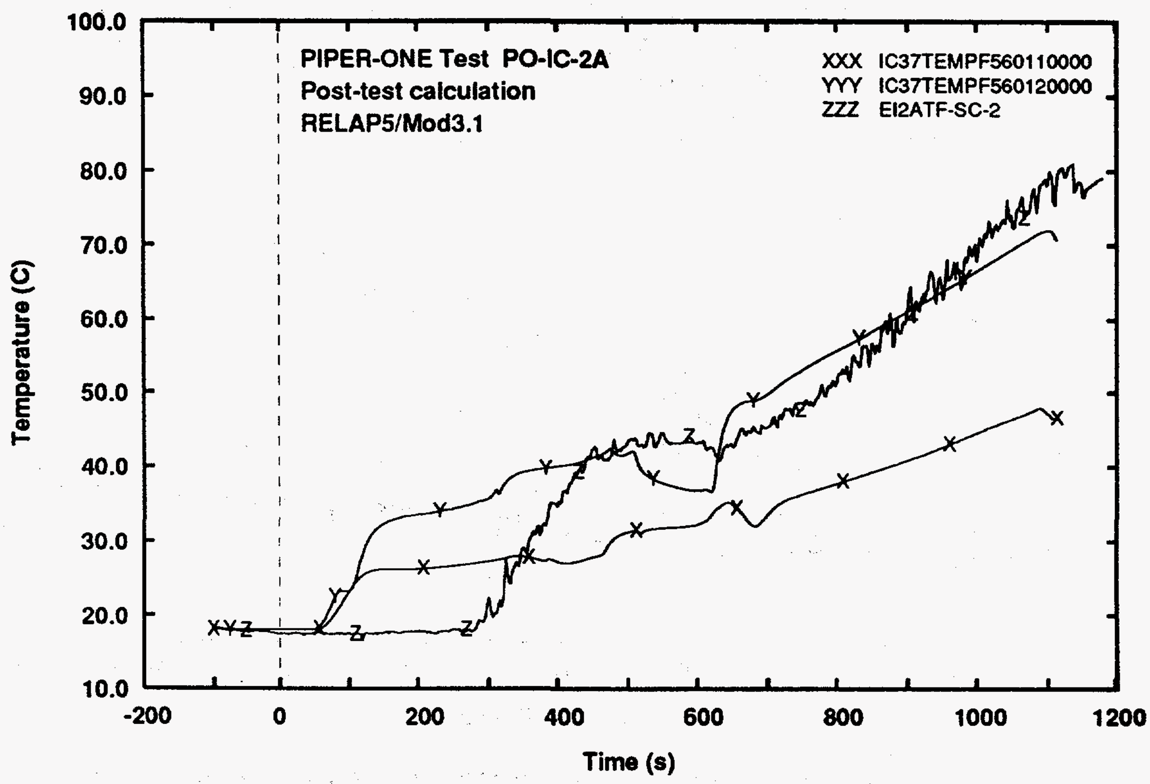

Fig. 20 - Measured and calculated trends of IC internal pool fluid temperature (level 2)

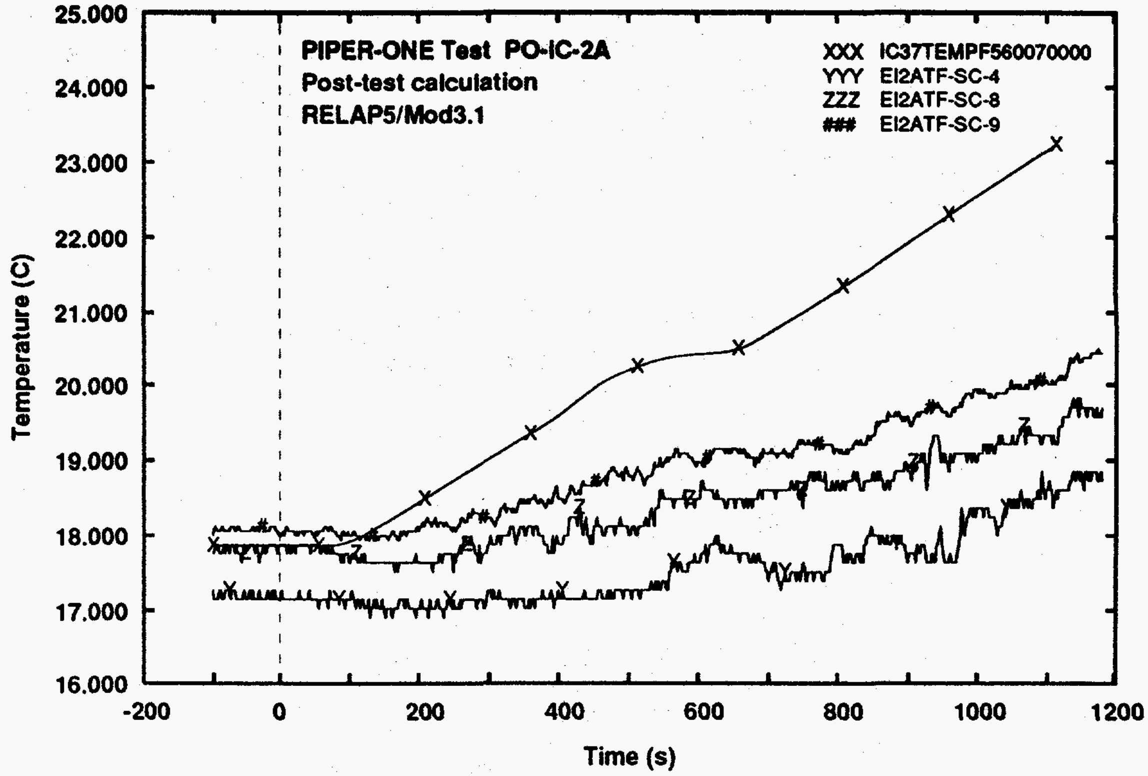

Fig. 21 - Measured and calculated trends of IC internal pool fluid temperature (middle level)

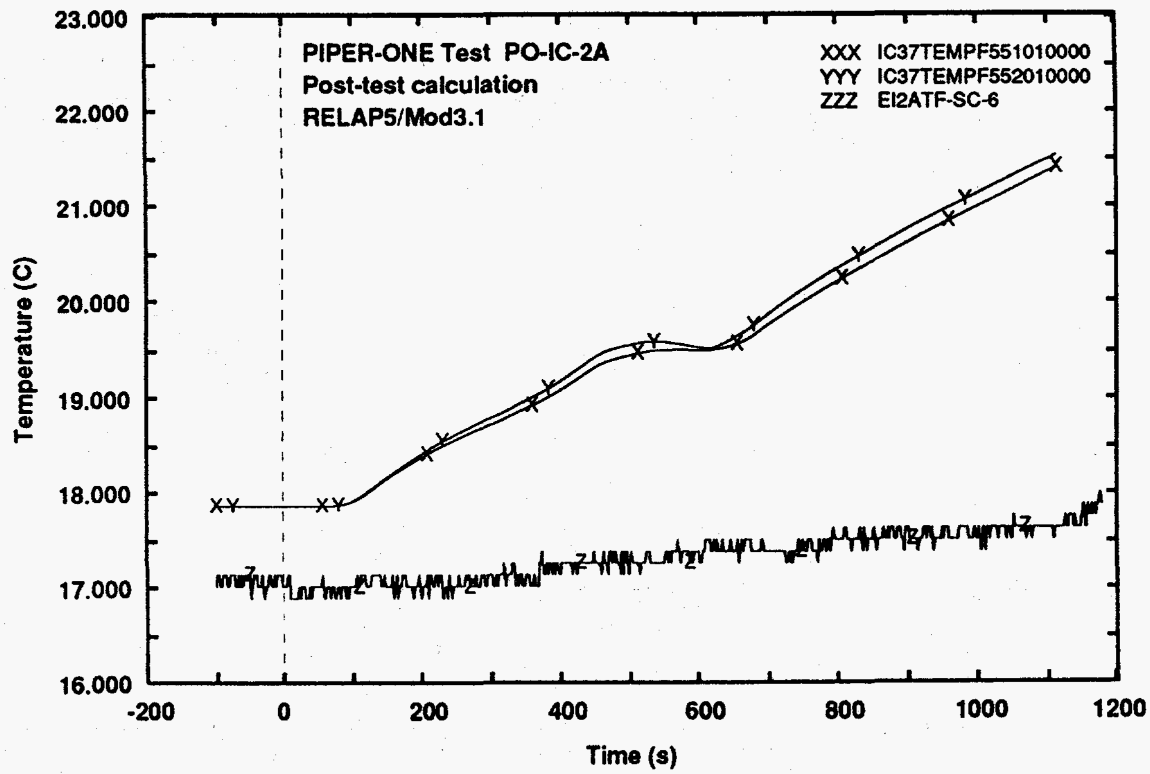

Fig. 22 - Measured and calculated trends of IC internal pool fluid temperature (bottom level)

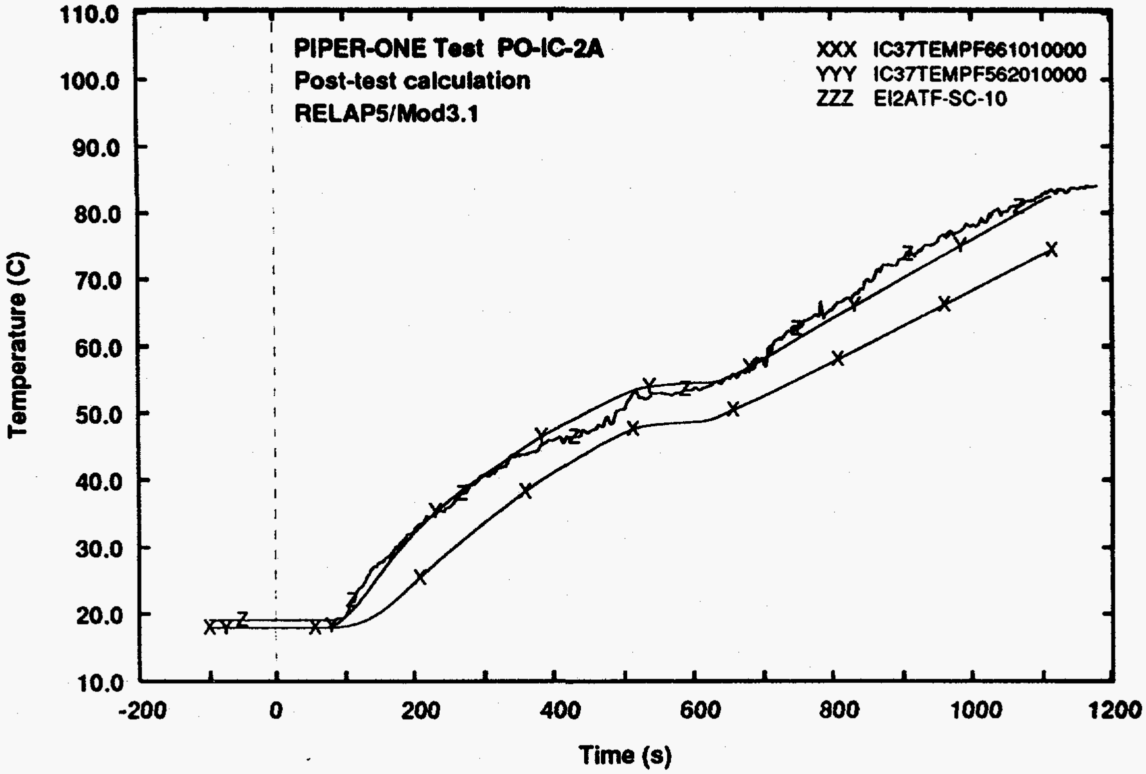

Fig. 23 - Measured and calculated trends of IC external pool fluid temperature (top level)

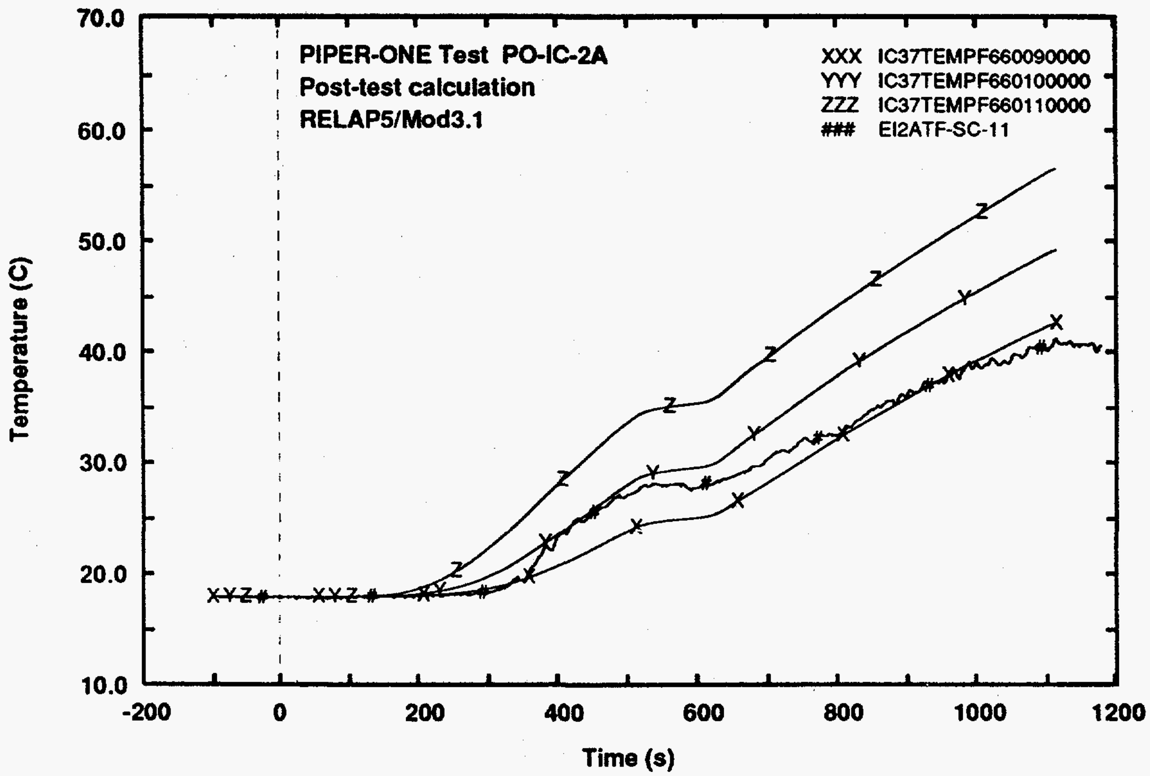

Fig. 24 - Measured and calculated trends of IC external pool fluid temperature (level 11)

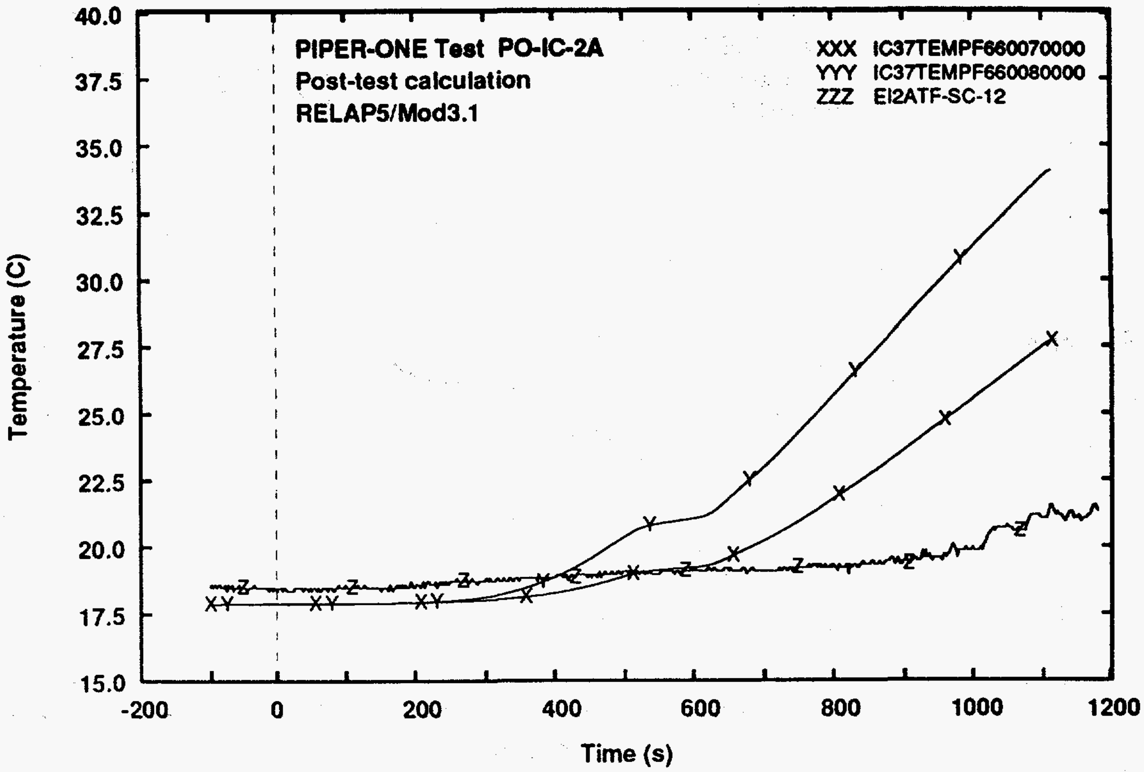

Fig. 25 - Measured and calculated trends of IC external pool fluid temperature (middle level)

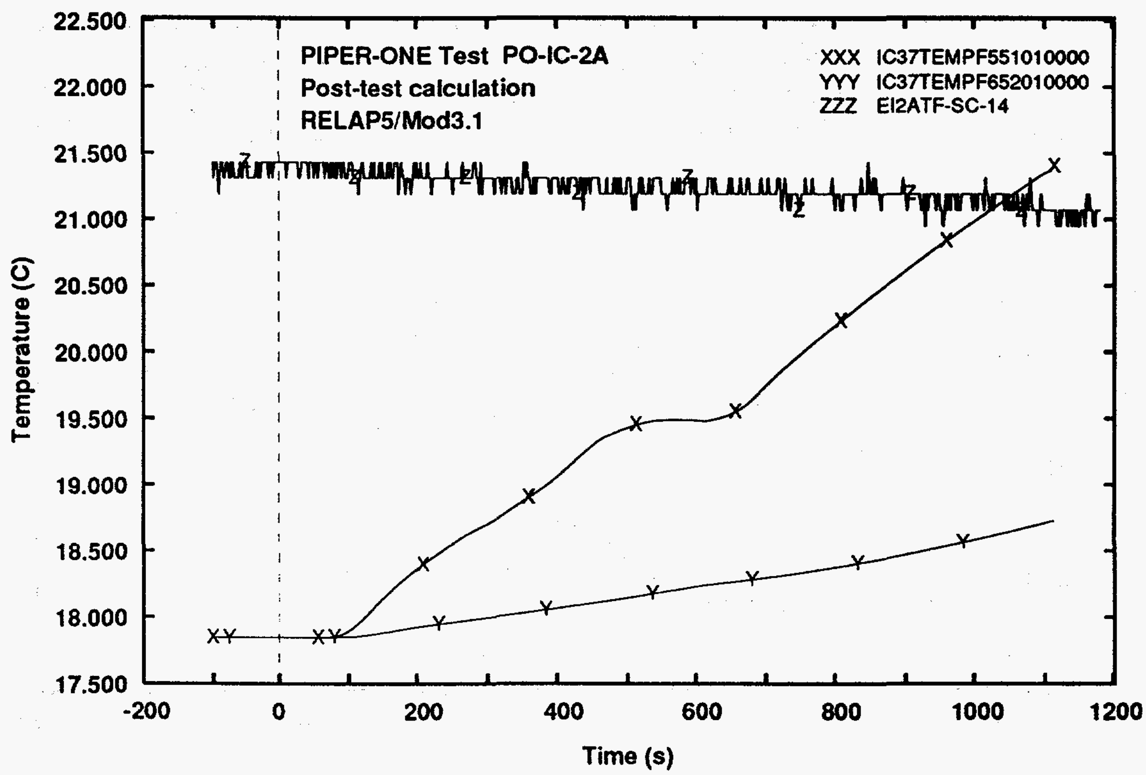

Fig. 26 - Measured and calculated trends of IC external pool fluid temperature (bottom level)

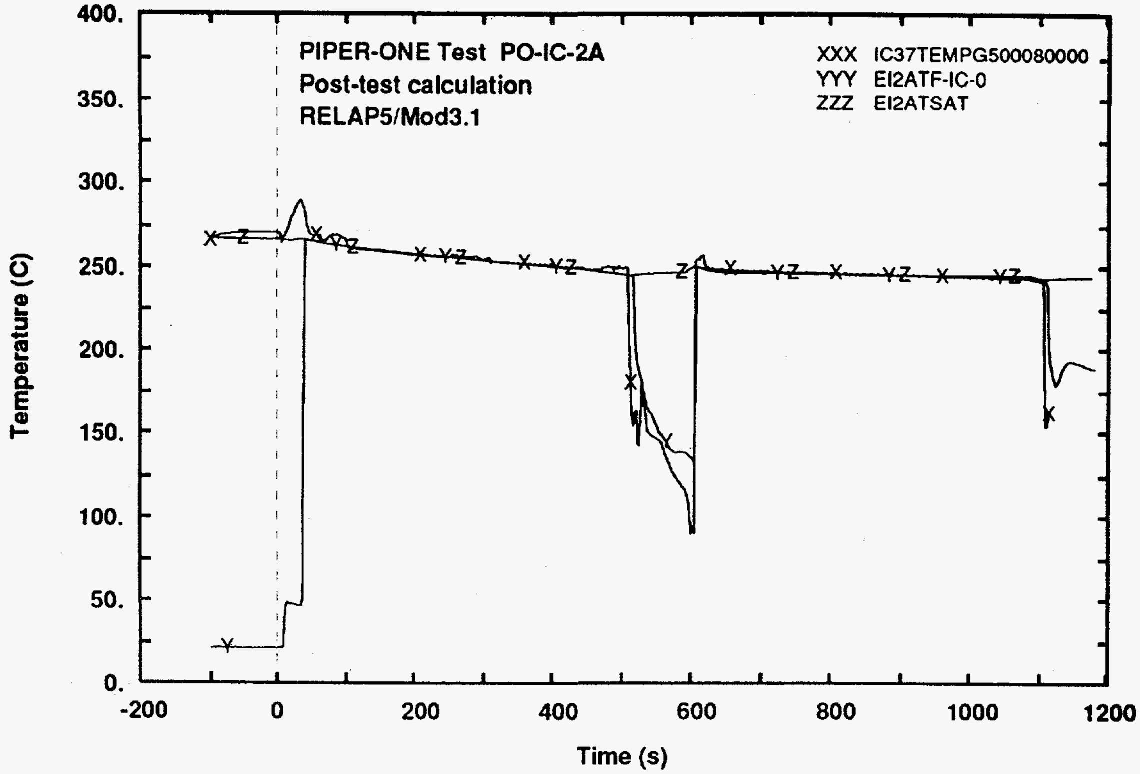

Fig. 27 - Measured and calculated trends of steam temperature at IC inlet compared with experimental saturated temperature

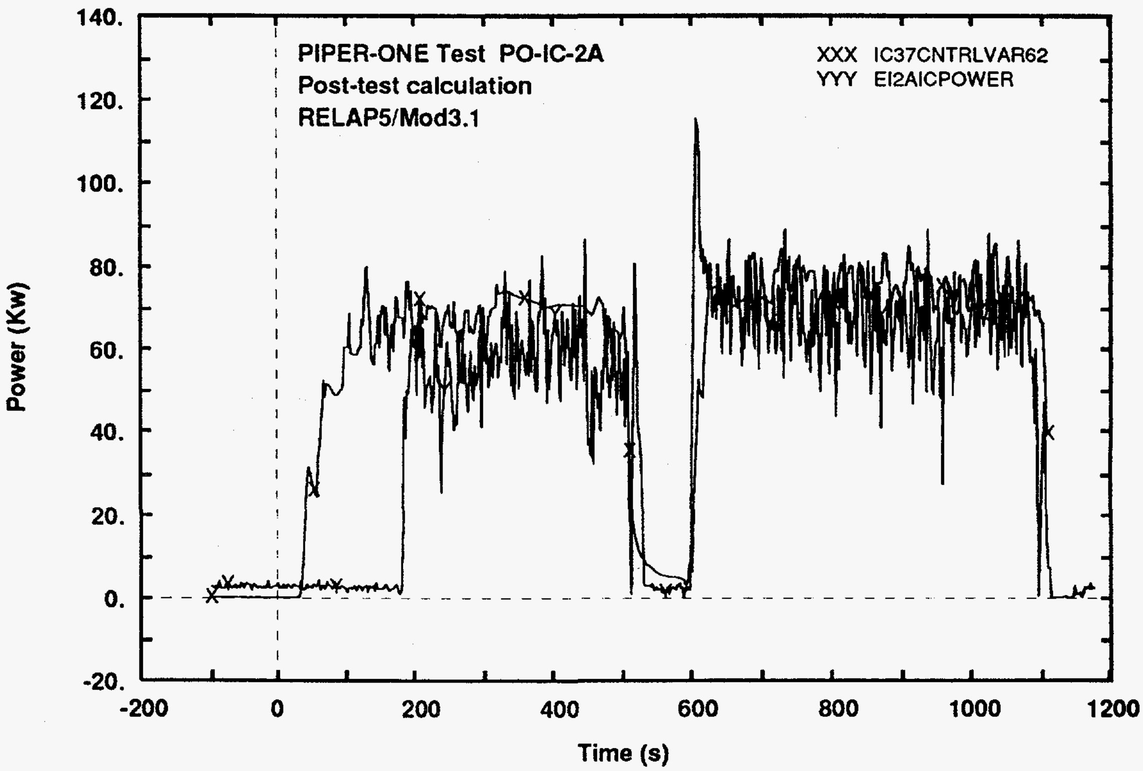

Fig. 28 - Measured and calculated trends of IC exchanged power

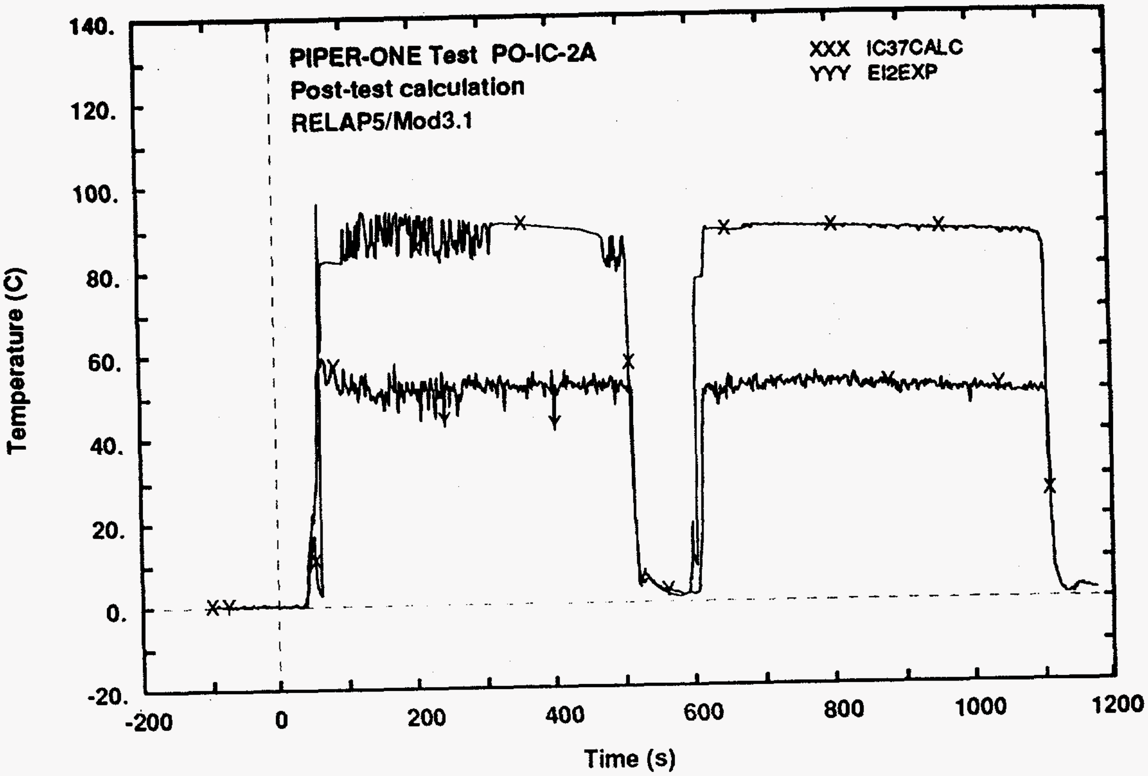

Fig. 29 - Measured and calculated trends of temperature difference between internal and external side of IC tubes wall (top elevation)

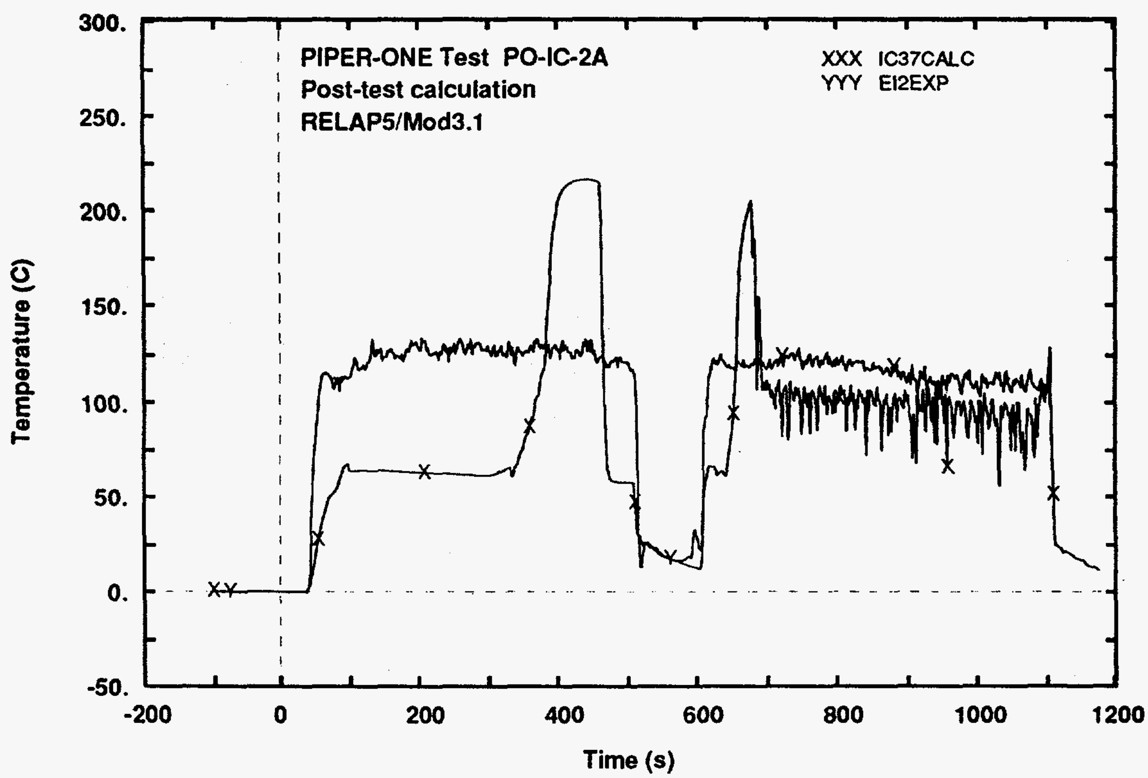

Fig. 30 - Measured and calculated trends of temperature difference between IC fluid and external side of IC tubes wall (middle elevation)

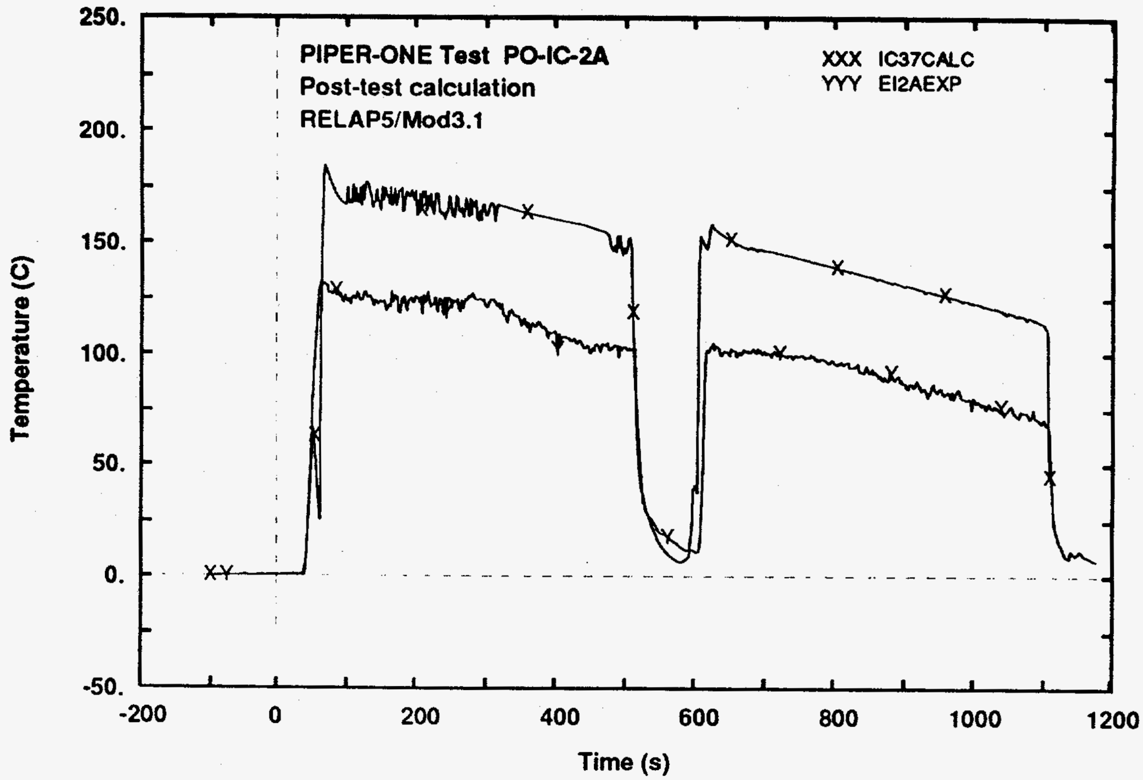

Fig. 31 - Measured and calculated trends of temperature difference between internal side of IC tubes wall and IC pool fluid temperature (top elevation)

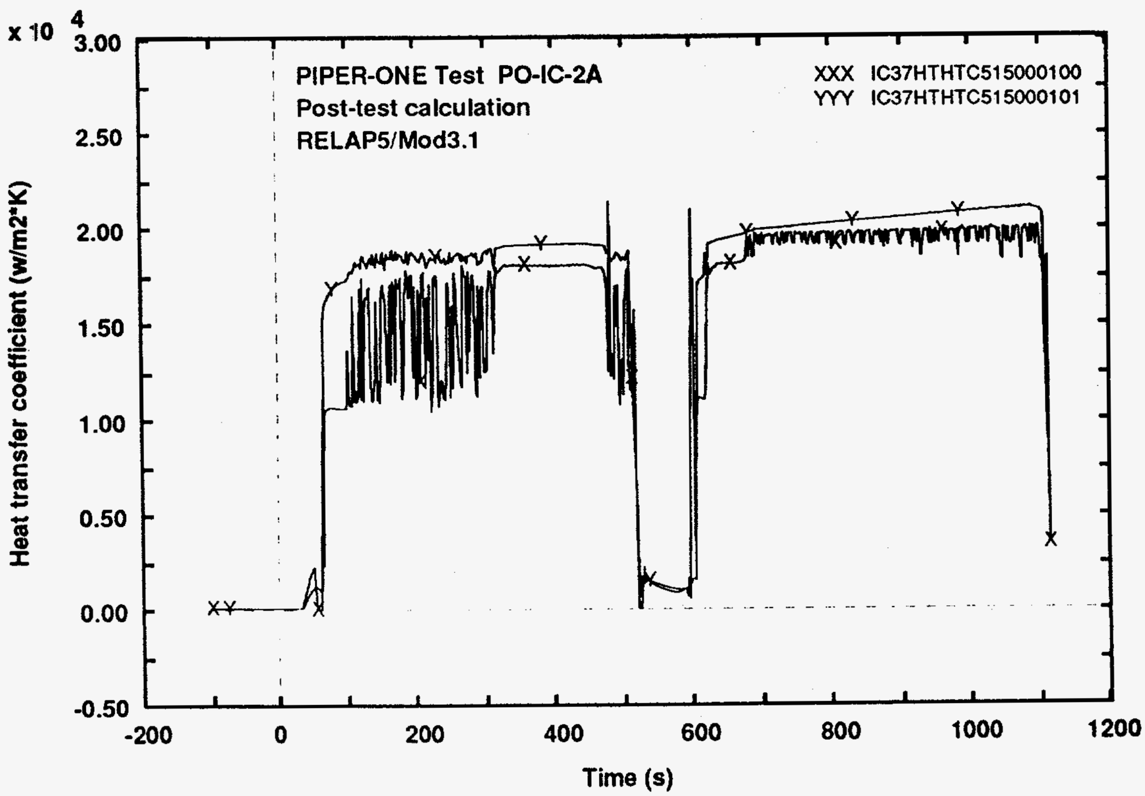

Fig. 32 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (top elevation)

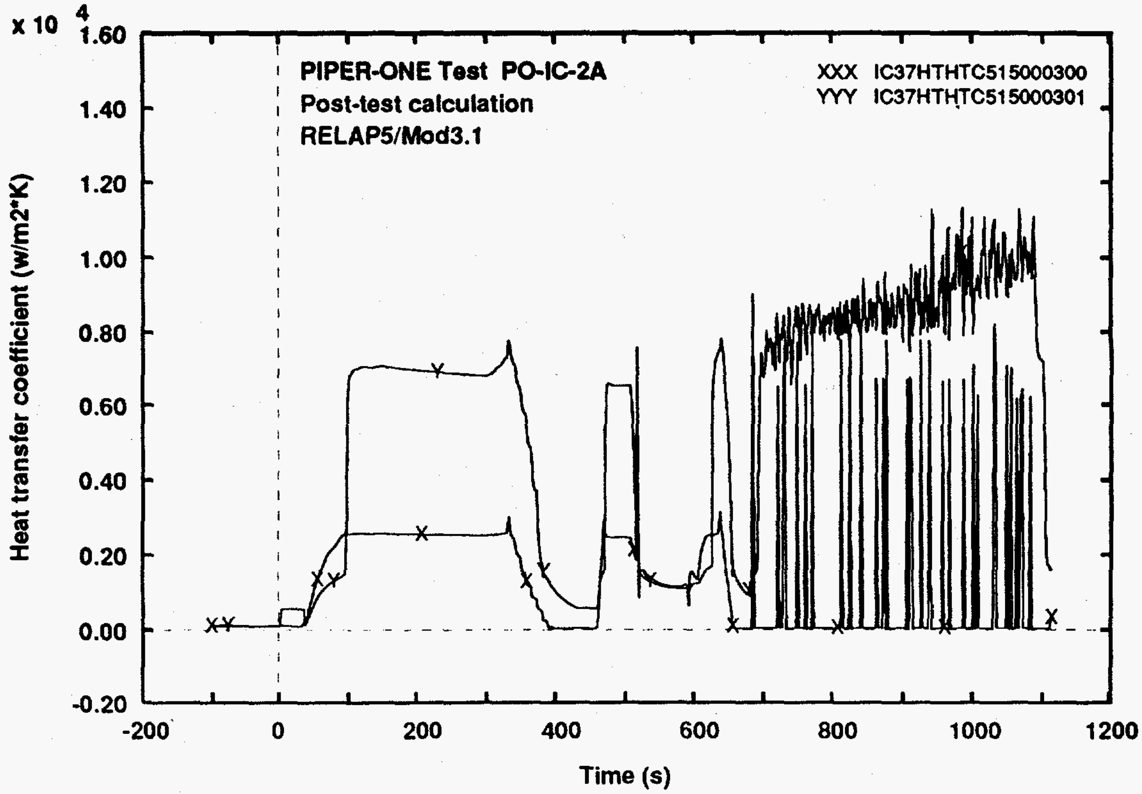

Fig. 33 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (middle elevation)

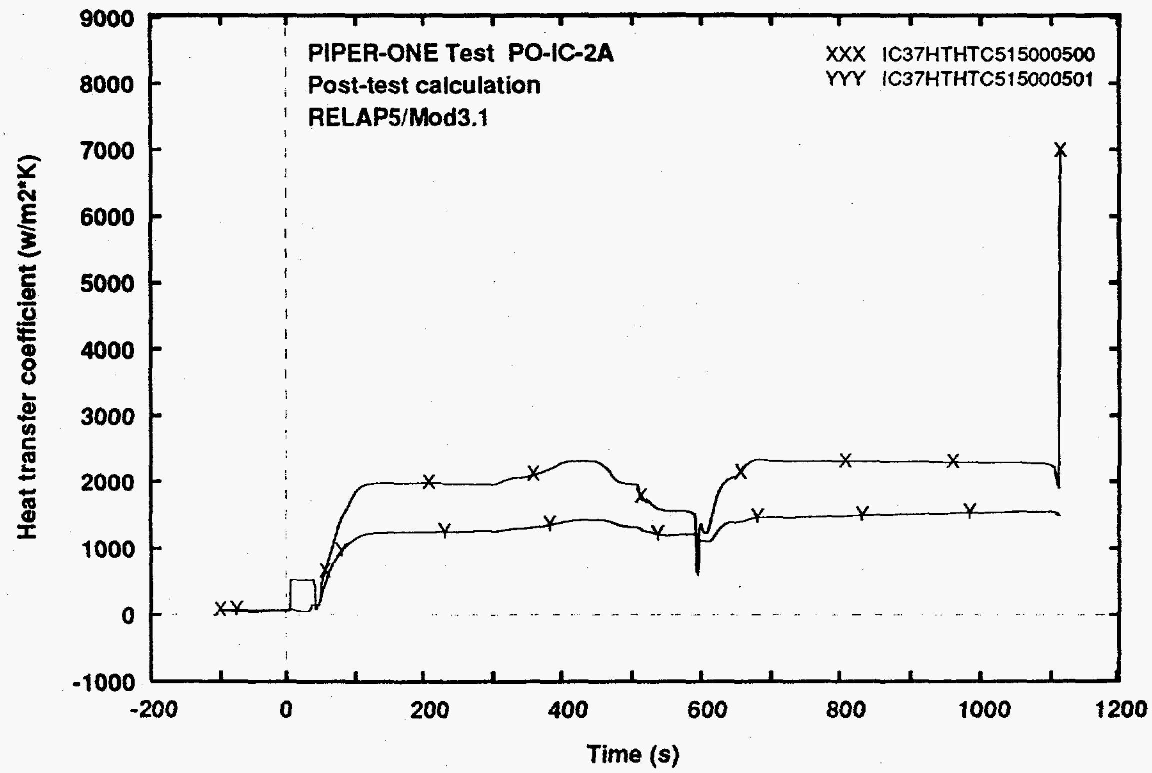

Fig. 34 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (bottom elevation)

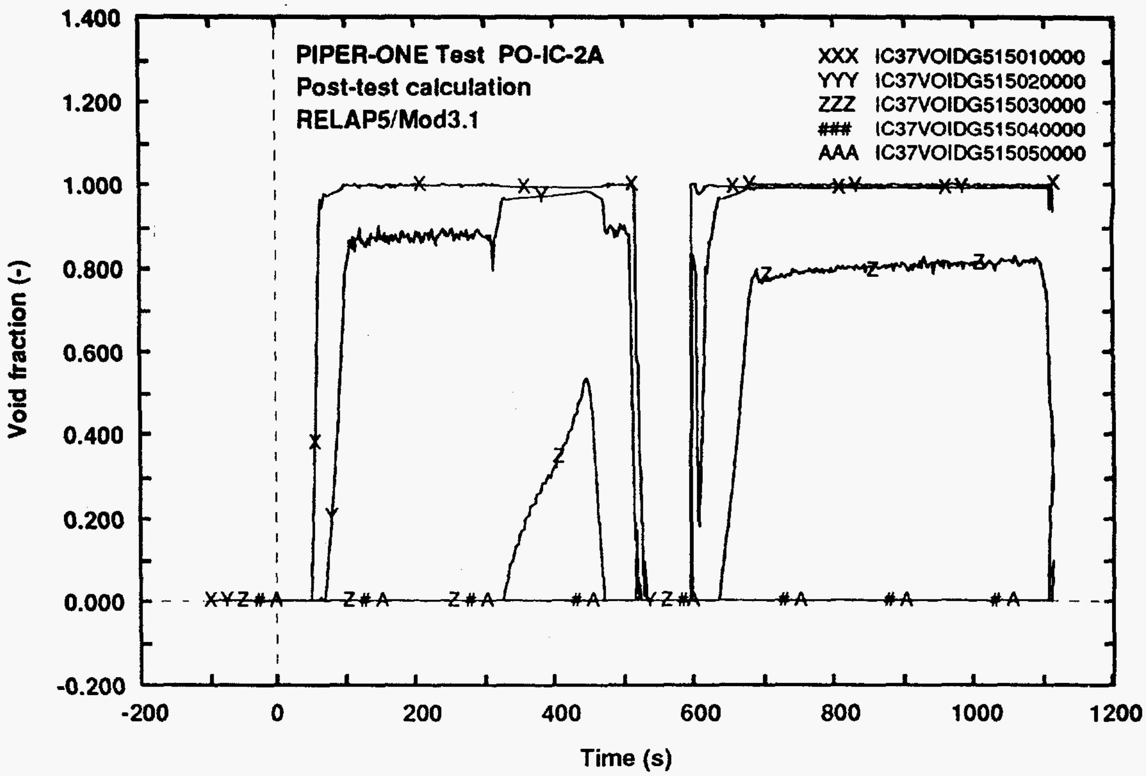

Fig. 35 - Calculated trends of IC tubes void fraction along the axis

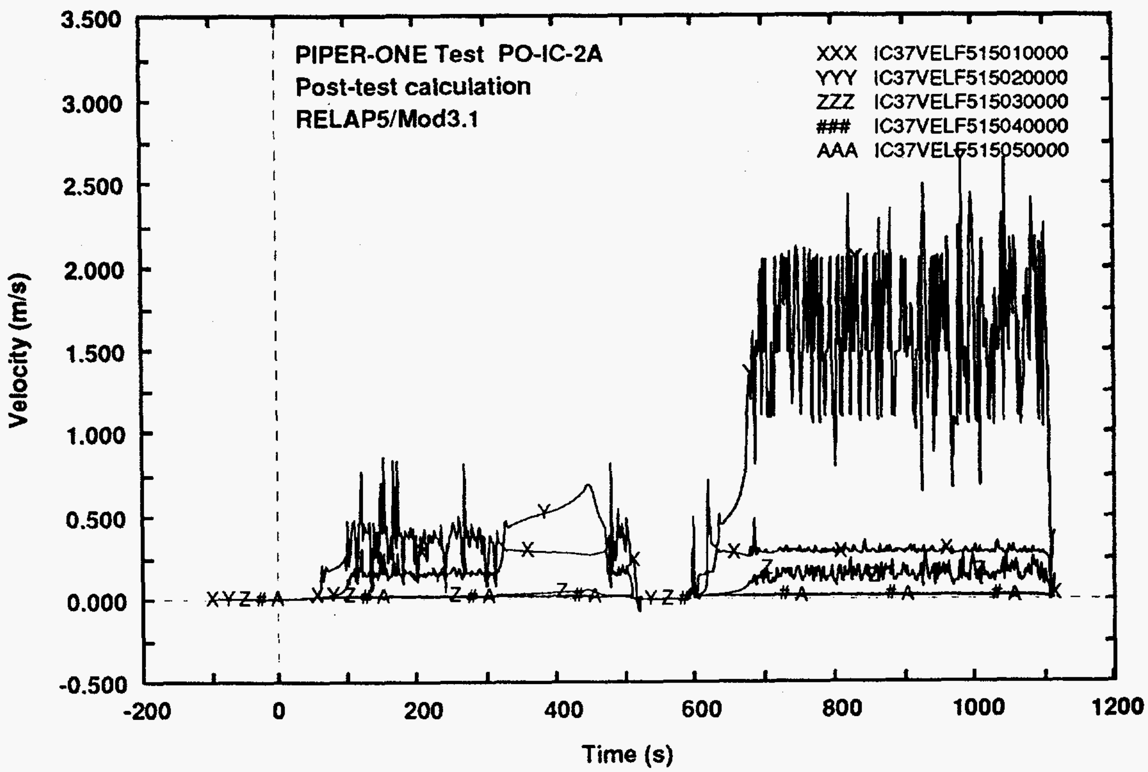

Fig. 36 - Calculated trends of IC tubes liquid velocity along the axis

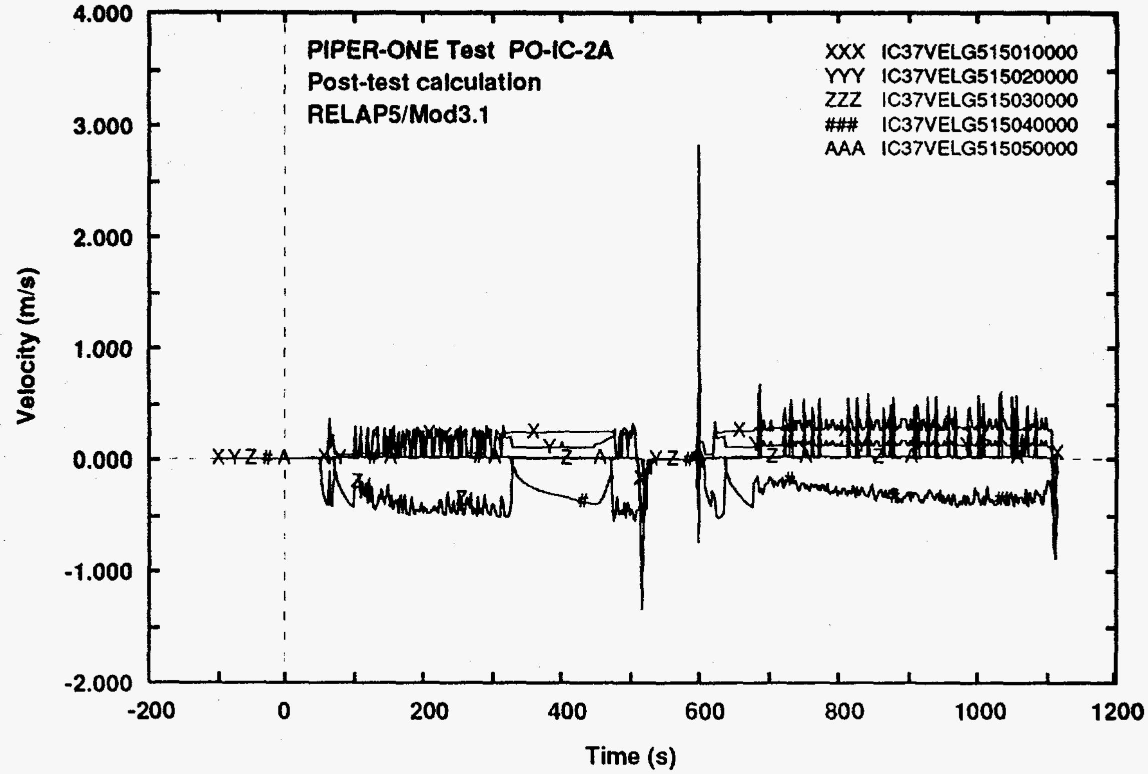

Fig. 37 - Calculated trends of IC tubes steam velocity along the axis

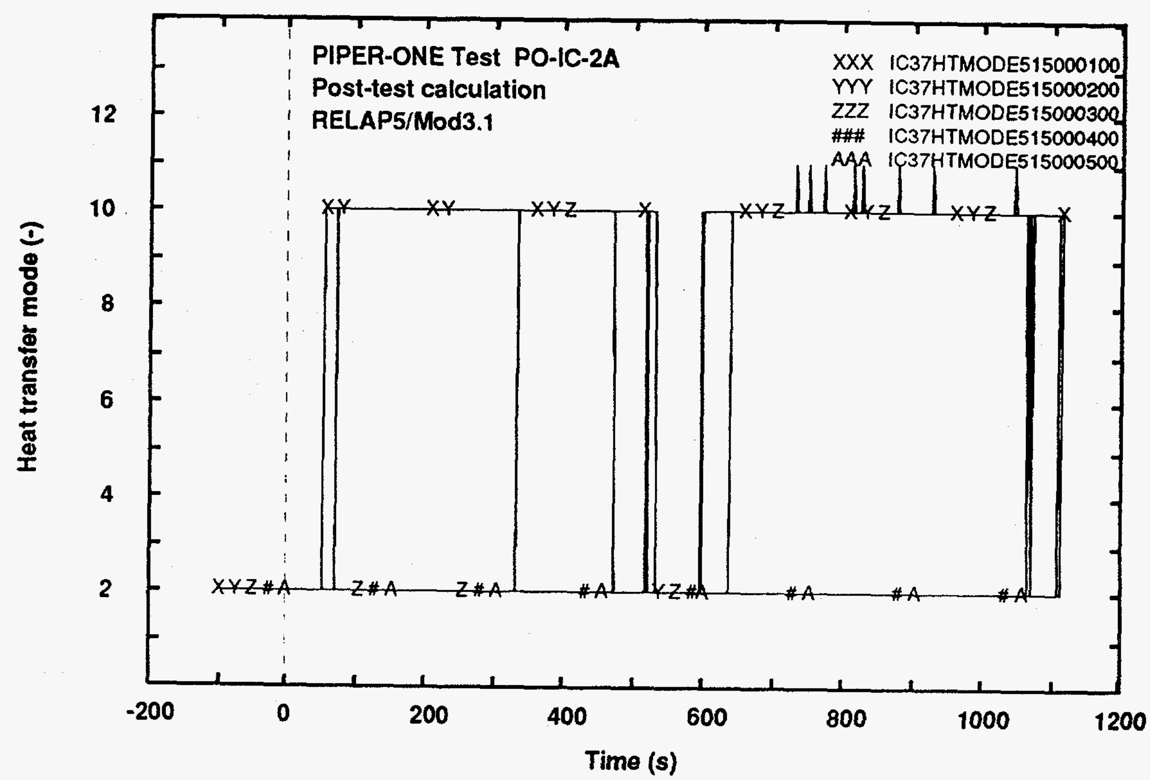

Fig. 38 - Calculated trends of IC tubes heat transfer mode (internal side)

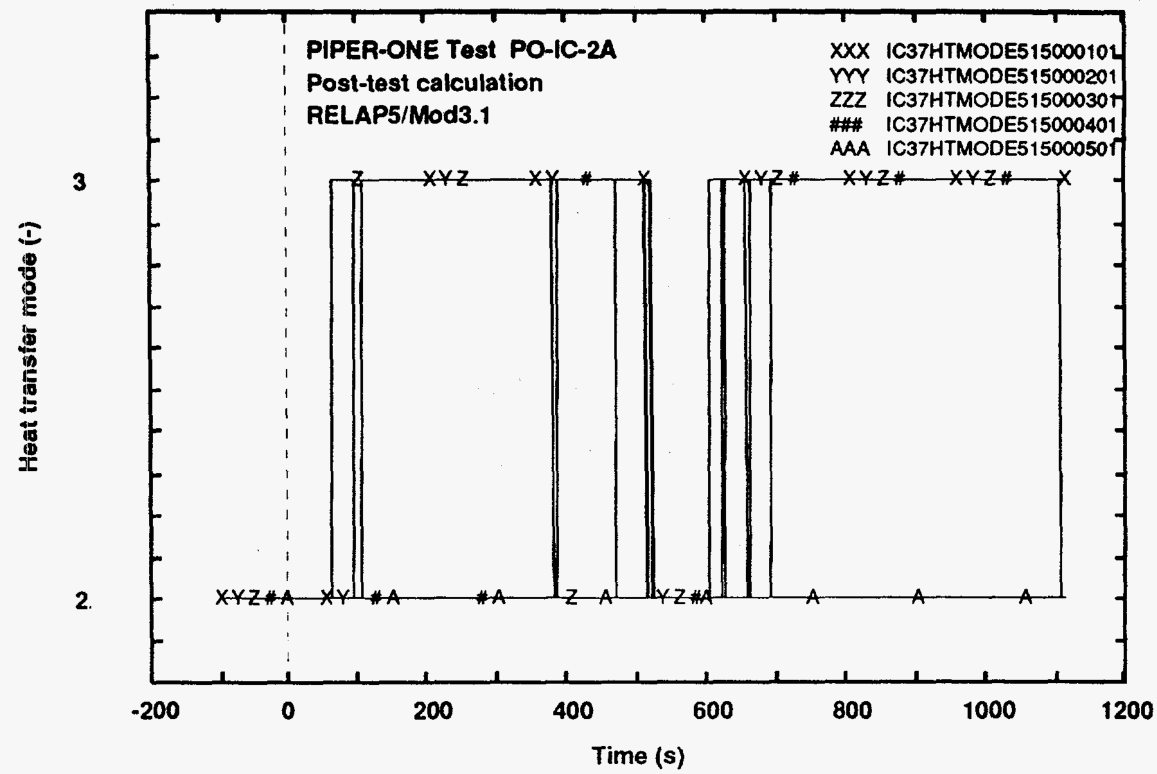

Fig. 39 - Calculated trends of IC tubes heat transfer mode (external side)

APPENDIX 4:

ICA6 Results

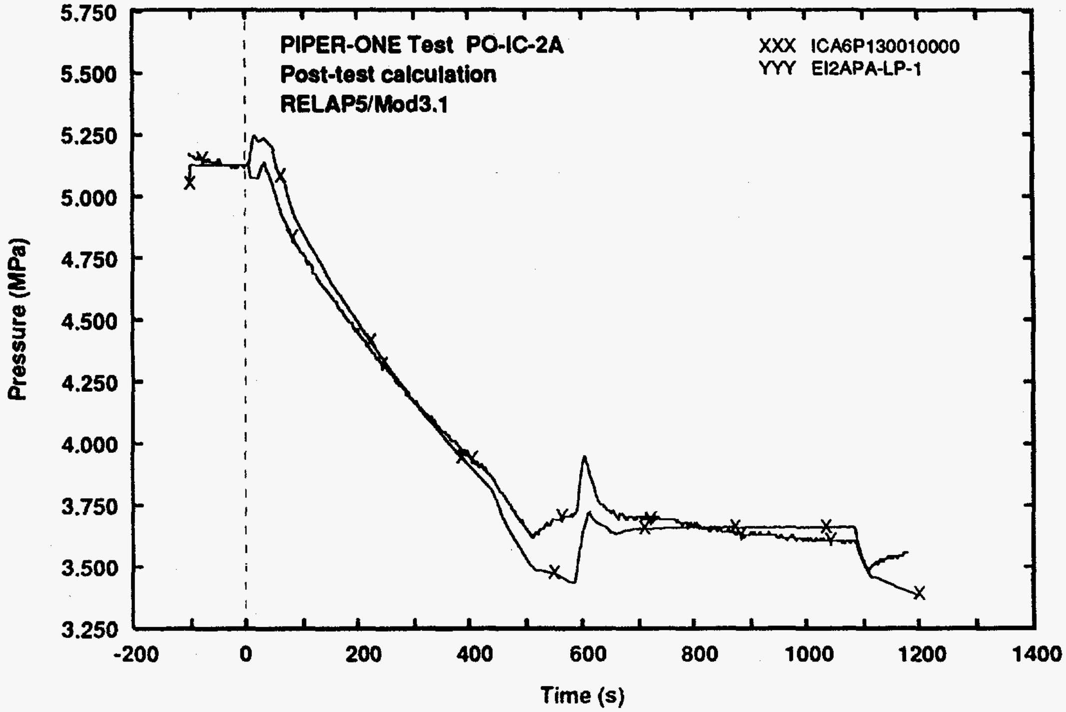

Fig. 1 - Measured and predicted trends of lower plenum pressure

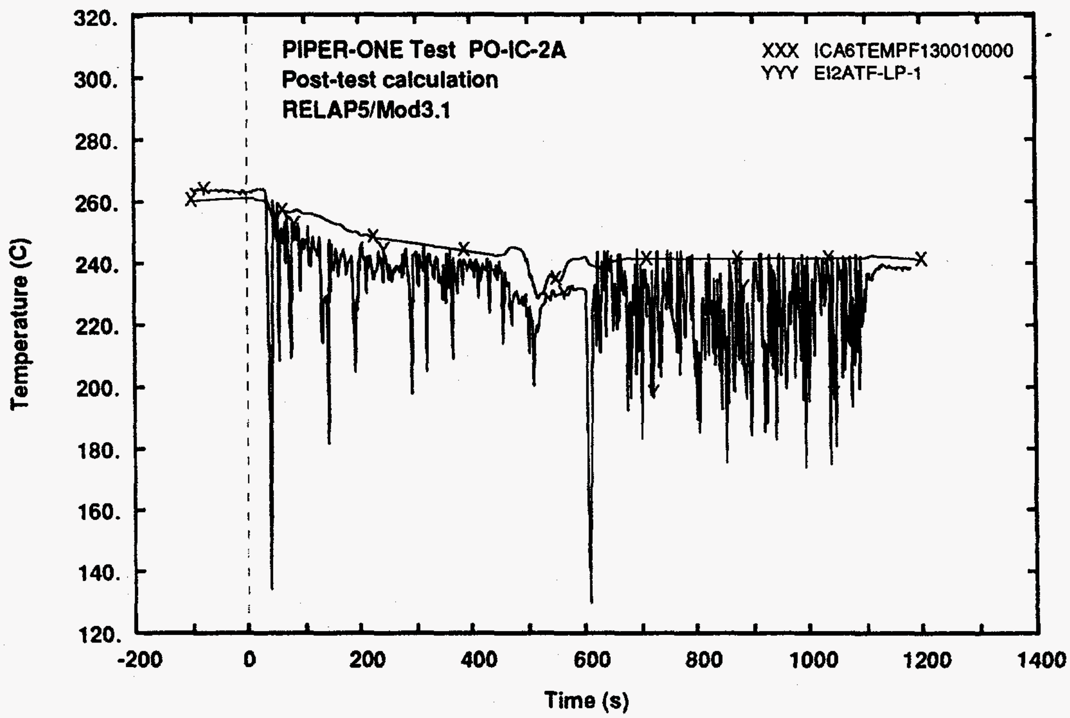

Fig. 2 - Measured and calculated trends of lower plenum temperature

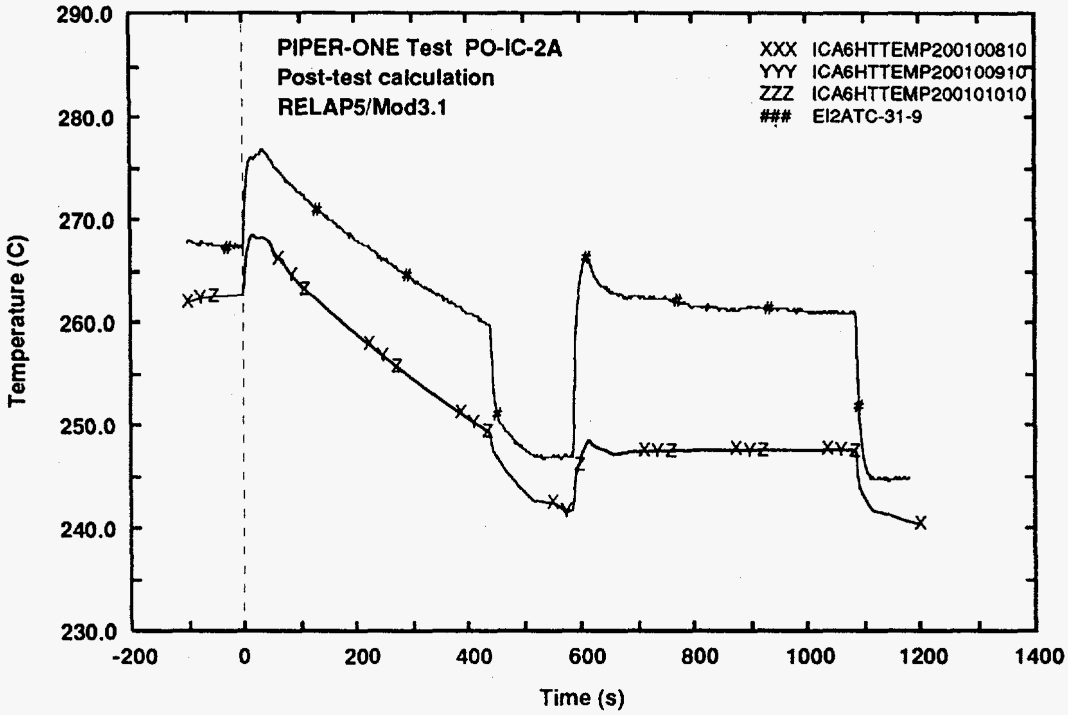

Fig. 3 - Measured and calculated trends of rod surface temperature (level 9)

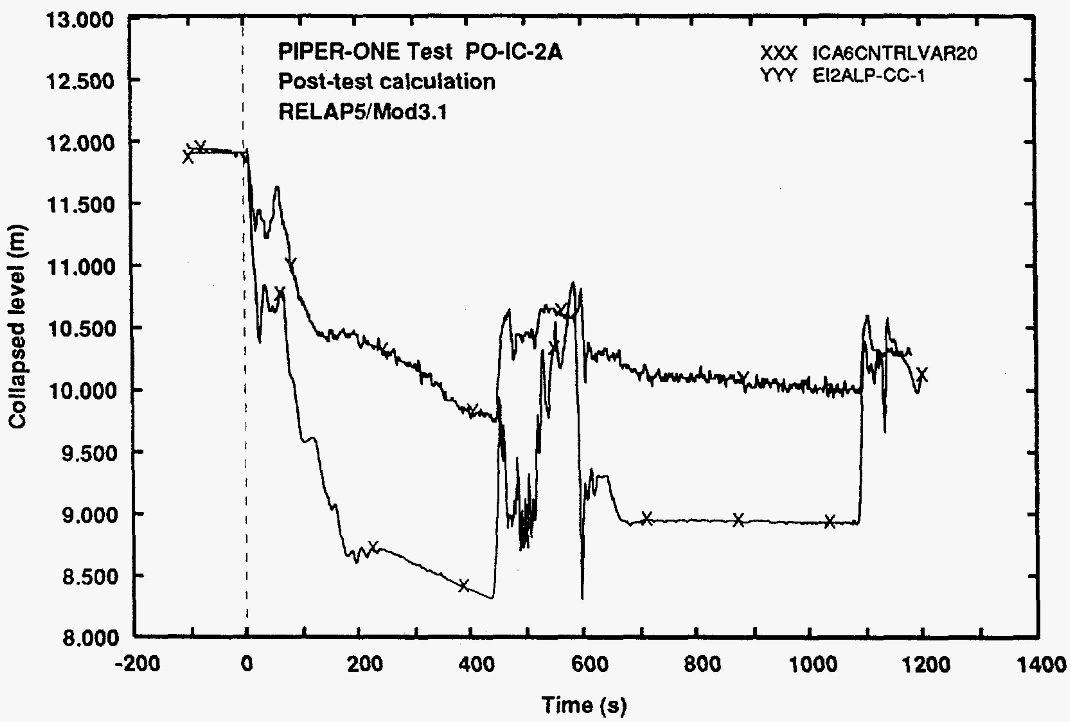

Fig. 4 - Measured and calculated trends of core level

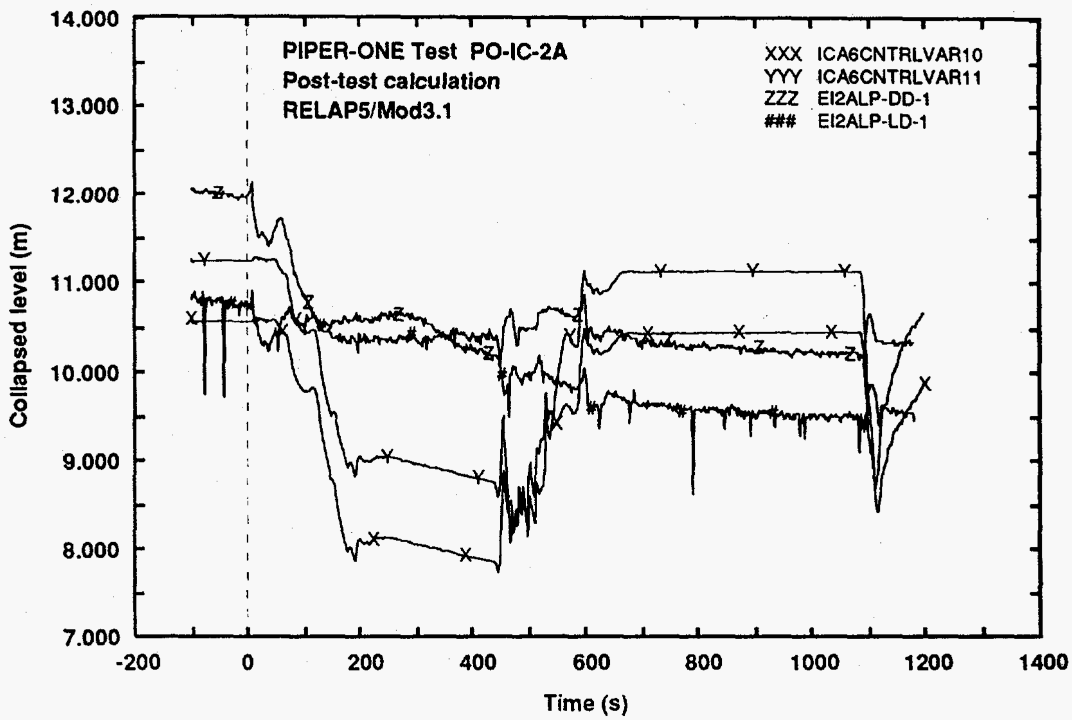

Fig. 5 - Measured and calculated trends of downcomer level

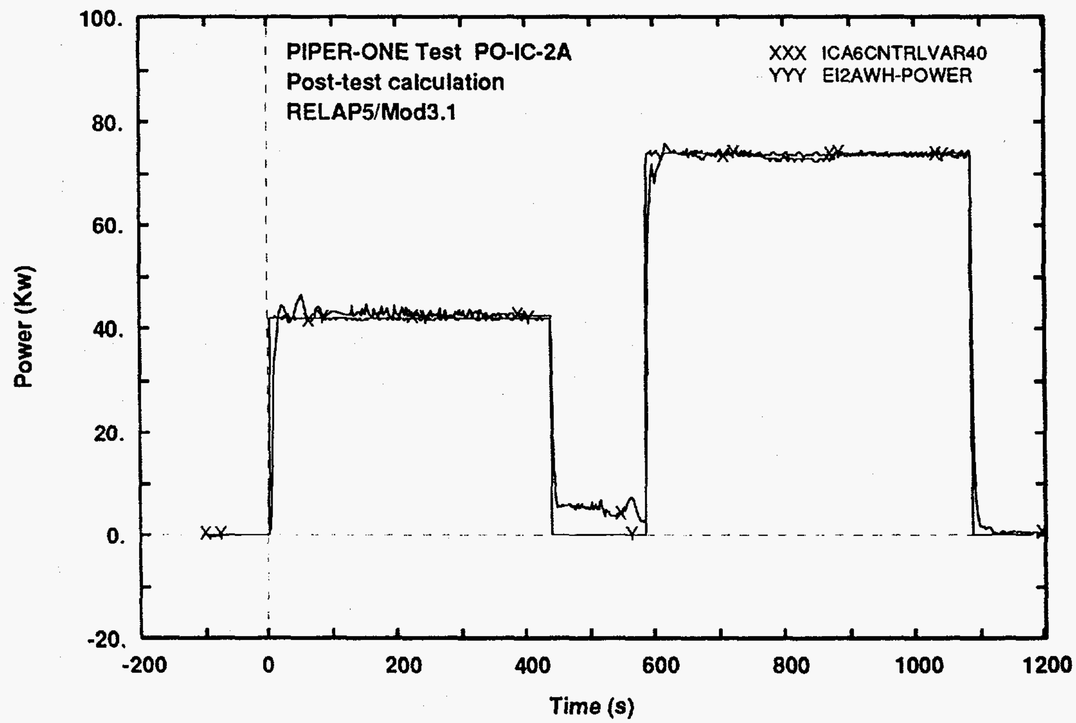

Fig. 6 - Measured and calculated trends of core power

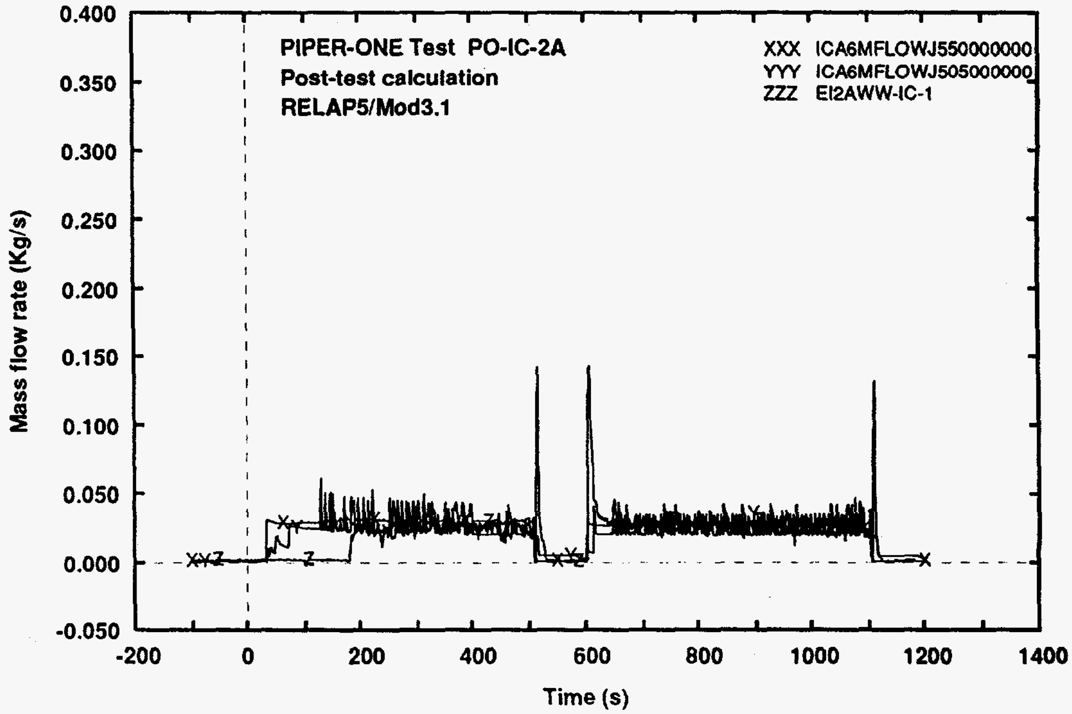

Fig. 7 - Measured and calculated trends of IC mass flow rate

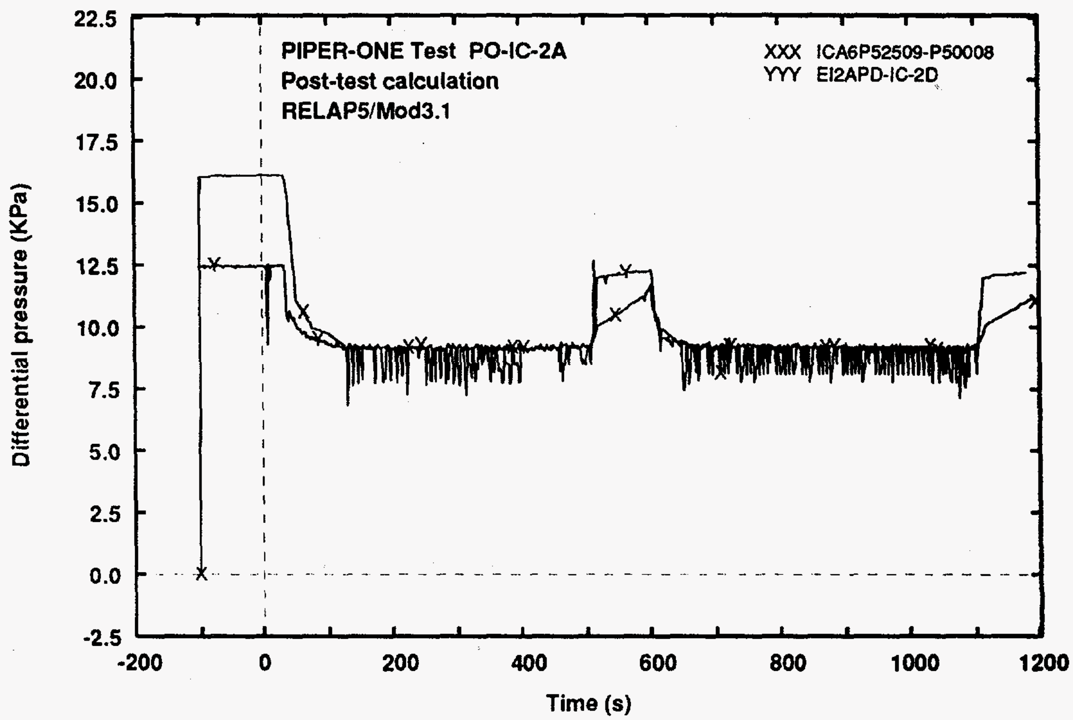

Fig. 8 - Measured and calculated trends of IC differential pressure

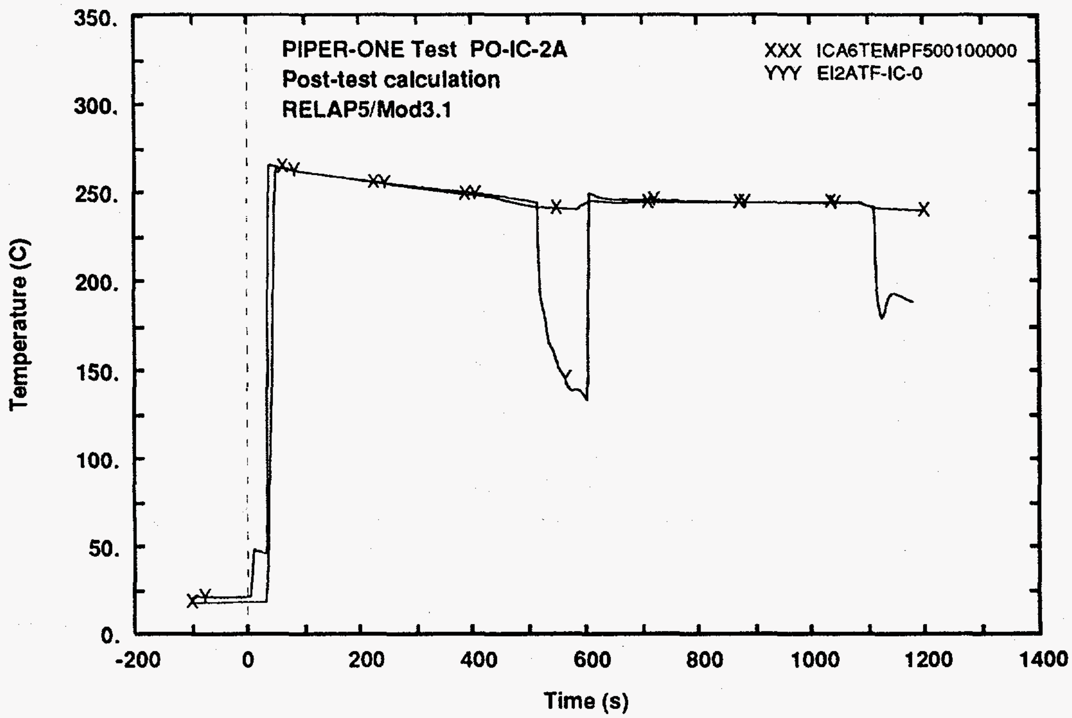

Fig. 9 - Measured and calculated trends of IC inlet fluid temperature

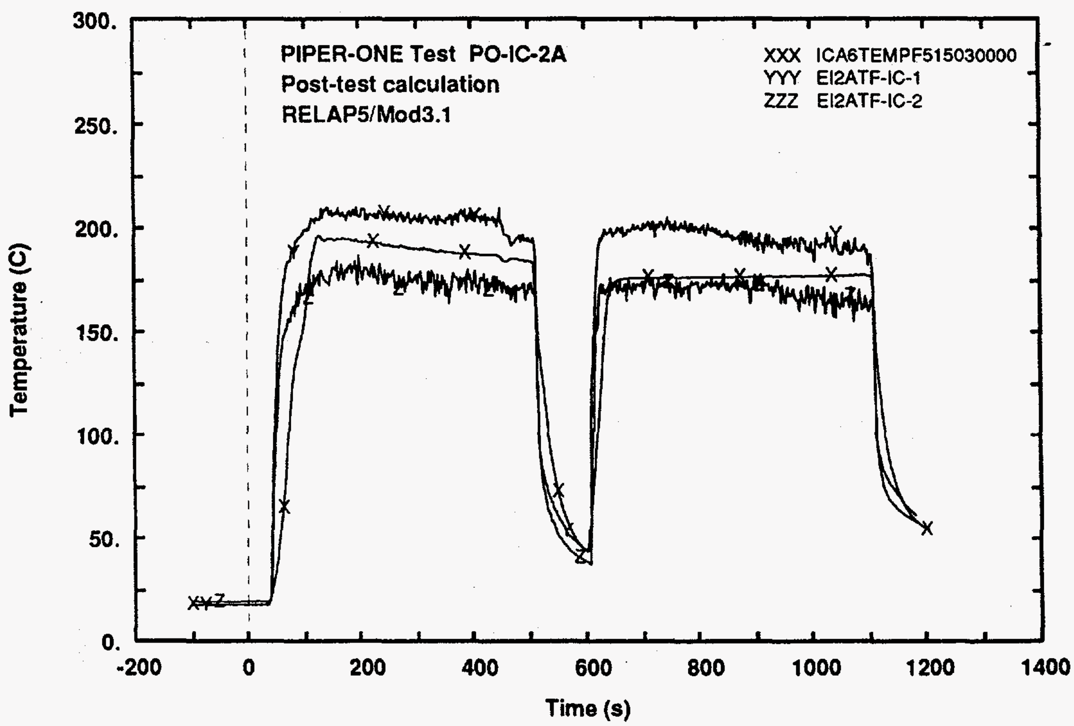

Fig. 10 - Measured and calculated trends of IC tubes fluid temperature (middle elevation)

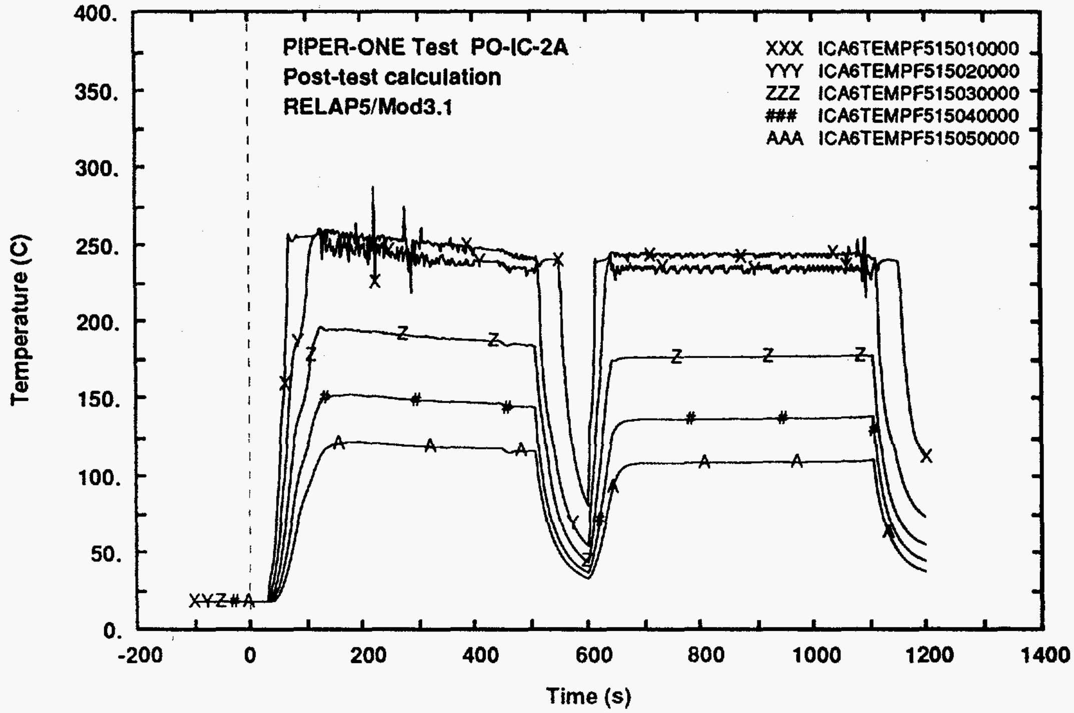

Fig. 11 - Calculated trends of IC tubes fluid temperature along the axis

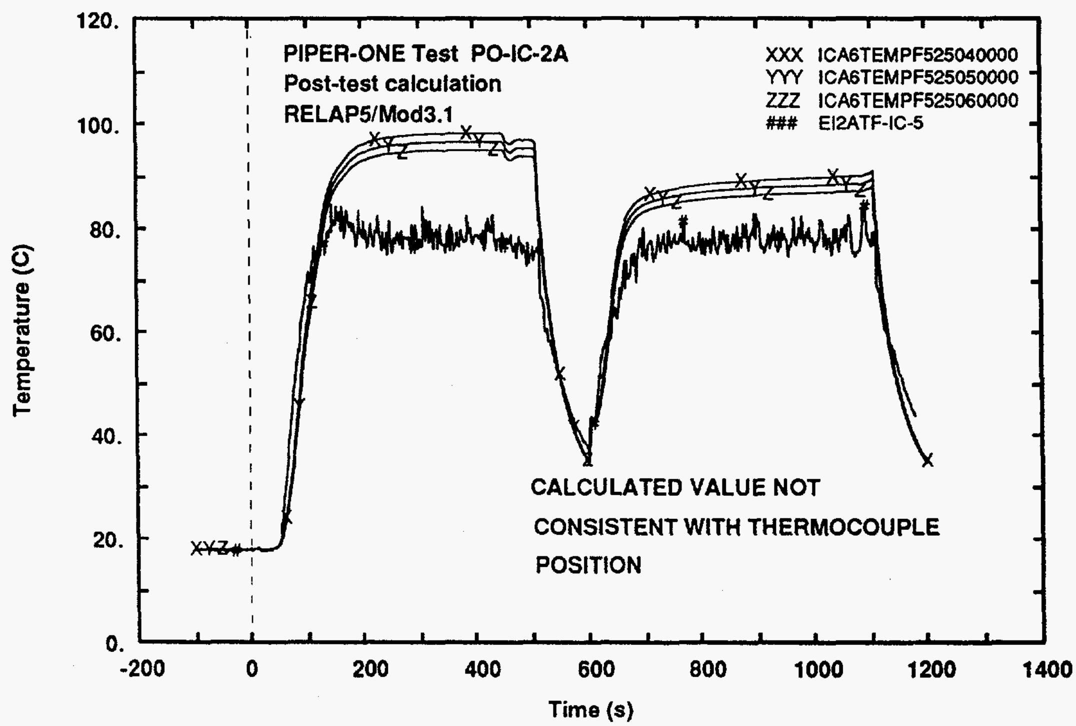

Fig. 12 - Measured and calculated trends of IC outlet fluid temperature

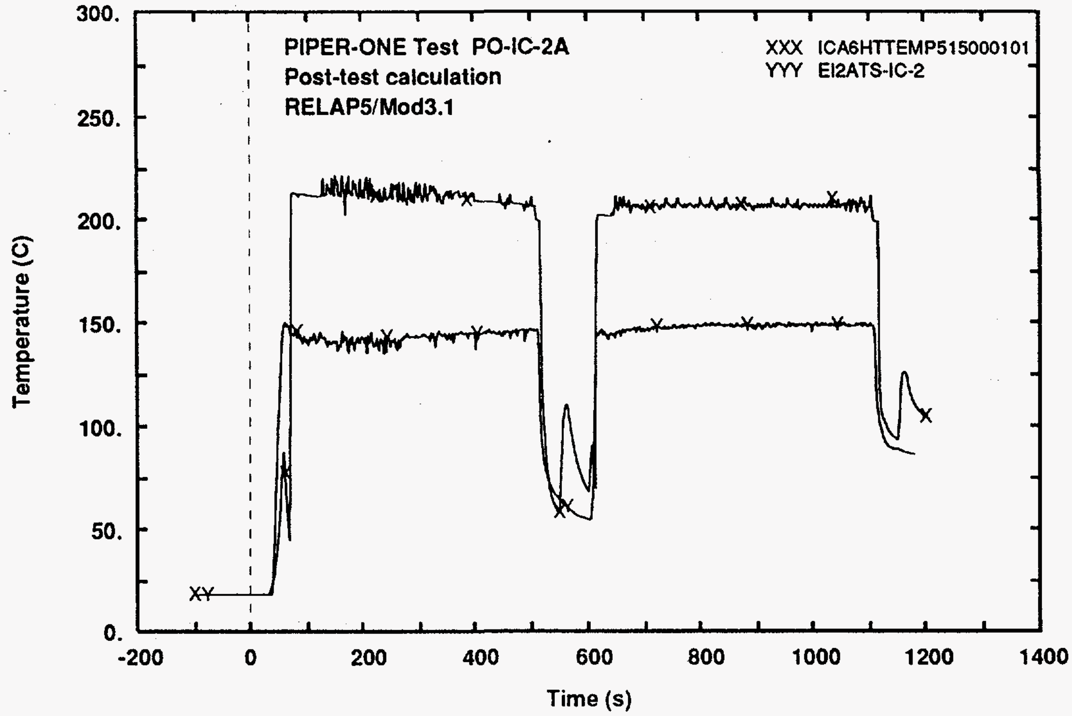

Fig. 13 - Measured and calculated trends of IC tubes wall surface temperature (internal side top elevation)

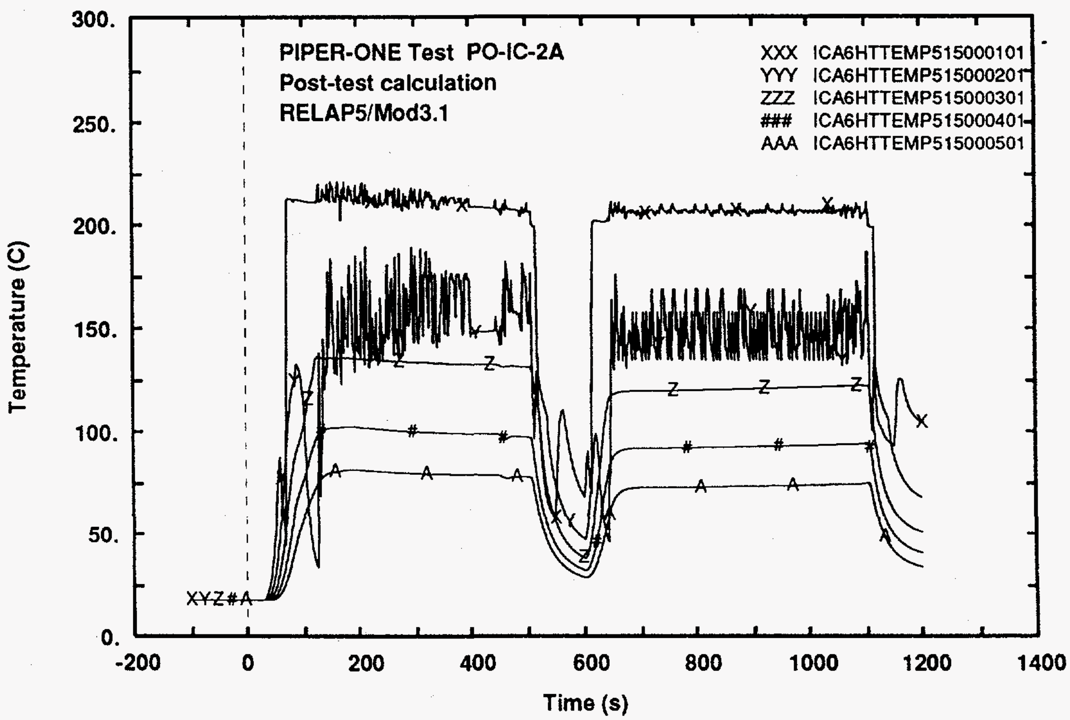

Fig. 14 - Calculated trends of IC tubes wall surface temperature along the axis (internal side)

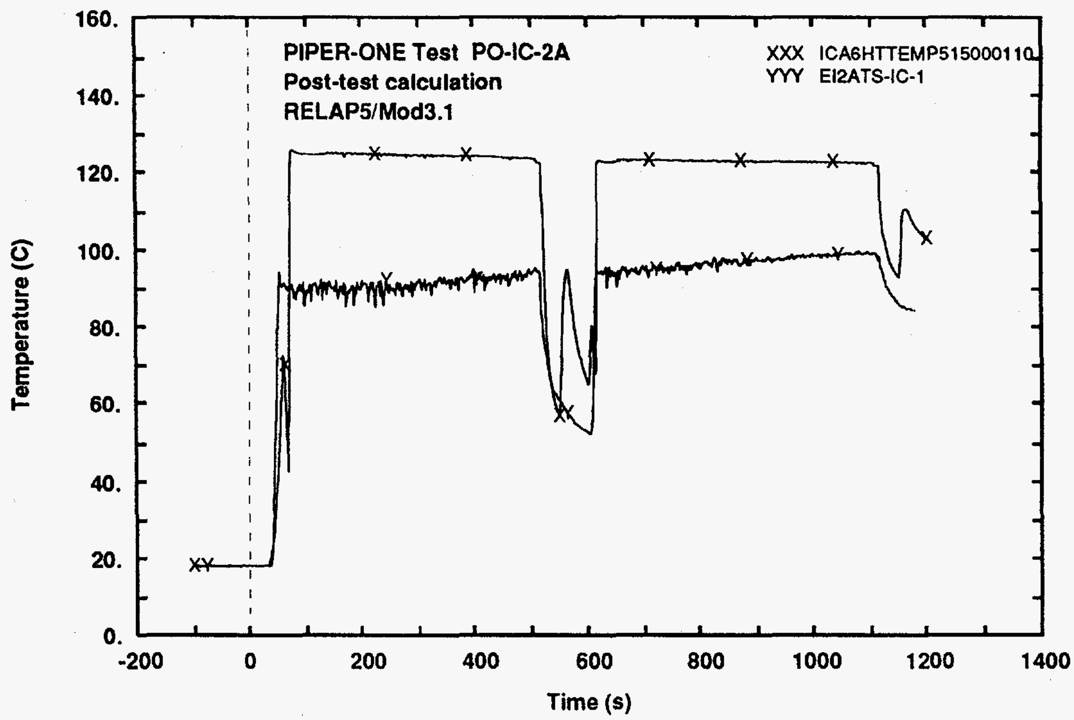

Fig. 15 - Measured and calculated trends of IC tubes wall surface temperature (external side top elevation)

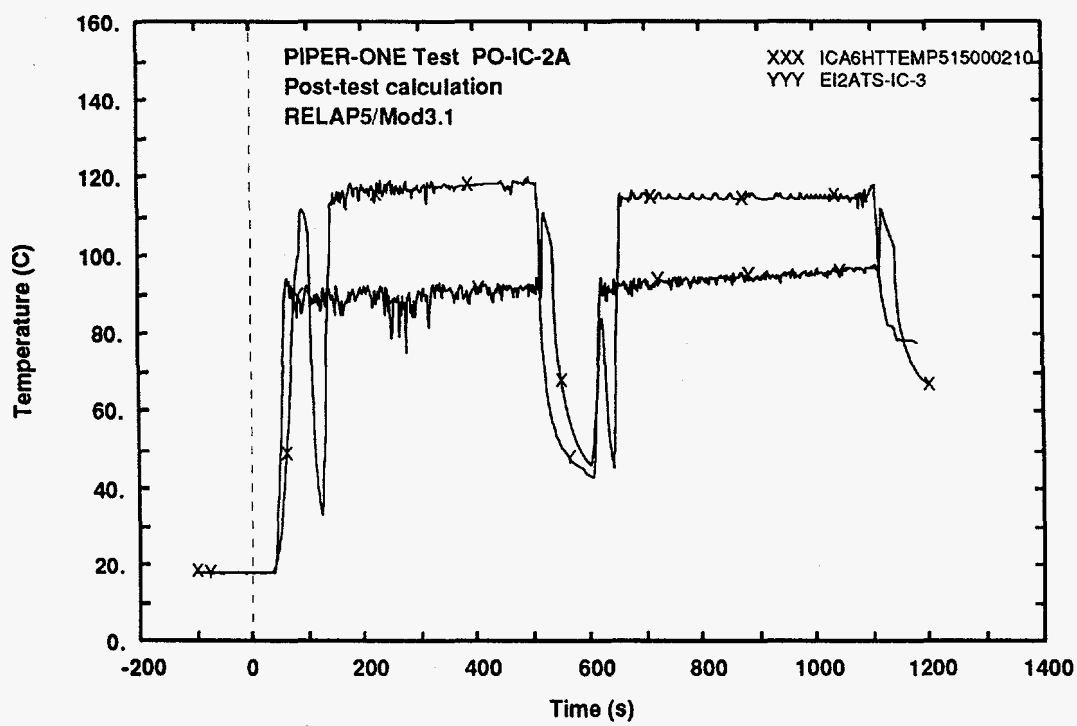

Fig. 16 - Measured and calculated trends of IC tubes wall surface temperature (external side level 3)

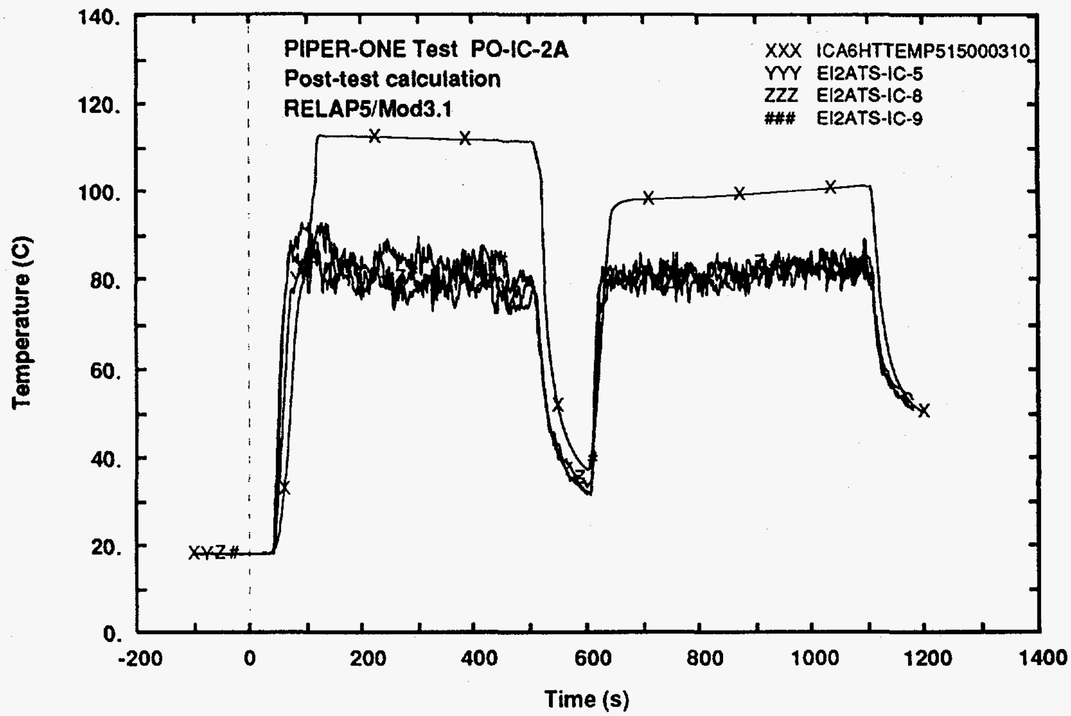

Fig. 17 - Measured and calculated trends of IC tubes wall surface temperature (external side middle elevation)

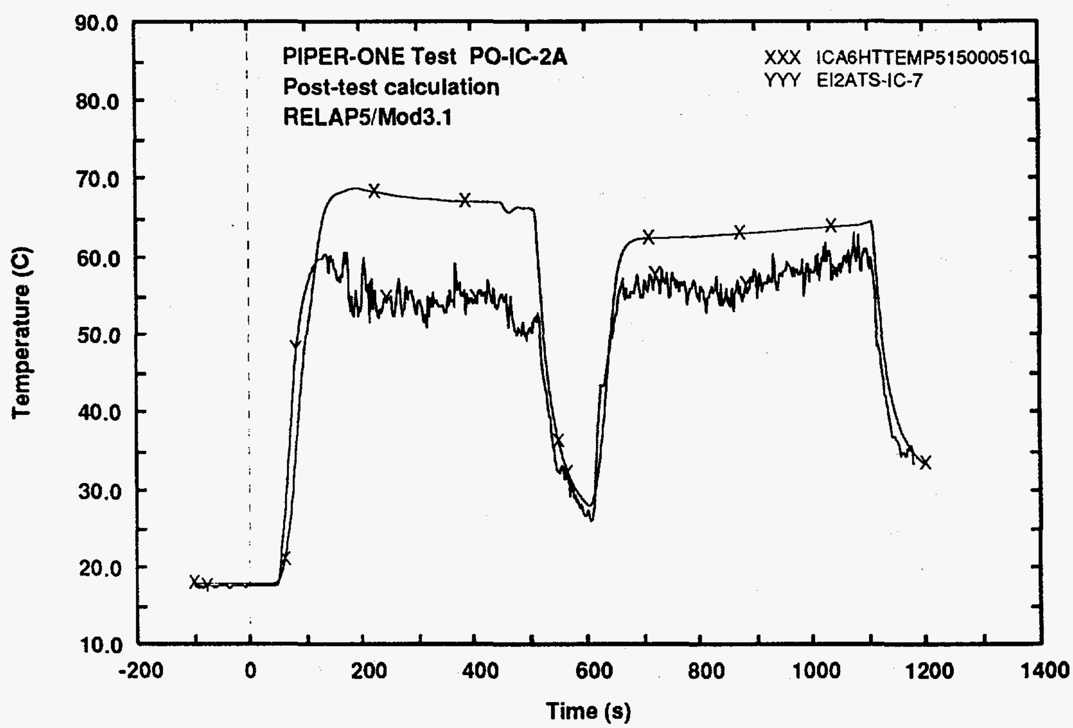

Fig. 18 - Measured and calculated trends of IC tubes wall surface temperature (external side bottom elevation)

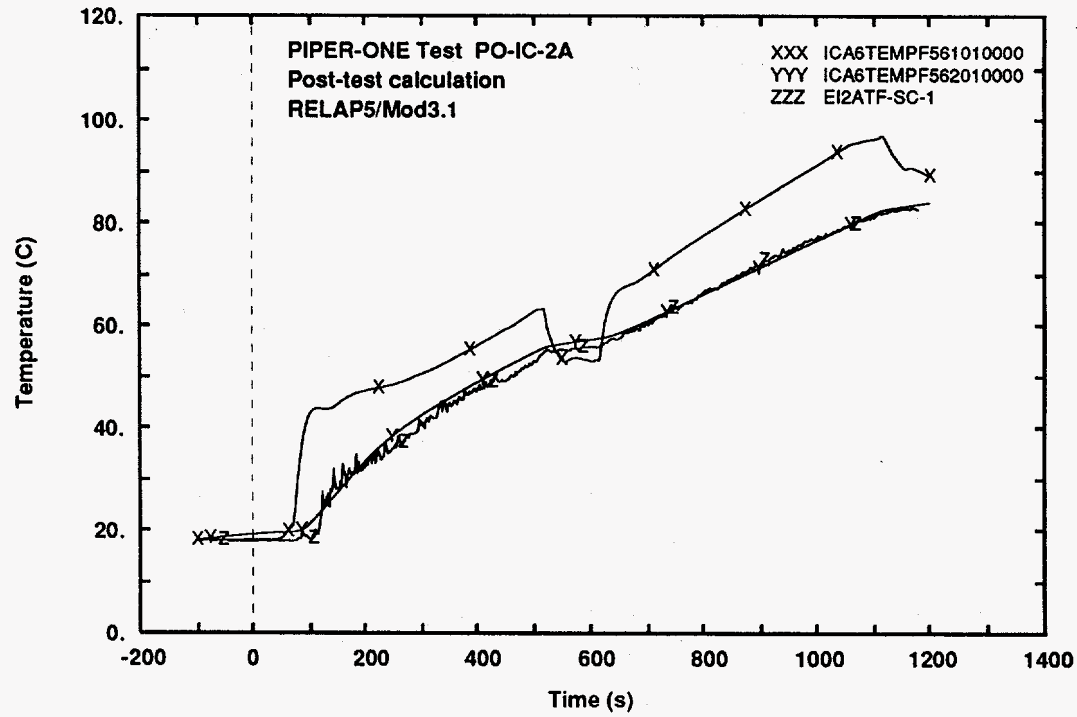

Fig. 19 - Measured and calculated trends of IC internal pool fluid temperature (top level)

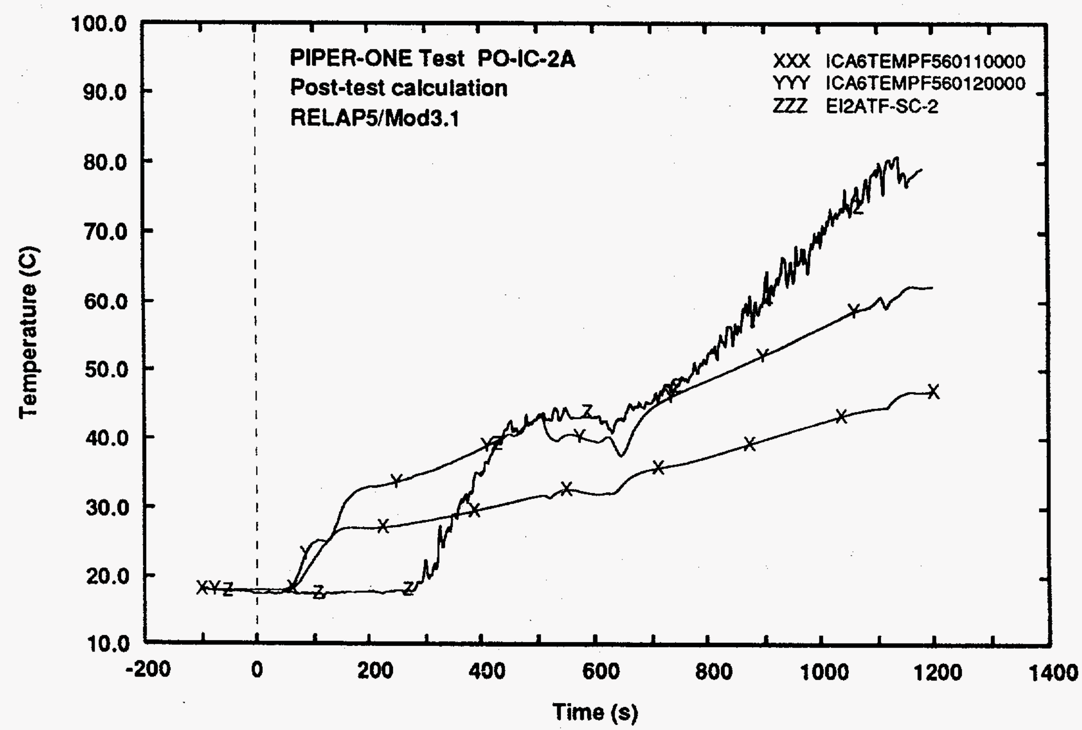

Fig. 20 - Measured and calculated trends of IC internal pool fluid temperature (level 2)

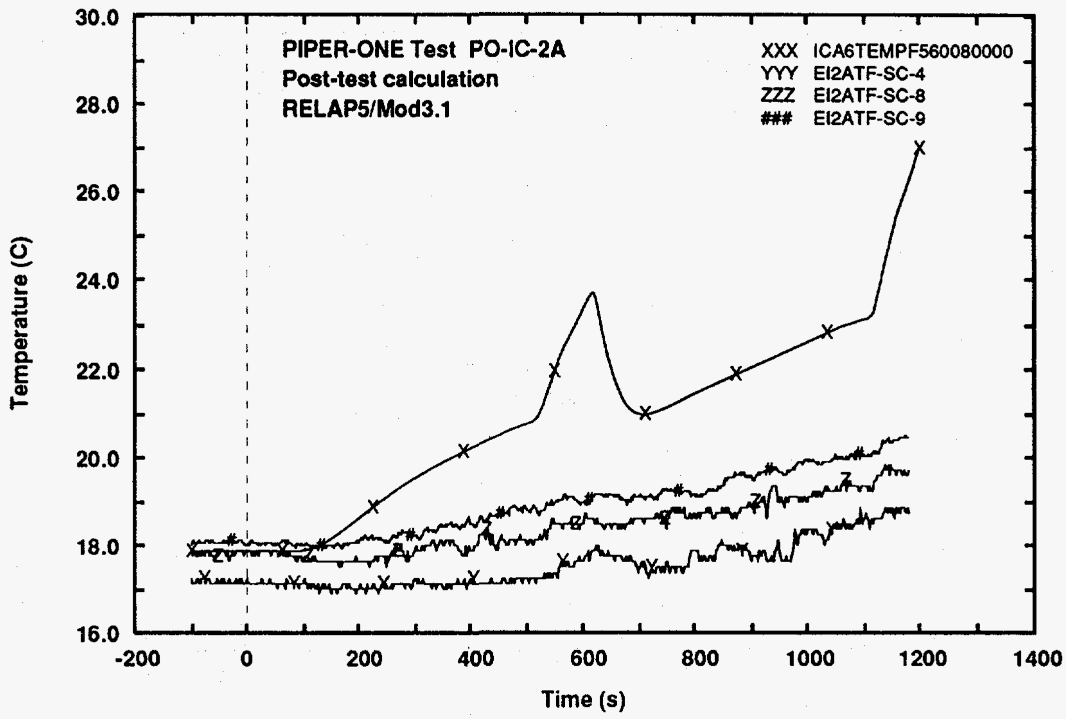

Fig. 21 - Measured and calculated trends of IC internal pool fluid temperature (middle level)

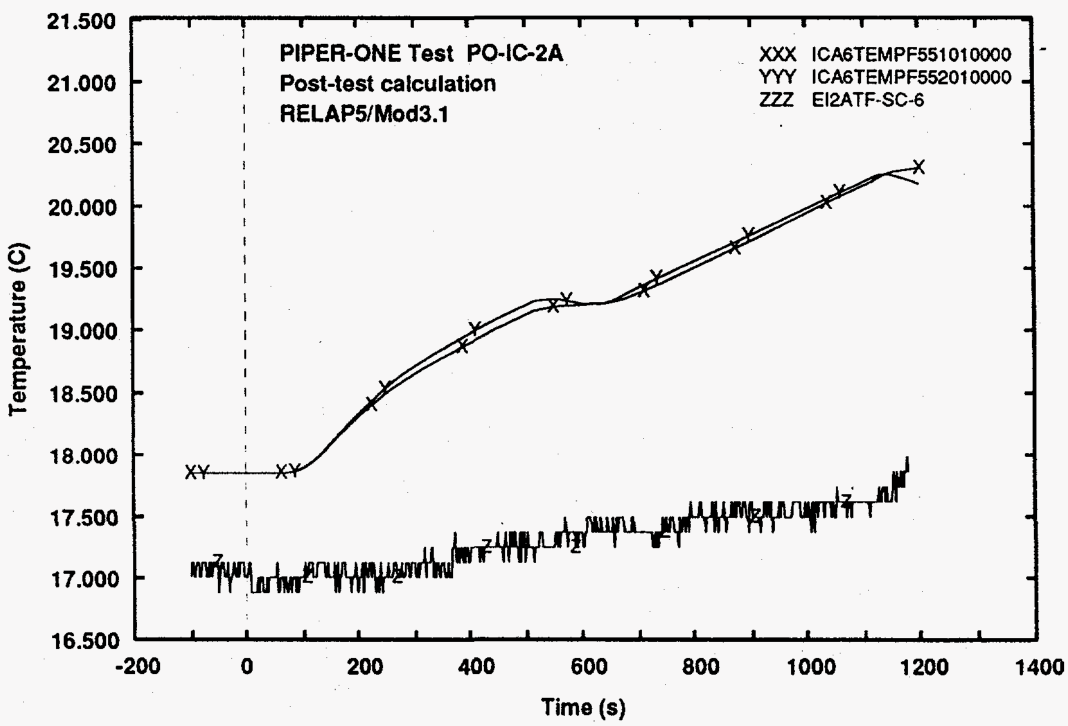

Fig. 22 - Measured and calculated trends of IC internal pool fluid temperature (bottom level)

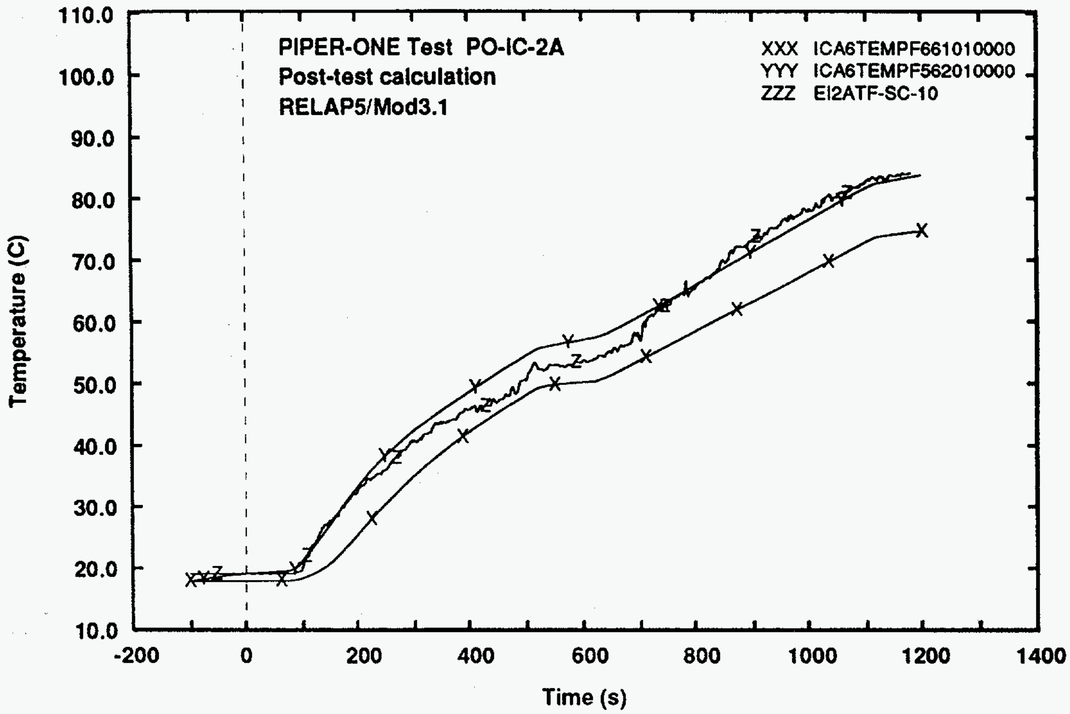

Fig. 23 - Measured and calculated trends of IC external pool fluid temperature (top level)

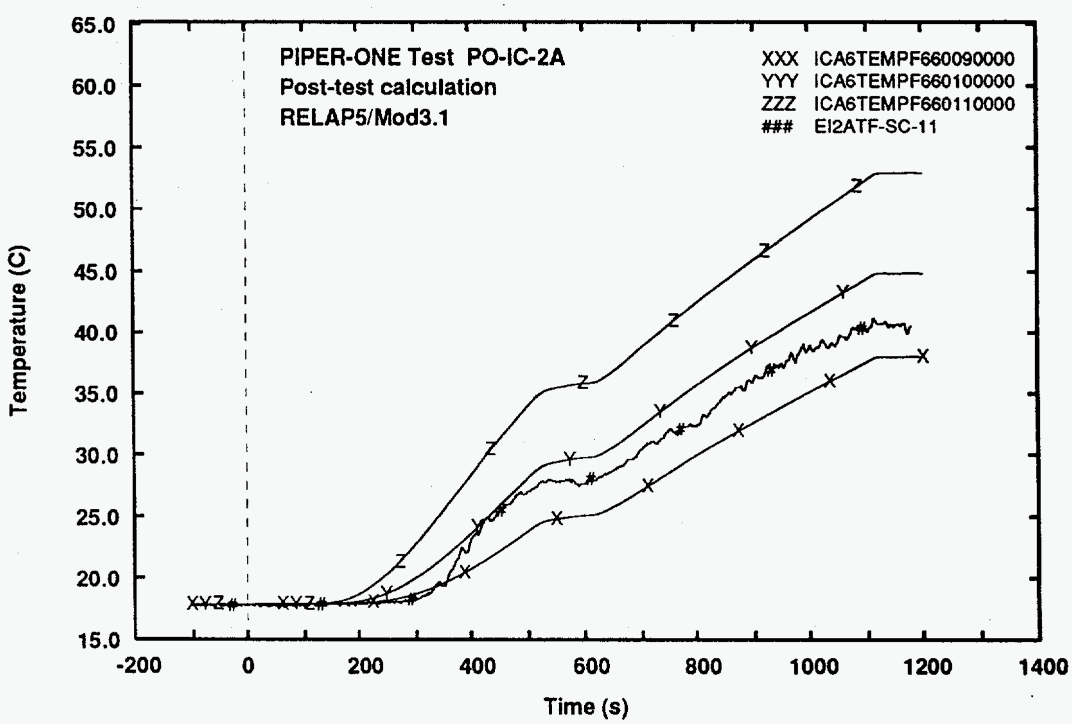

Fig. 24 - Measured and calculated trends of IC external pool fluid temperature (level 11)

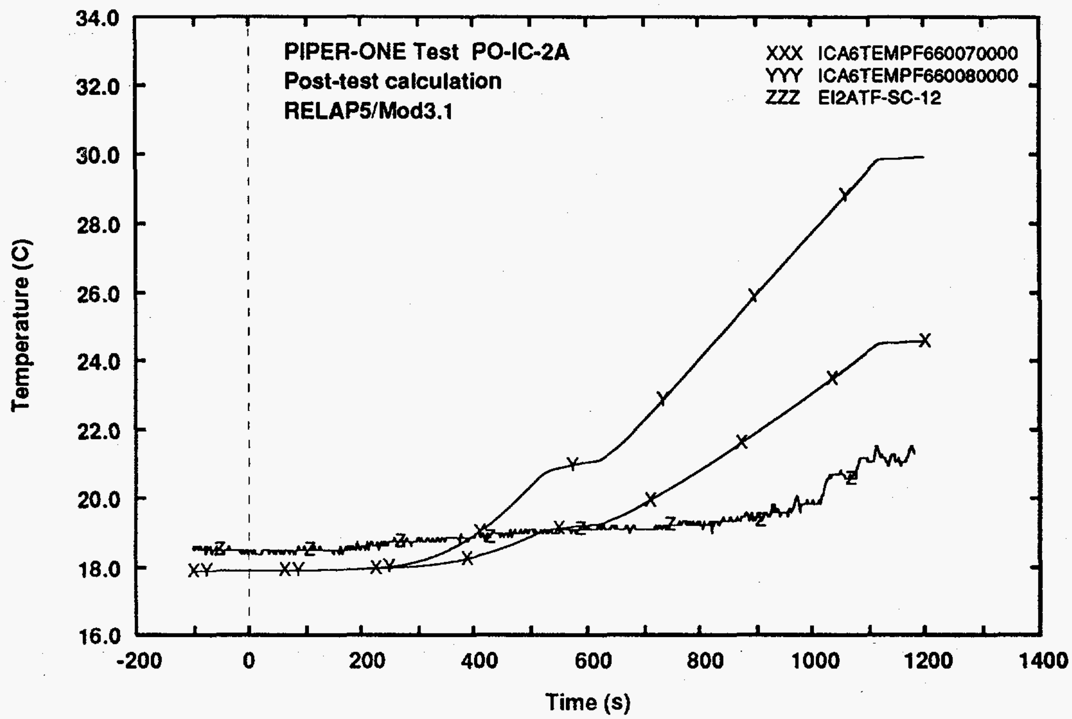

Fig. 25 - Measured and calculated trends of IC external pool fluid temperature (middle level)

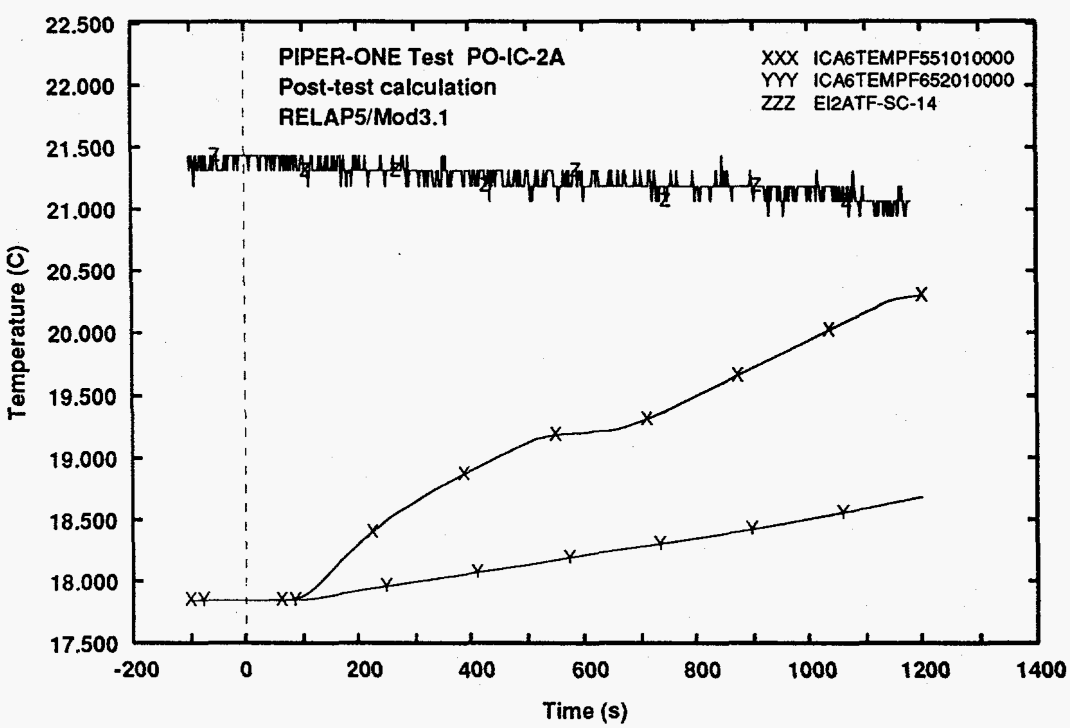

Fig. 26 - Measured and calculated trends of IC external pool fluid temperature (bottom level)

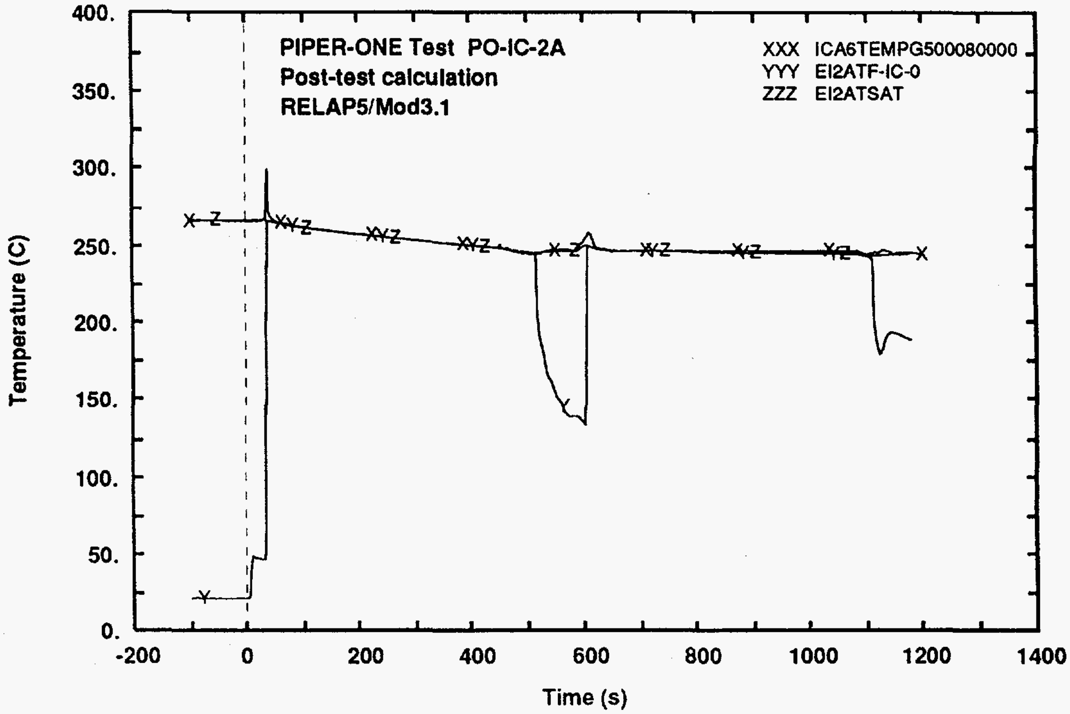

Fig. 27 - Measured and calculated trends of steam temperature at IC inlet compared with experimental saturated temperature

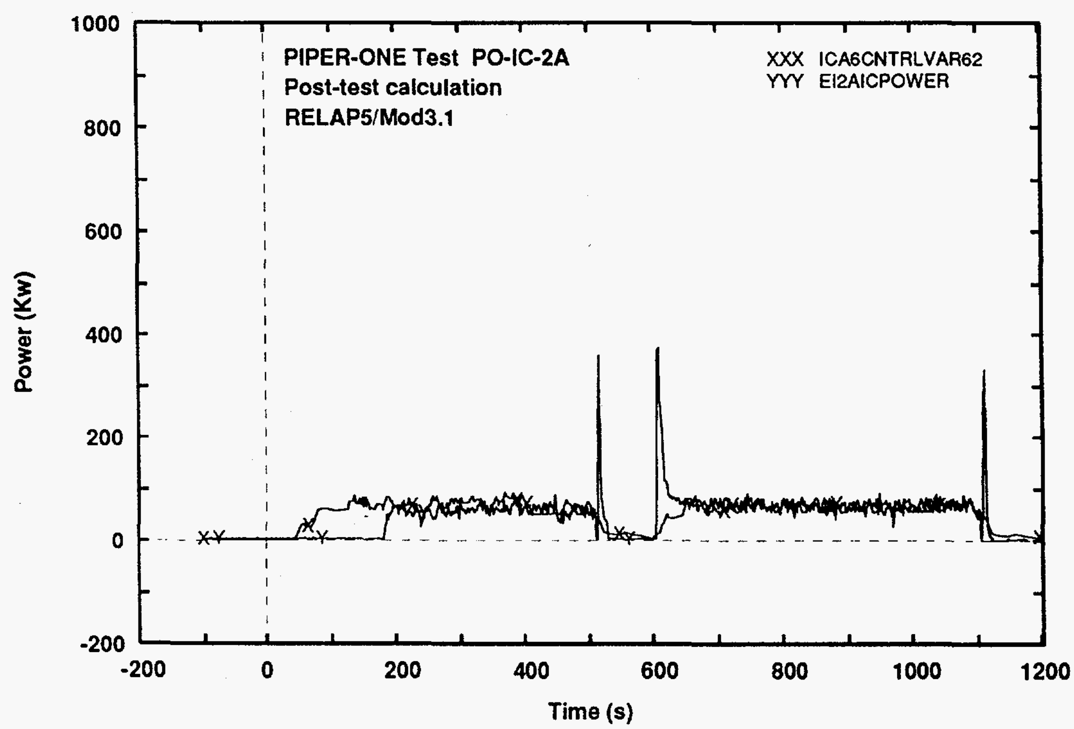

Fig. 28 - Measured and calculated trends of IC exchanged power

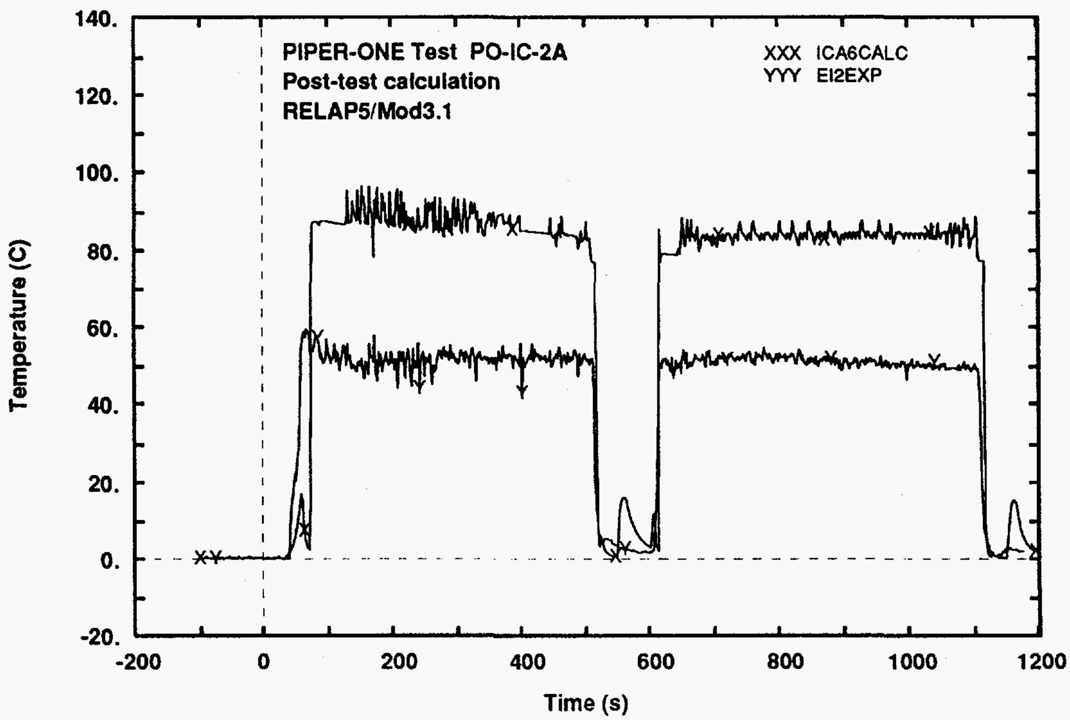

Fig. 29 - Measured and calculated trends of temperature difference between internal and external side of IC tubes wall (top elevation)

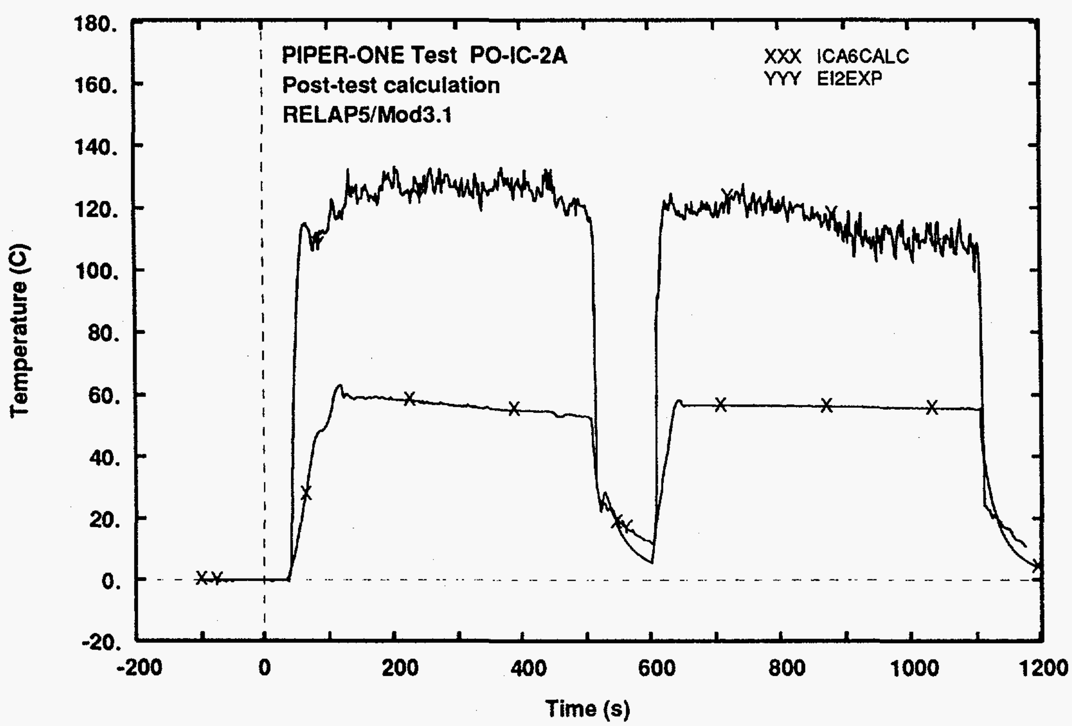

Fig. 30 - Measured and calculated trends of temperature difference between IC fluid and external side of IC tubes wall (middle elevation)

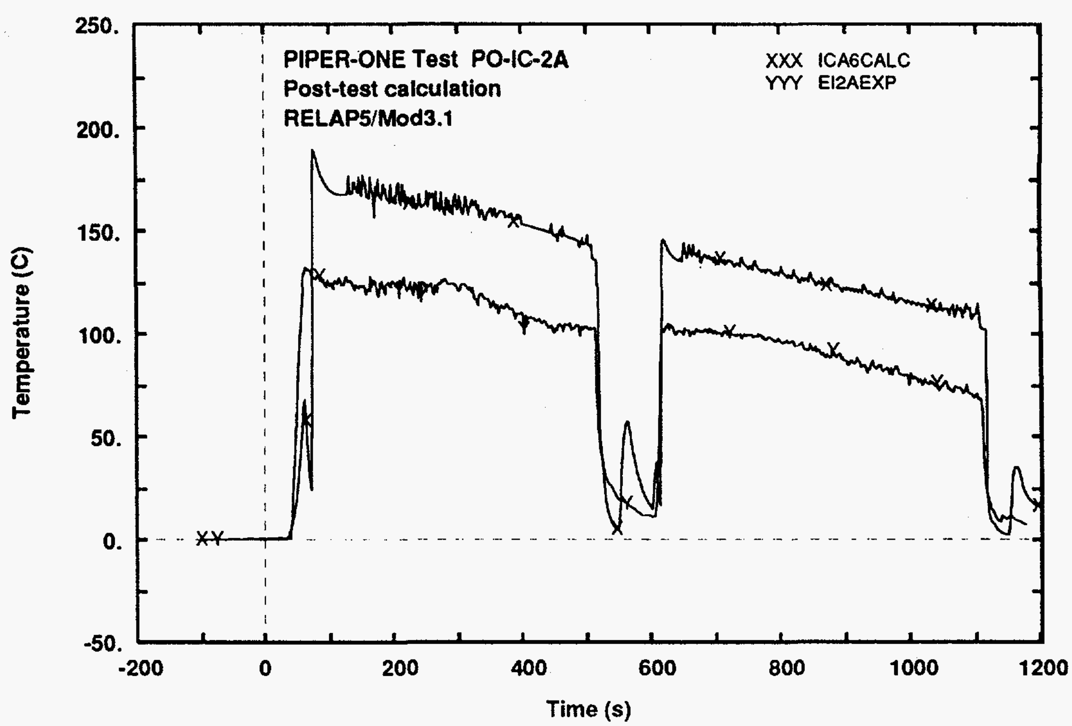

Fig. 31 - Measured and calculated trends of temperature difference between internal side of IC tubes wall and IC pool fluid temperature (top elevation)

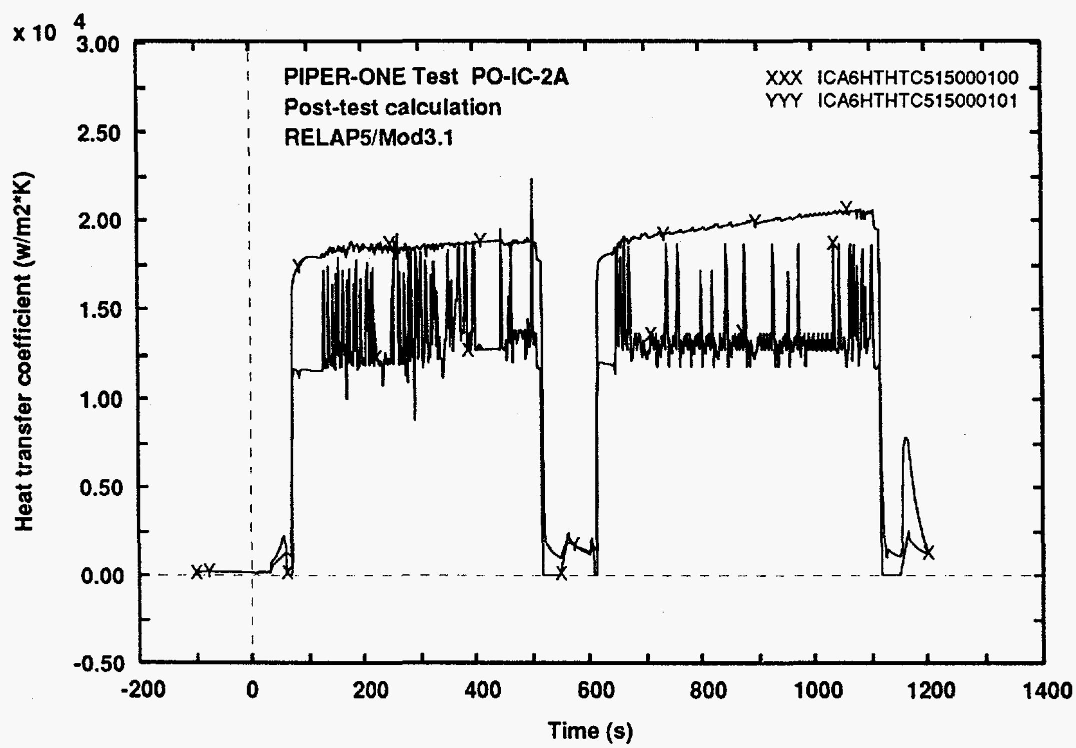

Fig. 32 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (top elevation)

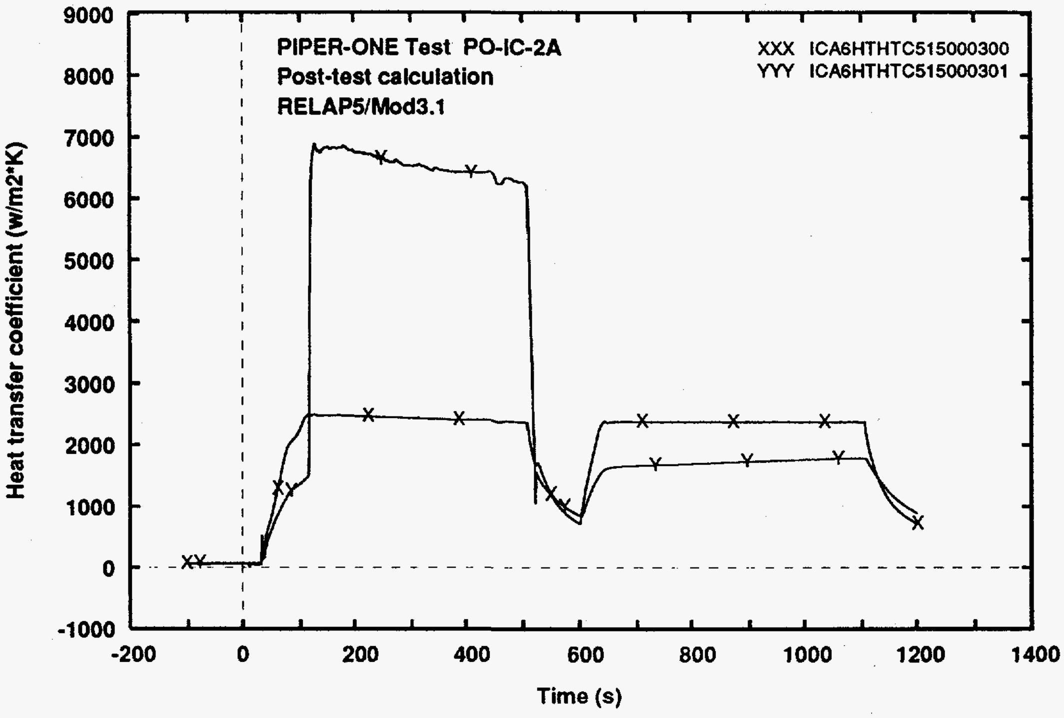

Fig. 33 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (middle elevation)

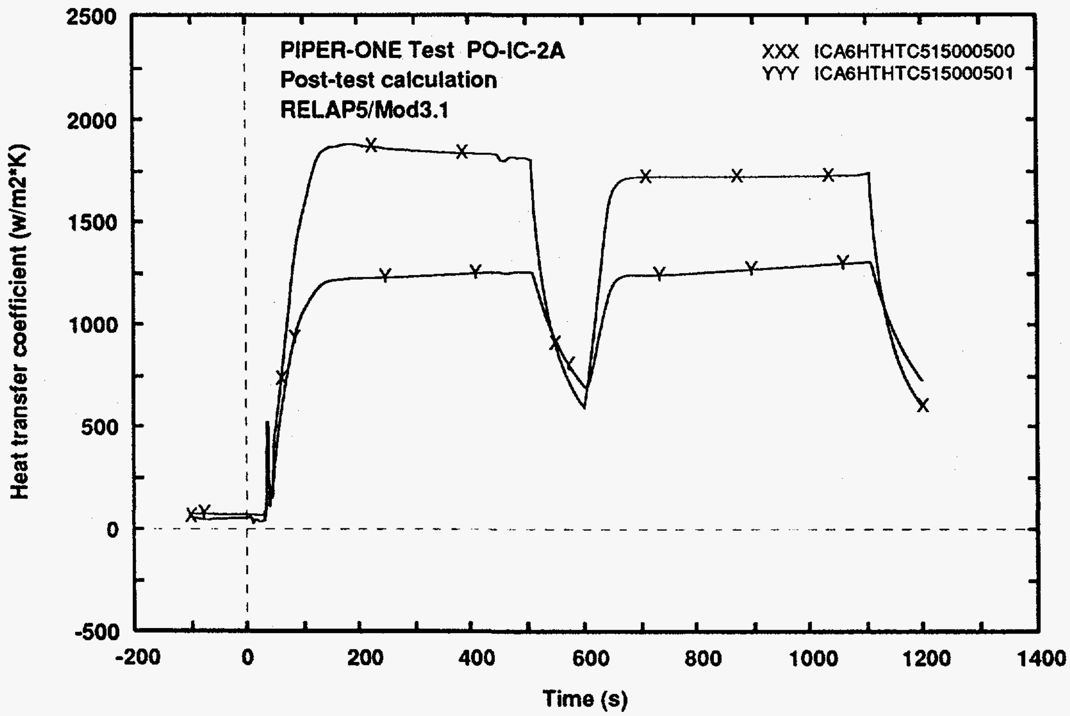

Fig. 34 - Calculated trends of the heat transfer coefficient at the inside and the outside of IC tubes wall (bottom elevation)

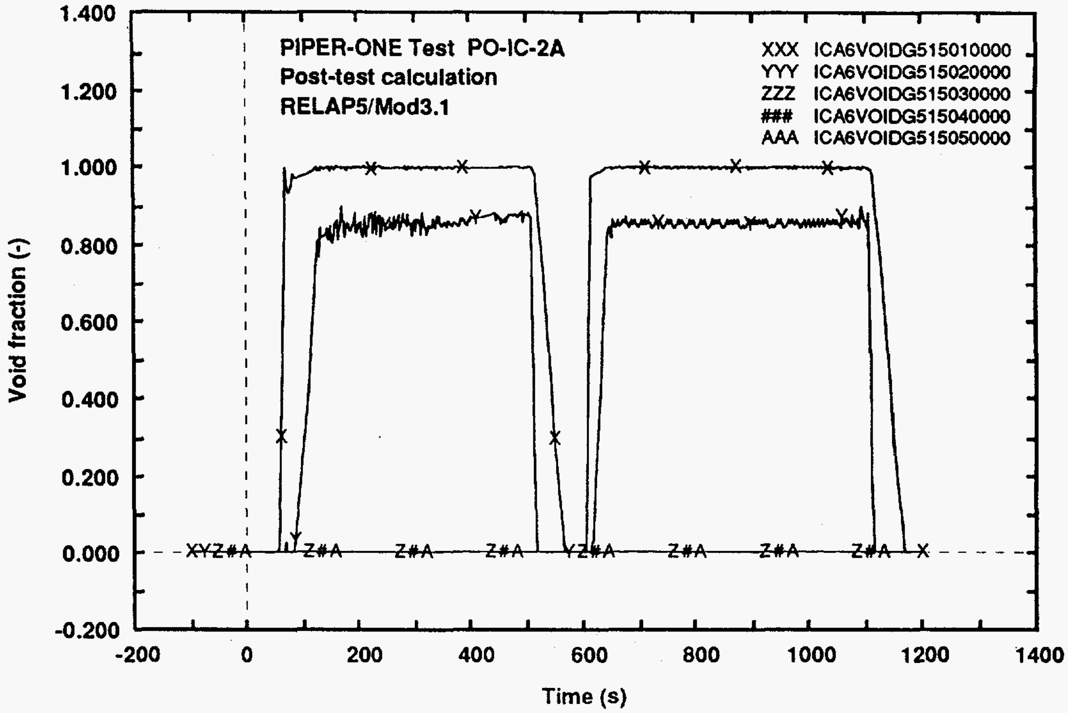

Fig. 35 - Calculated trends of IC tubes void fraction along the axis

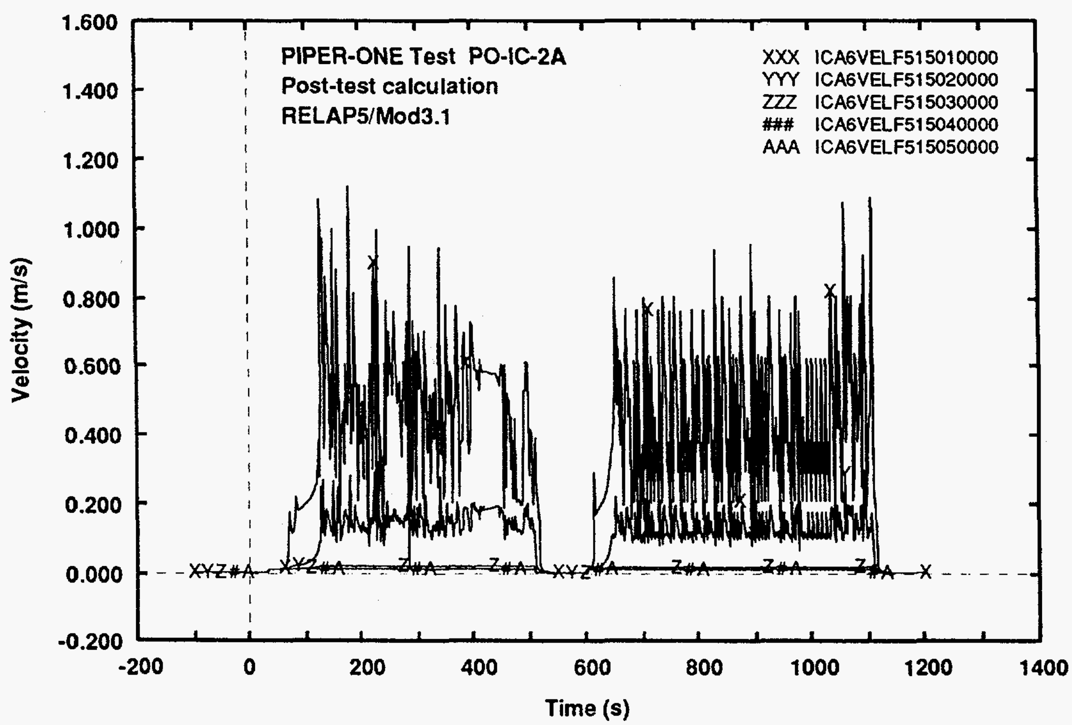

Fig. 36 - Calculated trends of IC tubes liquid velocity along the axis

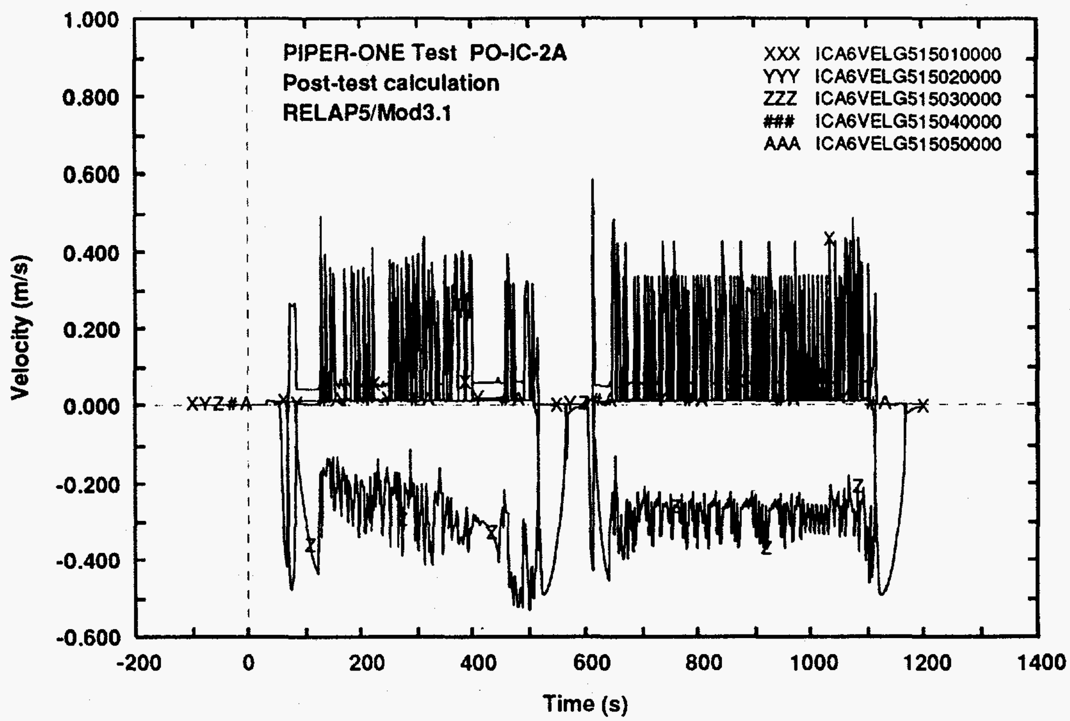

Fig. 37 - Calculated trends of IC tubes steam velocity along the axis

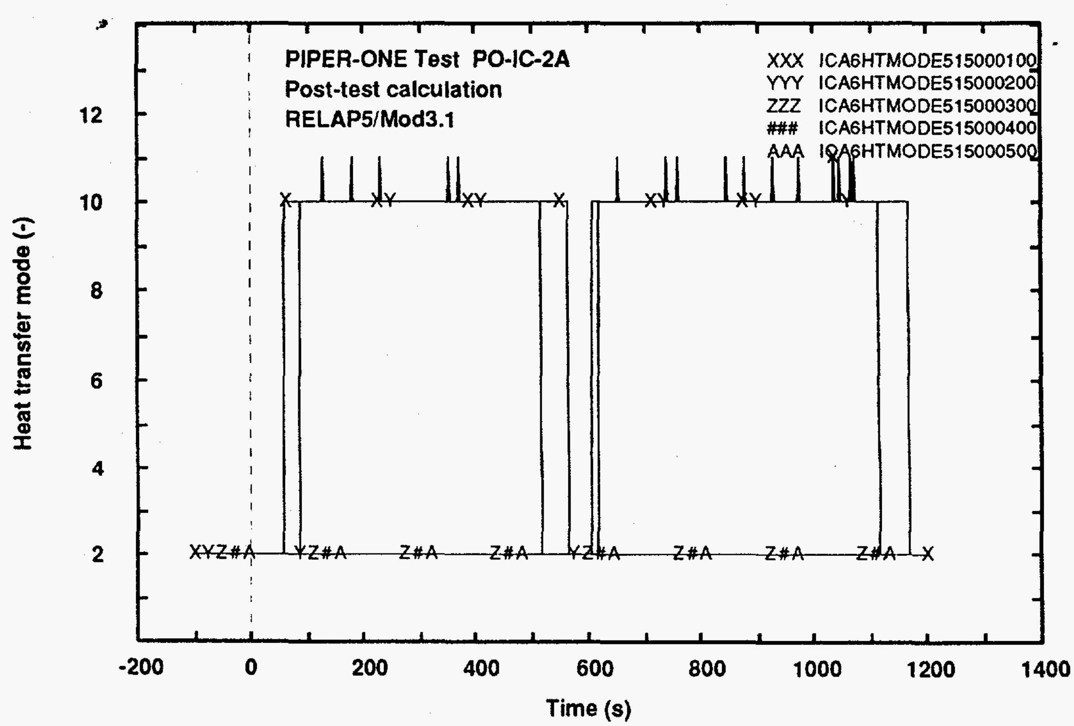

Fig. 38 - Calculated trends of IC tubes heat transfer mode (internal side)

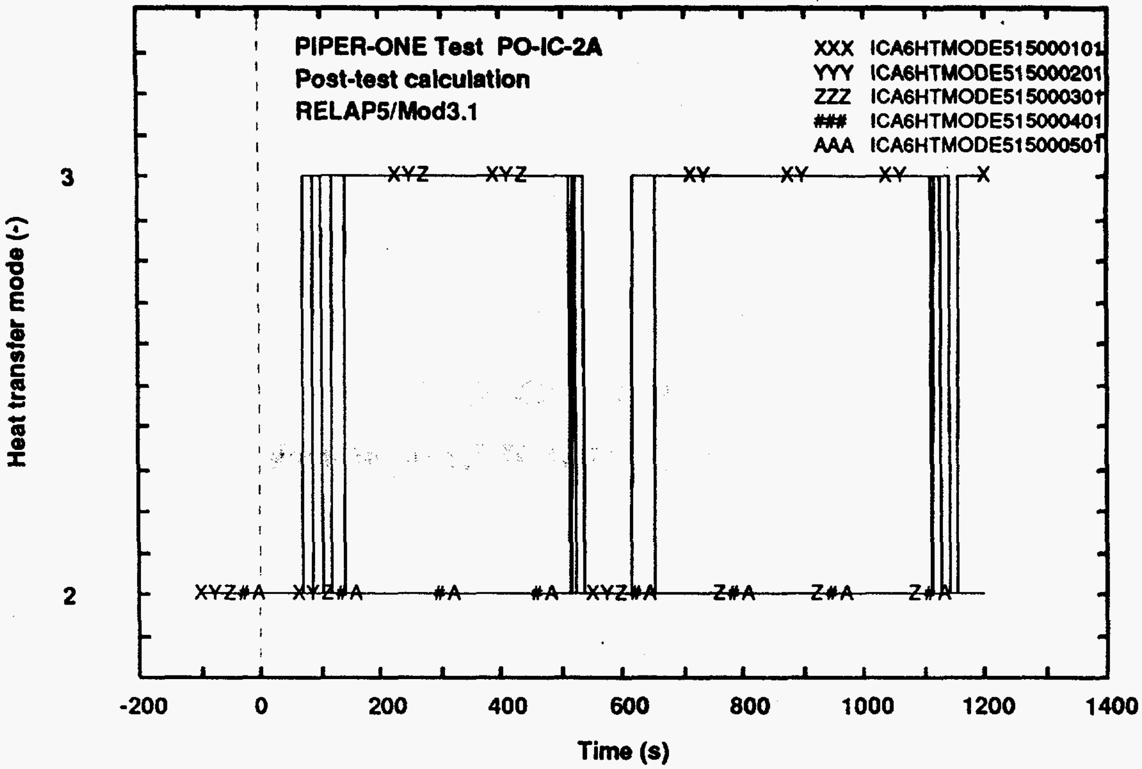

Fig. 39 - Calculated trends of IC tubes heat transfer mode (external side)

APPENDIX 5:

Listing of RELAP5/MOD3.1 input deck

```
=po-ic-02
*
*
*
100      new    transnt
*01      inp-chk
*
*=============================================================*
*  time steps
*         mint    maxt          mie  mae
201  100.    1.e-7   1.e-1    07003  20      500    500
202  600.    1.e-7   1.e-1    07003  20      1000   1000
203  636.    1.e-7   1.e-3    07003  1000    2000   2000
204  642.    1.e-7   5.e-4    07003  2000    2000   2000
205  730.    1.e-7   1.e-3    07003  1000    2000   2000
206  1200.   1.e-7   1.e-1    07003  20      1000   1000
207  1.e6    1.e-7   1.e-1    07003  20      1000   1000
*
*
*    added   minor edit request
*
20800001      htmode   515000100
20800002      htmode   515000200
20800003      htmode   515000300
20800004      htmode   515000400
20800005      htmode   515000500
20800006      htmode   515000101
20800007      htmode   515000201
20800008      htmode   515000301
20800009      htmode   515000401
20800010      htmode   515000501
*
*
*             minor edit request
*
*
* pressures and fluid temperatures
301  p         130010000     * pa-lp-1
302  p         245010000     * sd
303  tempf     100010000     * lp
304  tempf     110040000     * lp middle
305  tempf     140010000     * core inlet
306  tempf     200010000     * core bot
307  tempf     200070000     * core middle
308  tempf     200140000     * core top
309  tempg     200140000     * core top
*
* fluid temperatures
310  tempf     150010000     * by guide tube
311  tempf     155010000     * bypass bot
312  tempf     165010000     * bypass middle
313  tempf     175010000     * bypass top
314  tempg     175010000     * bypass top
315  tempf     220010000     * up
316  tempg     220010000     * up
317  tempf     245010000     * sd
318  tempg     245010000     * sd
*
* fluid temperatures
319  tempf     270010000     *
320  tempg     270010000     *
321  tempf     300010000     *
322  tempf     310010000     *
323  tempf     320150000     *
324  tempf     315150000     *
325  tempf     330010000     *
326  tempf     345010000     *
327  tempf     345050000     *
*
* levels
328  cntrlvar 010            * dc-ann
329  cntrlvar 011            * dc-jp
330  cntrlvar  015           * lp
331  cntrlvar  016           * core
332  cntrlvar  017           * up
333  cntrlvar  020           * core total
334  cntrlvar  030           * bypass
335  cntrlvar  035           * sea
336  cntrlvar  050           * fuel box exterior
*
* quality & void fraction
337  voidg     200010000     *
338  voidg     200080000     *
339  voidg     200130000     *
340  voidg     200140000     *
341  voidg     200150000     *
342  voidg     245010000     *
343  quals     200100000     *
344  quals     200110000     *
345  quals     200120000     *
*
*  mass flowrates
346  mflowj    340000000     *
347  mflowj    130010000     *
348  mflowj    130020000     *
349  mflowj    140020000     *
350  mflowj    205010000     *
351  mflowj    205020000     *
352  mflowj    360010000     *
353  mflowj    235010000     *
354  mflowj    235020000     *
*
*  mass  flowrates
355  mflowj    505000000     *  ic top
356  mflowj    245010000     *
357  mflowj    225020000     *
358  mflowj    245020000     *
359  mflowj    270020000     *
360  mflowj    563010000     *
361  mflowj    564010000     *
362  mflowj    463000000     *
363  mflowj    300010000     *
*
*  rod surface temp
364  httemp    200100110     *
365  httemp    200100410     *
366  httemp    200100510     *
367  httemp    200100710     *
368  httemp    200100810     *
369  httemp    200100910     *
370  httemp    200101010     *
371  httemp    200101210     *
372  httemp    200101410     *
*
* quality & void fraction (2nd group)
373  voidg     265010000     *
374  voidg     260010000     *
375  voidg     260030000     *
376  voidg     250010000     *
377  voidg     250030000     *
378  voidg     250050000     *
379  voidg     255010000     *
380  voidg     255030000     *
381  voidg     210010000     *
*
382  cntrlvar 040            * core power
383  cntrlvar 060            * ic power
384  cntrlvar 061            * ic power
385  cntrlvar 062            * ic power
386  cntrlvar 063            * ic power
*
*
*-------------------------------------------------------------*
*                  trips
*-------------------------------------------------------------*
*
* lp vlv
501 time  0    ge   null  0  98.              l *  op. vlv lp-jp
502 time  0    ge   null  0  1.e6             l *  clo. vlv lp-jp
*
* start heat losses sep. annulus
507 time  0    ge   null  0  100.             l *
*
* start heat losses upp. dc
508 time  0    ge   null  0  100.             l *
*
* heat losses
509 time  0    ge   null  0  100.             l *
510 time  0    ge   null  0  1.e6             l *
511 time  0    ge   null  0  0.               l *  table 801
*
* core @ bypass power
513 time  0    ge   null  0    100.           l *  start rod heat.
515 time  0    ge   null  0    500.           l *  start bypass
heat.
*
* fb1 & fb2 heat losses  (only fb1 utilized)
516 time  0    ge   null  0   200.            l *  fb1 start
517 time  0    ge   null  0   1.e6            l *  fb2 start
*
* ic loop control top vlv
520 time  0    ge   null  0   104.            l *  op vlv ic top
523 time  0    ge   null  0   608.            l *  cl vlv ic top
553 time  0    ge   null  0   705.            l *  op vlv ic top
554 time  0    ge   null  0  1206.            l *  cl vlv ic top
616  520  xor  523                            n *  op/cl ic top
632  553  xor  554                            n *  op/cl ic top
633  616   or  632                            n *  op/cl ic top
*
* ic loop control bot vlv
521 time  0    ge   null  0   132.            l *  op vlv ic bot
522 time  0    ge   null  0   608.            l *  cl vlv ic bot
551 time  0    ge   null  0   706.            l *  op vlv ic bot
552 time  0    ge   null  0  1206.            l *  cl vlv ic bot
615  521  xor  522                            n *  op/cl ic bot
630  551  xor  552                            n *  op/cl ic bot
*631  615   or  630                            n *  op/cl ic bot
631  521  and  521                             n *  op/cl ic bot
*
* added break control for po-ic-2
549 time  0    ge   null  0      710.        l *
*
* ic control water in.
560 time  0    ge   null  0    608.e6        l *
561 time  0    ge   null  0    690.e6        l *
635  560 xor 561                             n *
*
* ic control water out.
562 time  0    ge   null  0    691.e6        l *
563 time  0    ge   null  0    699.e6        l *
636  562 xor 563                             n *
*
* steam line (tj 433)
525 time  0    ge   null  0      1.e6        n *
*
* pressure control
526 time  0    ge   null  0      -1.         l *
527 time  0    ge   null  0      10.         l *
528 time  0    ge   null  0      99.         l *  actual clo.
617  527  xor  526                           n *  actual op.
*
* fw control
529 time  0    ge   null  0      1.e6        l *
*
* auxiliary systems
530  p    100010000  ge  null 0     1.e6     l *  start lpci
532  p    100010000  ge  null 0     1.e6     l *  start lpcs
534  p    100010000  ge  null 0     1.e6     l *  start hpcs
536  p    100010000  ge  null 0     1.e6     l *  start lpcsb
*
```

```
* srv control
537 p   245010000  ge   null 0    96.50e5  n *
539 p   245010000  gt   null 0    200.0e5  1 *
599 p   245010000  lt   null 0    92.50e5  n *  clo. srv
602  537  xor  539                         n *  op. srv
*
* ads control
540  time 0   ge null    0        100.     1 *  ads
541  p   245010000   ge   null 0     70.50e5   n *
601  540      and        541               1 *  op. ads
*
* draining sea
570  time 0   ge null    0         1.e6     1 * op. drain. ann
571 cntrlvar 035    ge   null   0 1.e6     n * clo. dra. an.
*
*  heat losses ic tank (including external pipes) & ic line liq.
580  time 0   ge null    0         200.     1 *
*
*  heat losses ic line
581  time 0   ge null    0         100.     1 *
*
*  heat losses sd
582  time 0   ge null    0         100.     1 *
*
*  heat losses core region (external vessel)
583  time 0   ge null    0         80.      1 *
*
*  end trip signal
512 time   0   ge  null  0         1300.    1 *  end of problem
600 512                                       *  end of problem
*
*
*
*-------------------------------------------------------------*
*  hydraulic components
*-------------------------------------------------------------*
*
* lower plenum bot
1000000  lw.plb          branch
1000001  2               1
1000101  0.010709   0.3      0.   0.  90.    0.3     4.e-5 0.065
00000
1000200  000          5.045e6  1.100e6    2597.e3     0.
1001101  100010000  110000000  0.00      0.  0.     000000
1002101  345010000  100010000  0.00      0.  0.     000000
1001201  0.      0.      0.
1002201  0.      0.      0.
*
* lower plenum central
1100000  lp.mid       pipe
1100001  5
1100101  0.010709          5
1100301  0.250             2
1100302  0.1443            4
1100303  0.1114            5
1100401  0.000             5
1100601  90.0              5
1100801  4.0e-5  0.065     5
1101001  00000             5
1101101  000000            4
1101201  000    5.045e6    1.100e6  2597.e3 0.0      0.  5
1101300  1
1101301  0.0      0.0      0.0     4
*
* lower plenum added br. for ic conn.
1110000  lw.ic1          branch
1110001  1               1
1110101  0.010709   0.1615   0.   0.  90.   0.1615 4.e-5 0.065
00000
1110200  000          5.045e6  1.100e6    2597.e3     0.
1111101  110010000  111000000  0.00      0.  0.     000000
1111201  0.0     0.      0.
*
* lower plenum added br. for ic conn.
1120000  lw.ic2          branch
1120001  1               1
1120101  0.010709   0.16     0.   0.  90.   0.16    4.e-5 0.065
00000
1120200  000          5.045e6  1.100e6    2597.e3     0.
1121101  111010000  112000000  0.00      0.  0.     000000
1121201  0.0     0.      0.
*
* lower plenum top1
1150000  lp.top1          branch
1150001  2                1
1150101  0.010709   0.1745   0.   0.  90.   0.1745 4.e-5 0.065
00000
1150200  000          5.045e6  1.120e6    2597.e3     0.
1151101  112010000  115000000  0.00      0.  0.     000000
1152101  115010000  120000000  0.00      0.  0.     000000
1151201  0.0     0.      0.
1152201  0.0     0.      0.
*
* lower plenum top2
1200000  lp.top2      pipe
1200001  2
1200101  0.00972           2
1200301  0.2               2
1200401  0.000             2
1200601  90.0              2
1200801  4.0e-5  0.065     2
1201001  00000             2
1201101  000000            1
1201201  000    5.045e6    1.120e6  2597.e3 0.0      0.  2
1201300  1
1201301  0.0      0.0      0.0     1
*
* lower plenum top3
1300000  lp.top3          branch
1300001  2                1
1300101  0.008457   0.176     0.   0.  90.   0.176  4.e-5 0.065
00000
1300200  000          5.045e6  1.120e6    2597.e3     0.
1301101  120010000  130000000  0.00      0.  0.     000000
1302101  130000000  145000000  0.00      0.  0.     000000
1301201  0.0     0.      0.
1302201  0.0     0.      0.
*
* lower plenum top4
1350000  lp.top4          branch
1350001  1                1
1350101  0.008457   0.2       0.   0.  90.   0.2    4.e-5 0.065
00000
1350200  000          5.045e6  1.120e6    2597.e3     0.
1351101  130010000  135000000  0.00      0.  0.     000000
1351201  0.0     0.      0.
*
* lower plenum top5
1400000  lp.top5          branch
1400001  2                1
1400101  0.008457   0.2       0.   0.  90.   0.2    4.e-5 0.065
00000
1400200  000          5.045e6  1.120e6    2597.e3     0.
1401101  135010000  140000000  0.00      0.  0.     000000
1402101  140010000  200000000 5.938e-4  0.9 0.9    000000
1401201  0.0     0.      0.
1402201  0.0     0.      0.
*
* core by bottom hor
1450000  by.bhor      pipe
1450001  7
1450101  0.000286          7
1450301  0.2               2
1450302  0.1892            7
1450401  0.000             7
1450601  -90.0             2
1450602   0.0              7
1450801  4.0e-5   0.0      7
1451001  00000             7
1451101  000000            6
1451201  000    5.045e6    1.120e6  2597.e3 0.0      0.  7
1451300  1
1451301  0.      0.0      0.0     6
*
* guide tube - bot.by
1500000  gui.tub      pipe
1500001  5
1500101  0.003953          5
1500301  0.2468            5
1500401  0.000             5
1500601  90.0              5
1500801  4.0e-5   0.0      5
1501001  00000             5
1501101  000000            4
1501201  000    5.045e6    1.120e6  2597.e3 0.0      0.  5
1501300  1
1501301  0.      0.0      0.0     4
*
* bypass vertical bot
1550000  by.vert1         branch
1550001  3                1
1550101  0.000835   0.223     0.   0.  90.   0.223  4.e-5 0.0
00000
1550200  000          5.045e6  1.120e6    2597.e3     0.
1551101  145010000  155000000 0.50e-4   1.   1.     000000
1552101  150010000  155000000 .827e-3   0.1  0.1    000000
1553101  155010000  160000000 0.         0.  0.     000000
1551201  0.      0.      0.
1552201  0.      0.      0.
1553201  0.      0.      0.
*
* bypass vertical n2
1600000  by.vert2     pipe
1600001  10
1600101  0.000835          10
1600301  0.2133            10
1600401  0.000             10
1600601  90.0              10
1600801  4.0e-5   0.0      10
1601001  00000             10
1601101  000000            9
1601201  000    5.045e6    1.120e6  2597.e3 0.0      0.  10
1601300  1
1601301  0.      0.0      0.0     9
*
* bypass vertical n3
1650000  by.vert3         branch
1650001  2                1
1650101  0.000835   0.2015    0.   0.  90.   0.2015 4.e-5 0.0
00000
1650200  000          5.045e6  1.120e6    2597.e3     0.
1651101  160010000  165000000 0.         0.  0.     000000
1652101  165010000  170000000 0.         0.  0.     000000
1651201  0.      0.      0.
1652201  0.      0.      0.
*
* bypass vertical n4
1700000  by.vert4     pipe
1700001  10
1700101  0.000835          10
1700301  0.235             10
1700401  0.000             10
1700601  90.0              10
1700801  4.0e-5   0.0      10
1701001  00000             10
1701101  000000            9
1701201  000    5.045e6    1.120e6  2597.e3 0.0      0.  10
1701300  1
1701301  0.0      0.0      0.0     9
*
```

```
1700001  10
1700101  0.000835          10
1700301  0.235             10
1700401  0.000             10
1700601  90.0              10
1700801  4.0e-5  0.0       10
1701001  00000             10
1701101  000000            9
1701201  000    5.045e6    1.120e6   2597.e3 0.0      0.  10
1701300  1
1701301  0.0     0.0       0.0     9
*
* bypass vertical n5
1750000  by.vert5          branch
1750001  2                 1
1750101  0.000835    0.2075    0.    0.   90.    0.2075 4.e-5 0.0
00000
1750200  000            5.045e6  1.120e6     2597.e3      0.
1751101  170010000  175000000 0.           0.    0.    000000
1752101  175010000  180000000 0.           0.1   0.1   000000
1751201  0.0     0.       0.
1752201  0.0     0.       0.
*
* bypass horizontal top
1800000  by.hort       pipe
1800001  5
1800101  0.00119           5
1800301  0.1776            5
1800401  0.000             5
1800601   0.0              5
1800801  4.0e-5  0.0       5
1801001  00000             5
1801101  000000            4
1801201  000    5.045e6    1.120e6   2597.e3 0.0      0.  5
1801300  1
1801301  0.0     0.0       0.0     4
*
* core channel
2000000  core          pipe
2000001  16
2000101  0.002943          14
2000102  0.003556          16
2000301  0.265             14
2000302  0.229             15
2000303  0.2               16
2000401  0.000             16
2000601  90.0              16
2000801  4.0e-5  0.013     16
2001001  00000             16
2001101  000000            15
2001201  000    5.045e6    1.128e6   2597.e3 0.0      0.  2
2001202  000    5.045e6    1.128e6   2597.e3 0.       0.  4
2001203  000    5.045e6    1.128e6   2597.e3 0.       0.  6
2001204  000    5.045e6    1.128e6   2597.e3 0.       0.  8
2001205  000    5.045e6    1.128e6   2597.e3 0.       0.  10
2001206  000    5.045e6    1.128e6   2597.e3 0.       0.  12
2001207  000    5.045e6    1.128e6   2597.e3 0.       0.  14
2001208  000    5.045e6    1.128e6   2597.e3 0.       0.  16
2001300  1
2001301  0.      0.0       0.0     5
2001302  0.      0.        0.0     10
2001303  0.      0.        0.0     15
*
* core top
2050000  core.top          branch
2050001  2                 1
2050101  0.01028     0.22      0.    0.   90.    0.22    4.e-5 0.0
00000
2050200  000            5.045e6  1.151e6     2597.e3      0.
2051101  200010000  205000000 1.649e-3 14.5 10.6   000000
2052101  180010000  205000000 0.83e-3   0.1  0.1   000000
2051201  0.      0.       0.
2052201  0.0     0.       0.
*
* upper plenum 1
2100000  up.col            branch
2100001  2                 1
2100101  0.01028     0.22      0.    0.   90.    0.22    4.e-5 0.0
00000
2100200  000            5.045e6  1.151e6     2597.e3      0.
2101101  205010000  210000000 0.           0.    0.    000000
2102101  210010000  220000000 0.           0.    0.    000000
2101201  0.      0.       0.
2102201  0.      0.       0.
*
* steam separator pipe
2200000  st.sep        pipe
2200001  20
2200101  0.01028           2
2200102  0.00241           20
2200301  0.214             2
2200302  0.2345            20
2200401  0.000             20
2200601  90.0              20
2200801  4.0e-5  0.0       20
2201001  00000             20
2201101  000000            19
2201201  000    5.045e6    1.151e6   2597.e3 0.       0.  10 *
1.115e6
2201202  000    5.045e6    1.151e6   2597.e3 0.       0.  16 *
2201203  000    5.045e6    1.151e6   2597.e3 0.9      0.  20
2201300  1
2201301  0.0     0.        0.0     19
*
* bot ssa
2250000  ssa.bot           branch
2250001  2                 1
2250101  0.007196    0.34      0.    0.   90.    0.34    4.e-5 0.052
00000
2250200  000            5.045e6  1.120e6     2597.e3      0.
```

```
2251101  225010000  230000000 0.          0.    0.    000000
2252101  225010000  290000000 0.          0.    0.    000000
2251201  0.      0.       0.
2252201  0.      0.       0.
*
* steam separator annulus
2300000  ssa           pipe
2300001  8
2300101  0.007196          8
2300301  0.512             1
2300302  0.469             8
2300401  0.000             8
2300601  90.0              8
2300801  4.0e-5  0.052     8
2301001  00000             8
2301101  000000            7
2301201  000    5.045e6    1.151e6   2597.e3 0.0      0.0  5
2301202  000    5.045e6    1.151e6   2597.e3 0.0      0.0  6
2301203  000    5.045e6    1.151e6   2597.e3 0.5      0.0  8
2301300  1
2301301  0.      0.        0.0     7
*
* steam dome bot (k in j. 2 changed for po-ic-01)
2350000  sdo.bot           branch
2350001  4                 1
2350101  0.01038     0.246     0.    0.   90.    0.246   4.e-5 0.0
00000
2350200  000            5.045e6  1.151e6     2597.e3      0.9
2351101  220010000  235000000 0.           0.    0.    000000
2352101  235000000  230010000 3.94e-4     100.  100.  000000
2353101  235000000  255000000 0.00426     0.1   0.1   000000
2354101  235010000  240000000 0.           0.    0.    000000
2351201  0.0     0.       0.
2352201  0.      0.       0.
2353201  0.      0.       0.
2354201  0.      0.       0.
*
* steam dome vert.left
2400000  sd.ver.l      pipe
2400001  4
2400101  0.01038           4
2400301  0.25              4
2400401  0.000             4
2400601  90.0              4
2400801  4.0e-5  0.0       4
2401001  00000             4
2401101  000000            3
2401201  000    5.045e6    1.151e6   2597.e3 0.9      0.  4
2401300  1
2401301  0.      0.        0.0     3
*
* steam dome top left
2450000  sdo.top           branch
2450001  2                 1
2450101  0.01038     0.365     0.    0.   90.    0.365   4.e-5 0.0
00000
2450200  000            5.045e6  1.151e6     2597.e3      1.
2451101  240010000  245000000 0.           0.    0.    000000
2452101  245000000  250000000 0.           0.1   0.1   000000
2451201  0.      0.       0.
2452201  0.      0.       0.
*
* steam dome top hor pipe
2500000  sd.toh        pipe
2500001  5
2500101  0.005382          5
2500301  0.289             5
2500401  0.000             5
2500601   0.0              5
2500801  4.0e-5  0.0       5
2501001  00000             5
2501101  000000            4
2501201  000    5.045e6    1.151e6   2597.e3 0.95     0.  5
2501300  1
2501301  0.      0.0       0.0     4
*
* steam dome bot hor pipe
2550000  sd.boh        pipe
2550001  5
2550101  0.00570           5
2550301  0.289             5
2550401  0.000             5
2550601   0.0              5
2550801  4.0e-5  0.074     5
2551001  00000             5
2551101  000000            4
2551201  000    5.045e6    1.151e6   2597.e3 1.0      0.  5
2551300  1
2551301  0.      0.        0.0     4
*
* sj connecting upper parts of sd
2590000  sj.tsd        sngljun
2590101  250010000  260000000   0.005382 0.1      0.1   000000
2590201  1             0.       0.000  0.000
*
* steam dome vert.right
2600000  sd.ver.r      pipe
2600001  4
2600101  0.006647          4
2600301  0.25              4
2600401  0.000             4
2600601 -90.0              4
2600801  4.0e-5  0.0       4
2601001  00000             4
2601101  000000            3
2601201  000    5.045e6    1.151e6   2597.e3 1.0      0.  4
2601300  1
2601301  0.      0.        0.0     3
*
* steam dome right part bottom
```

```
2650000  sdo.rib          branch
2650001  2                1
2650101  0.006647    0.246     0.    0. -90.   -0.246  4.e-5 0.0
00000
2650200  000          5.045e6  1.151e6    2597.e3    1.
2651101  260010000   265000000 0.         0.   0.    000000
2652101  265010000   270000000 0.         0.   0.    000000
2651201  0.     0.       0.
2652201  0.     0.       0.
*
* dc top
2700000  dc.top           branch
2700001  2                1
2700101  0.005534    0.247     0.    0. -90.   -0.247  4.e-5 0.0
00000
2700200  000          5.045e6  1.151e6    2597.e3    0.1
2701101  255010000   270000000 0.         0.1  0.1   000000
2702101  270010000   275000000 0.         0.   0.    000000
2701201  0.     0.       0.
2702201  0.     0.       0.
*
* dc top upstream fw
2750000  sd.tufw      pipe
2750001  4
2750101  0.005534          4
2750301  0.362             4
2750401  0.000             4
2750601  -90.0             4
2750801  4.0e-5  0.0       4
2751001  00000             4
2751101  000000            3
2751201  000   5.045e6   1.151e6  2597.e3 0.0      0.   4
2751300  1
2751301  0.       0.       0.0    3
*
* dc fw connection zone
2800000  dc.fwz           branch
2800001  2                1
2800101  0.005534    0.3       0.    0. -90.   -0.3    4.e-5 0.0
00000
2800200  000          5.045e6  1.100e6    2597.e3    0.
2801101  275010000   280000000 0.         0.1  0.1   000000
2802101  280010000   285000000 0.         0.   0.    000000
2801201  0.     0.       0.
2802201  0.0    0.       0.
*
* dc top downstream fw
2850000  dc.tdfw      pipe
2850001  6
2850101  0.005534          6
2850301  0.3               6
2850401  0.000             6
2850601  -90.0             6
2850801  4.0e-5  0.0       6
2851001  00000             6
2851101  000000            5
2851201  000   5.045e6   1.100e6  2597.e3 0.0      0.   6
2851300  1
2851301  0.0     0.       0.0    5
*
* bypass of steam dome
2900000  by.sd        pipe
2900001  2
2900101  0.001269          2
2900301  0.3295            2
2900401  0.000             2
2900601   0.0              2
2900801  4.0e-5  0.04      2
2901001  00000             2
2901101  000000            1
2901201  000   5.045e6   1.100e6  2597.e3 0.       0.   2
2901300  1
2901301  0.       0.0      0.0    1
*
* vlv of sd bypass
2920000  vlv.sdby  valve
2920101  290010000  295000000  0.001256    0.0  0.0 000100  1.
1. 1.
2920201  0  0.000  0.000  0.000
2920300  mtrvlv
2920301  570     571    1.  0.
*
* bypass of steam dome
2950000  by.sd2       pipe
2950001  2
2950101  0.002765          2
2950301  0.39              2
2950401  0.000             2
2950601   0.0              2
2950801  4.0e-5  0.04      2
2951001  00000             2
2951101  000000            1
2951201  000   5.045e6   1.100e6  2597.e3 0.0      0.0 2
2951300  1
2951301  0.       0.0      0.0    1
*
* dc middle zone
3000000  dc.mid1          branch
3000001  3                1
3000101  0.00349     0.283     0.    0. -90.   -0.283  4.e-5 0.0
00000
3000200  000          5.045e6  1.100e6    2597.e3    0.
3001101  285010000   300000000 0.         0.   0.    000000
3002101  300010000   305000000 0.         0.   0.    000000
3003101  295010000   300000000 0.00046    0.1  0.1   000000
3001201  0.0    0.       0.
3002201  0.0    0.       0.
3003201  0.     0.       0.
*
* dc middle zone n2
3050000  dc.mid2      pipe
3050001  8
3050101  0.00349           3
3050102  0.004261          8
3050301  0.29              3
3050302  0.281             8
3050401  0.000             8
3050601  -90.0             8
3050801  4.0e-5  0.0       8
3051001  00000             8
3051101  000000            7
3051201  000   5.045e6   1.100e6  2597.e3 0.0      0.   8
3051300  1
3051301  0.0     0.       0.0    7
*
* dc jet pump top
3100000  dc.jpto          branch
3100001  3                1
3100101  0.004261    0.325     0.    0. -90.   -0.325  4.e-5 0.0
00000
3100200  000          5.045e6  1.100e6    2597.e3    0.
3101101  305010000   310000000 0.         0.   0.    000000
3102101  310010000   320000000 0.         0.   0.    000000
3103101  310010000   315000000 0.         1.   1.    000000
3101201  0.0    0.       0.
3102201  0.     0.       0.
3103201  0.0    0.       0.
*
* jet pump
3150000  jet.pump     pipe
3150001  15
3150101  0.0013            15
3150301  0.273             15
3150401  0.000             15
3150601  -90.0             15
3150801  4.0e-5  0.0       15
3151001  00000             15
3151101  000000            14
3151201  000   5.045e6   1.100e6  2597.e3 0.0      0.   15
3151300  1
3151301  0.0     0.       0.0    14
*
* dc annular part
3200000  dc.ann       pipe
3200001  15
3200101  0.0027            15
3200301  0.273             14
3200302  0.1               15
3200401  0.000             15
3200601  -90.0             15
3200801  4.0e-5  0.0       15
3201001  00000             15
3201101  000000            14
3201201  000   5.045e6   1.100e6  2597.e3 0.0      0.   15
3201300  1
3201301  0.      0.       0.0    14
*
* dc jet pump bot
3250000  dc.jpbo          branch
3250001  3                1
3250101  0.00426     0.327     0.    0. -90.   -0.327  4.e-5 0.0244
00000
3250200  000          5.045e6  1.100e6    2597.e3    0.
3251101  315010000   325000000 0.         1.   1.    000000
3252101  325010000   330000000 0.         0.   0.    000000
3253101  325010000   335000000 0.         0.1  0.1   000000
3251201  0.0    0.       0.
3252201  0.     0.       0.
3253201  0.0    0.       0.
*
* dc  bot
3300000  dc.jpbo          branch
3300001  0                1
3300101  0.000      0.185  0.89e-3  0. -90.   -0.185  4.e-5 0.0244
00000
3300200  000          5.045e6  1.100e6    2597.e3    0.
*
* added break for po-ic-2
3310000  br.vol     tmdpvol
3310101  0.  10.    10.  0.  0.  0.  4.e-5  0.  00000
3310200  000
3310201      0.  1.5e6  1.286e5  2.601e6  0.
3310202   1.e6   1.5e6  1.286e5  2.601e6  0.
*
* fw  injection in dc
3320000  br.j       tmdpjun
3320101  330010000  331000000  0.0
3320200  1       549
3320201     -1.        0.0     0.  0.
3320202      0.        0.05    0.  0.
3320203    100.        0.05    0.  0.
3320204    101.        0.0     0.  0.
3320205    1.e6        0.0     0.  0.
*
* lower plenum horizontal part
3350000  lp.horl      pipe
3350001  4
3350101  0.0042            2
3350102  0.00756           4
3350201  0.                1
3350202  0.                2    * 18.1e-6
3350203  0.                3
3350301  0.257             4
3350401  0.000             4
3350601   0.0              4
3350801  4.0e-5   0.0      4
3350901  0.       0.0      1
3350902  0.       0.       2  * 0.57 0.57
3350903  0.       0.0      3
3351001  00000             4
```

```
3351101  000000          3
3351201  000   5.045e6   1.100e6  2597.e3 0.0     0.0 4
3351300  1
3351301  0.0     0.0     0.0     3
*
*  lower plenum valve
3400000  va.lopl   valve
3400101  335010000  345000000  8.500e-4  5.0   5.0  000100  1.
1. 1. *1.
3400201  1  0.0     0.000  0.000
3400300  mtrvlv
3400301  501    502    1.    0.
*
* lower plenum hor-2
3450000  lp.hor2     pipe
3450001  5
3450101  0.00756         1
3450102  0.00137         5
3450301  0.16            1
3450302  0.18            3
3450303  0.25            5
3450401  0.000           5
3450601   0.0            3 .
3450602 -90.0            5
3450801  4.0e-5  0.0     5
3450901  0.      0.0     2
3450902  0.5     0.5     3
3450903  0.      0.0     4
3451001  00000           5
3451101  000000          4
3451201  000   5.045e6   1.100e6  2597.e3 0.0     0.    5
3451300  1
3451301  0.0     0.      0.0     4
*
* fuel box exterior top
3600000  fuel.box        branch
3600001  2               1
3600101  4.4896e-3  0.429    0.   0.  90.   0.429  4.e-5 0.0
00000
3600200  000          5.045e6  1.151e6    2597.e3    1.
3601101  360010000  205000000 1.e-5    10.  10.    000000  *
3602101  360000000  370010000 0.        0.   0.    000000
3601201  0.      0.      0.
3602201  0.      0.      0.
*
* fuel box exterior
3700000  fuel.bo     pipe
3700001  7
3700101  4.4896e-3       7
3700301  0.53            7
3700401  0.000           7
3700601  90.0            7
3700801  4.0e-5  0.0     7
3701001  00000           7
3701101  000000          6
3701201  000   5.045e6   1.151e6  2597.e3 0.0     0.  7
3701300  1
3701301  0.      0.0     0.0     6
*
*  up lpcs injection tank sim
4000000  vlpcs         tmdpvol
4000101  0.  10.    10.  0.  0.  0. 4.e-5  0.  00000
4000200  000
4000201     0.  22.7e5 4.134e4  2.601e6   0.
4000202  1000.  22.7e5 4.134e4  2.601e6   0.
4000203  1.e6   22.7e5 4.134e4  2.601e6   0.
*
* lpcs injection tj in up
4030000  up.lpcsj  tmdpjun
4030101  400000000  210010000  0.0
4030200  1       532      p 110010000
4030201     -1.        0.0      0.  0.
4030202     0.         0.232    0.  0.
4030203     0.30e6     0.232    0.  0.
4030204     0.60e6     0.209    0.  0.
4030205     0.86e6     0.190    0.  0.
4030206     1.10e6     0.173    0.  0.
4030207     1.38e6     0.148    0.  0.
4030208     1.64e6     0.120    0.  0.
4030209     1.90e6     0.089    0.  0.
4030210     2.05e6     0.060    0.  0.
4030211     2.09e6     0.048    0.  0.
4030212     2.15e6     0.0      0.  0.
4030213     9.00e6     0.0      0.  0.
*
*  by lpcs injection tank sim
4100000  vbycs         tmdpvol
4100101  0.  10.    10.  0.  0.  0. 4.e-5  0.  00000
4100200  000
4100201     0.  22.7e5 4.134e4  2.601e6   0.
4100202  1000.  22.7e5 4.134e4  2.601e6   0.
4100203  1.e6   22.7e5 4.134e4  2.601e6   0.
*
*  by lpcs injection tj
4130000  jby.cs    tmdpjun
4130101  410000000  175010000  0.0
4130200  1       536      p 110010000
4130201     -1.        0.0      0.  0.
4130202     0.         0.116    0.  0.
4130203     0.30e6     0.116    0.  0.
4130204     0.60e6     0.105    0.  0.
4130205     0.86e6     0.095    0.  0.
4130206     1.10e6     0.086    0.  0.
4130207     1.38e6     0.074    0.  0.
4130208     1.64e6     0.060    0.  0.
4130209     1.90e6     0.044    0.  0.
4130210     2.05e6     0.030    0.  0.
4130211     2.09e6     0.024    0.  0.
4130212     2.15e6     0.0      0.  0.
```

```
* lpci tank simluator
4200000  vlpci       tmdpvol
4200101  0.  10.    10.  0.  0.  0.  4.e-5  0.  00000
4200200  000
4200201      0.  28.e5  4.134e4  2.601e6  0.
4200202   1.e6   28.e5  4.134e4  2.601e6  0.
*
* lpci injection in core.bypass
4230000  lpcij.by tmdpjun
4230101  420000000  165010000  0.0
4230200  1       530      p 110010000
4230201    -1.        0.000    0.  0.
4230202     0.        0.360    0.  0.
4230203     0.30e6    0.360    0.  0.
4230204     0.50e6    0.345    0.  0.
4230205     0.68e6    0.330    0.  0.
4230206     0.90e6    0.310    0.  0.
4230207     1.25e6    0.250    0.  0.
4230208     1.41e6    0.188    0.  0.
4230209     1.51e6    0.115    0.  0.
4230210     1.55e6    0.069    0.  0.
4230211     1.65e6    0.       0.  0.
4230212     9.51e6    0.       0.  0.
*
* steam line downstream
4300000  out.sl   tmdpvol
4300101  0.   3.  10.  0.  0.  0.  4.e-5  0.  00000
4300200  000
4300201     0.  1.e5  4.175e5 2.506e6  1.
4300202     1.  1.e5  4.175e5 2.506e6  1.
4300203   1.e6  1.e5  4.175e5 2.506e6  1.
*
* steam line during steady state
4330000  steam.li tmdpjun
4330101  245010000  430000000  0.0
4330200  1       525
4330201    -1.        0.0      0.       0.
4330202     0.        0.       0.348   0.
4330203     1.e6      0.       0.348   0.
*
* pre control volume
4400000  out.sl   tmdpvol
4400101  0.  0.5  10.  0.  0.  0.  4.e-5  0.  00000
4400200  000
4400201     0. 5.045e6 1.151e6 2597.e3  1.
4400202     1. 5.045e6 1.151e6 2597.e3  1.
4400203   1.e6 5.045e6 1.151e6 2597.e3  1.
*
*  pressure control for steady state
4430000  va.lopl   valve
4430101  245010000  440000000  5.00e-3   0.0   0.0  000100  1.
1. 1.
4430201  1  0.     0.0463 0.000
4430300  mtrvlv
4430301  617    528    1.    1.
*
* fw   tank simluator
4500000  fw.vol    tmdpvol
4500101  0.  10.   10.  0.  0.  0.  4.e-5  0.  00000
4500200  000
4500201      0.  5.5e6  6.286e5  2.601e6  0.
4500202   1.e6   5.5e6  6.286e5  2.601e6  0.
*
* fw   injection in dc
4530000  fw.j      tmdpjun
4530101  450000000  280000000  0.0
4530200  1       529
4530201    -1.        0.0      0.  0.
4530202     0.        0.0463   0.  0.
4530203     100.      0.0463   0.  0.
4530204     101.      0.       0.  0.
4530205     1.e6      0.       0.  0.
*
* srv tank
4600000  outsrv   tmdpvol
4600101  0.   3.  10.  0.  0.  0.  4.e-5  0.  00000
4600200  000
4600201     0.  1.e5  4.175e5   2.506e6   1.
4600202  1.e6   1.e5  4.175e5   2.506e6   1.
*
* srv vlv
4630000  va.srv     valve
4630101  245010000  460000000   1.54e-6  1.e-6  1.e-6 000100 1.
1. 1.
4630201  0  0.000  0.000  0.000
4630300  mtrvlv
4630301  602     599  100.  0.
*
* ads tvol
4700000  outads   tmdpvol
4700101  0.  10.  100.  0.  0.  0.  4.e-5  0.  00000
4700200  000
4700201     0.  1.e5    83224.  2.50606e6   1.
4700202   1.e6  1.e5    83224.  2.50606e6   1.
*
* ads vlv
4730000  val.ads   valve
4730101 245010000  470000000  38.3e-6  0.1  0.1  000100  1.
1.
4730201  0  0.000  0.000  0.000
4730300  trpvlv
4730301  601
*
*  ic    line  top
5000000 iclin.t  pipe
5000001  10
5000101  3.7e-4          5
5000102  3.7e-4          10
5000301  0.38             5
5000302  0.312            9
```

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5000303  0.212          10
5000401  0.0            10
5000601  0.              5
5000602  -90.           10
5000701  0.             5
5000702  -0.212         9
5000703  -0.112         10
5000801  4.0e-6  0.0    10
5000901  0.0     0.0    4
5000902  0.3     0.3    5
5000903  0.0     0.0    9
5001001  01000          5
5001002  00000          10
5001101  000000         9
5001201  000  5.045e6    0.7461e5    2597.e3    1.     0.  6
5001202  000  5.045e6    0.7461e5    2597.e3    1.     0.  7
5001203  000  5.045e6    0.7461e5    2597.e3    1.     0.  8
5001204  000  5.045e6    1.1510e6    2597.e3    0.5    0.  9
5001205  000  5.045e6    0.7461e5    2597.e3    0.     0.  10
5001301  0.0       0.0       0.0      9
*
*   vlv ic top
5050000  vlv.ict    valve
5050101  245000000  500000000  3.e-4    10.  10.  000100  1.  1.
1.
5050201  0  0.000  0.000  0.000
5050300  trpvlv
5050301  633
*
*  ic top
5100000  top.icb    branch
5100001  2          0
5100101  6.0e-4     0.2      0.  0. -90.  -0.1  4.e-5  1.6e-3
00000
5100200  000           5.045e6    0.7461e5      2597.e3    0.0
5101101  510010000  515000000  0.         0.1       0.1  000000
5102101  500010000  510000000  0.         0.1       0.1  000000
5101201  0.          0.         0.
5102201  0.          0.         0.
*
* ic control
5110000  iccon     tmdpvol
5110101  0.  10.  100.  0.  0.  0.  4.e-5  0.  00000
5110200  000
5110201     0.  3.5e6   6.53e5  2.603e6   0.   *
5110202   1.e6  3.5e6   6.53e5  2.603e6   0.
*
*   vlv ic control
5120000  vlv.icc    valve
5120101  520000000  511000000  3.e-7    100. 100. 000100  1.  1.
1.
5120201  0  0.000  0.000  0.000
5120300  trpvlv
5120301  635
*
* ic control
5130000  iccon     tmdpvol
5130101  0.  10.  100.  0.  0.  0.  4.e-5  0.  00000
5130200  000
5130201     0.  2.5e6   6.53e5  2.603e6   0.   *
5130202   1.e6  2.5e6   6.53e5  2.603e6   0.
*
*   vlv ic control
5140000  vlv.icc    valve
5140101  520000000  513000000  8.e-6    100. 100. 000100  1.  1.
1.
5140201  0  0.000  0.000  0.000
5140300  trpvlv
5140301  636
*
* ic    tubes
5150000 ic.tubes pipe
5150001  5
5150101  3.05e-3         5
5150301  0.0632          5
5150401  0.0             5
5150601  -90.            5
5150801  4.0e-6  0.018   5
5150901  0.0     0.0     4
5151001  00000           5
5151101  000000          4
5151201  000  5.045e6    0.7461e5  2597.43e3     0.0     0.    5
5151301  0.0       0.0       0.0      4
*
* ic bot
5200000  bot.icb    branch
5200001  2          0
5200101  3.0e-4     0.1      0.  0. -90.  -0.1  4.e-5  1.6e-3
00000
5200200  000           5.045e6    0.7461e5     2598.e3    0.0
5201101  515010000  520000000  0.         0.1       0.1  000000
5202101  520010000  525000000  1.7e-4     0.1       0.1  000000
5201201  0.          0.         0.
5202201  0.          0.         0.
*
* ic    tube internal to the tank
5250000 ic.tubel pipe
5250001  14
5250101  2.4e-4          14
5250301  0.1             1
5250302  0.07875         9
5250303  0.104           14
5250401  0.0             14
5250601  -90.            9
5250602  0.              14
5250801  4.0e-6  0.018   14
5250901  0.0     0.0     9
5250902  0.2     0.2     10
5250903  0.0     0.0     13
5251001  00000           9
5251002  01000           14
5251101  000000          13
5251201  000  5.045e6    0.7461e5  2597.43e3    0.0     0.   1
5251202  000  5.045e6    0.7461e5  2597.43e3    0.0     0.   3
5251203  000  5.045e6    0.7461e5  2597.43e3    0.0     0.   5
5251204  000  5.045e6    0.7461e5  2597.43e3    0.0     0.   7
5251205  000  5.045e6    0.7461e5  2597.43e3    0.0     0.   14
5251301  0.0       0.0      0.0      13
*
* exit tank junct.
5300000  ic.ej       sngljun
5300101  525010000  540000000  2.5e-4   0.1     0.1   000000
5300201  0               0.000  0.000  0.000
*
* ic     tube external to the tank
5400000 ic.tubel pipe
5400001  27
5400101  2.544e-4        27
5400301  0.35            2
5400302  0.472           22
5400303  0.4             23
5400304  0.3             24
5400305  0.35            27
5400401  0.0             27
5400601  0.              2
5400602  -90.            22
5400603  0.              23
5400604  -90.            24
5400605  0.              27
5400801  4.0e-6  0.018   27
5400901  0.0     0.0     2
5400902  0.2     0.2     3
5400903  0.0     0.0     21
5400904  0.3     0.3     22
5400905  0.0     0.0     26
5401001  01000           2
5401002  00000           22
5401003  01000           23
5401004  00000           24
5401005  01000           27
5401101 000000           26
5401201  000  5.045e6    0.7461e5  2597.43e3    0.0     0.   27
5401301  0.0       0.0      0.0      26
*
* vlv     ic bot
5500000  vlv.icb    valve
5500101  540010000  111000000 0.06e-4 300. 1.e9   000100  1.
1.  1.
5500201  0  0.000  0.000  0.000
5500300  trpvlv
5500301  631
*
* ic tank bot1
5510000  icta.b1    branch
5510001  3          0
5510101  0.708      0.07875 0.  0.  90.   0.07875 4.e-5  1.6e-3
00000
5510200  000       1.07e5   0.7488e5       3342.43e3    0.0
5511101  551010000  552000000  0.         0.      0.   000000
5512101  551010000  563000000  0.1        0.1     0.   000000
5513101  551010000  564000000  0.1        0.1     0.   000000
5511201  0.          0.         0.
5512201  0.          0.         0.
5513201  0.          0.         0.
*
* ic tank bot2 internal part
5520000  icta.b2    branch
5520001  1          0
5520101  0.1        0.07875 0.  0.  90.   0.07875 4.e-5  1.6e-3
00000
5520200  000       1.07e5   0.7488e5       3342.43e3    0.0
5521101  552010000  560000000  0.         0.      0.   000000
5521201  0.          0.         0.
*
* ic-tank internal part (with baffle)
5600000 ic.tank  pipe
5600001  12
5600101  0.1             7
5600102  0.051           8
5600103  0.087           12
5600301  0.07875         6
5600302  0.1             8
5600303  0.0632          12
5600401  0.0             12
5600601  90.             12
5600801  4.0e-6  1.000   12
5600901  0.0     0.0     11
5601001  00000           12
5601101  000000          11
5601201  000  1.07e5     0.7488e5  3382.43e3    0.0     0.   2
5601202  000  1.07e5     0.7488e5  3382.43e3    0.0     0.   4
5601203  000  1.07e5     0.7488e5  3382.43e3    0.0     0.   6
5601204  000  1.07e5     0.7488e5  3382.43e3    0.0     0.   8
5601205  000  1.07e5     0.7488e5  3382.43e3    0.0     0.   10
5601206  000  1.07e5     0.7488e5  3382.43e3    0.0     0.   12
5601301  0.0       0.0      0.0      11
*
* ic tank top1
5610000  icta.t1    branch
5610001  1          0
5610101  0.087      0.0632  0.  0.  90.   0.0632  4.e-5  1.6e-3
00000
5610200  000       1.07e5   0.7488e5       3342.43e3    0.0
5611101  560010000  561000000  0.         0.      0.   000000
5611201  0.          0.         0.
*
* ic tank top2
5620000  icta.t2    branch
5620001  3          0
```

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5620101  0.659      0.1      0.  0.  90.    0.1      4.e-5  1.6e-3
00000
5620200  000      1.07e5     0.7488e5      3342.43e3    0.0
5621101  561010000  562000000  0.          0.       0.    000000
5622101  562000000  563010000  0.1         0.1      0.    000000
5623101  562000000  564010000  0.1         0.1      0.    000000
5621201  0.          0.          0.
5622201  0.          0.          0.
5623201  0.          0.          0.
*
* ic-tank longer ext. piping
5630000 ic.te.p1 pipe
5630001  22
5630101  2.248e-3          22
5630301  0.11              4
5630302  0.07875           11
5630303  0.1               13
5630304  0.0632            18
5630305  0.11              22
5630401  0.0               22
5630601   0.               4
5630602  90.               18
5630603   0.               22
5630801  4.0e-6   0.000    22
5630901  0.0      0.0      3
5630902  0.1      0.1      4
5630903  0.0      0.0      17
5630904  0.1      0.1      18
5630905  0.0      0.0      21
5631001  00000             22
5631101  000000            21
5631201  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   2
5631202  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   4
5631203  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   6
5631204  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   8
5631205  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   10
5631206  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   22
5631301  0.0        0.0       0.0      21
*
* ic-tank short  ext. piping
5640000 ic.te.p2 pipe
5640001  22
5640101  2.248e-3          22
5640301  0.03              4
5640302  0.07875           11
5640303  0.1               13
5640304  0.0632            18
5640305  0.03              22
5640401  0.0               22
5640601   0.               4
5640602  90.               18
5640603   0.               22
5640801  4.0e-6   0.000    22
5640901  0.0      0.0      3
5640902  0.1      0.1      4
5640903  0.0      0.0      17
5640904  0.1      0.1      18
5640905  0.0      0.0      21
5641001  00000             22
5641101  000000            21
5641201  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   2
5641202  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   4
5641203  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   6
5641204  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   8
5641205  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   10
5641206  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   22
5641301  0.0        0.0       0.0      21
*
* top of ic tank
5650000  outic     tmdpvol
5650101  0.  10.  100.  0.  0.  0.  4.e-5  0.  00000
5650200  000
5650201     0.  1.e5    83224.  2.50606e6   1.
5650202   1.e6  1.e5    83224.  2.50606e6   1.
*
*  top ic     - tmdpvol atmosfera
5660000  icctop     sngljun
5660101  570010000  565000000  0.1       0.1       0.1    000000
5660201  0                     0.000  0.000  0.000
*
*  top of ic tank
5700000 icctop  pipe
5700001  3
5700101  1.00              3
5700301  0.2               3
5700401  0.0               3
5700601  90.               3
5700801  4.0e-6   0.0      3
5700901  0.0      0.0      2
5701001  00000             3
5701101  000000            2
5701201  000  1.07e5     425.05e3  2504.22e3  1.0     0.   3
5701301  0.0        0.0       0.0       2
*
*  top ic - surgeline
5750000  icccsl     sngljun
5750101  570000000  580010000  0.1       0.1       0.1    000000
5750201  0                     0.000  0.000  0.000
*
* surge line del ic
5800000 iccctop  pipe
5800001  5
5800101  0.1               5
5800301  0.2               5
5800401  0.0               5
5800601  90.               5
5800801  4.0e-6   0.0      5
5800901  0.0      0.0      4
5801001  00000             5
5801101  000000            4
```

```
5801201  000  1.07e5     0.7488e5  2504.e3    0.0     0.  1
5801202  000  1.07e5     0.7488e5   2504.e3    0.0     0.  2
5801203  000  1.07e5      425.5e3  2504.e3    0.5     0.  3
5801204  000  1.07e5      425.5e3  2504.e3    1.0     0.  5
5801301  0.0        0.0       0.0      4
*
*   top surgeline- tank ic
5850000  icccsj     sngljun
5850101  580000000  562010000  0.1       0.1       0.1    000000
5850201  0                     0.000  0.000  0.000
*
* ic tank bot2 external part
6520000  icta.b2    branch
6520001  2          0
6520101  0.608      0.07875 0.  0.  90.   0.07875 4.e-5  1.6e-3
00000
6520200  000      1.07e5    0.7488e5      3342.43e3    0.0
6521101  652010000  660000000  0.          0.       0.    000000
6522101  551010000  652000000  0.          0.       0.    000000
6521201  0.          0.          0.
6522201  0.          0.          0.
*
* ic-tank external part (with baffle)
6600000 ic.tane  pipe
6600001  12
6600101  0.608             12
6600301  0.07875           6
6600302  0.1               8
6600303  0.0632            12
6600401  0.0               12
6600601  90.               12
6600801  4.0e-6   1.000    12
6600901  0.0      0.0      11
6601001  00000             12
6601101  000000            11
6601201  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   2
6601202  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   4
6601203  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   6
6601204  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   8
6601205  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   10
6601206  000  1.07e5      0.7488e5  3382.43e3    0.0      0.   12
6601301  0.0        0.0       0.0      11
*
* ic tank top1 external
6610000  icta.t1e   branch
6610001  2          0
6610101  0.608      0.0632  0.  0.  90.   0.0632  4.e-5  1.6e-3
00000
6610200  000      1.07e5    0.7488e5      3342.43e3    0.0
6611101  661010000  562000000  0.          0.       0.    000000
6612101  660010000  661000000  0.          0.       0.    000000
6611201  0.          0.          0.
6612201  0.          0.          0.
*
*
*-------------------------------
*     structures
*-------------------------------
*
*
* lower plenum  bottom flange
11001000  1   5  1  1  0.0
11001100  0   1
11001101  4   0.073
11001201  1   4
11001301  0.0 4
11001400  0
11001401  551.0       5
11001501  100010000  0   1   1   0.011   1
11001601  000000000  0   0   1   0.011   1
11001701  0  0.0   0.0   0.0  1
11001801  0. 100. 100. 0. 0. 0. 0.  1. 1
*
* thick flange in various zones
11002000  8     10  2  1  0.058
11002100  0     1
11002101  9     0.1875
11002201  1     9
11002301  0.0   9
11002401  551.0      10
11002501  100010000  0       1       1     0.080  1
11002502  130010000  0       1       1     0.080  2
11002503  110040000  0       1       1     0.080  3
11002504  210010000  0       1       1     0.080  4
11002505  235010000  0       1       1     0.080  5
11002506  245010000  0       1       1     0.080  6
11002507  225010000  0       1       1     0.080  7
11002508  220020000  0       1       1     0.080  8
11002601  000000000  0       0       1     0.080  8
11002701  0                  0.0     0.0   0.0    8
11002801  0. 100. 100. 0. 0. 0. 0. 0.  1. 8
*
* added structure for n2 heat losses
11003000  1     10  1  1  0.058
11003100  0     1
11003101  9     0.068
11003201  1     9
11003301  0.0   9
11003401  551.0      10
11003501  130010000  0       1       1     0.100  1
11003601  000000000  0       2902    1     0.100  1
11003701  0                  0.0     0.0   0.0    1
11003801  0. 100. 100. 0. 0. 0. 0.  1. 1
*
* core region cylindrical vessel
11103000  39    5  2  1  0.0565
11103100  0     1
11103101  4     0.07065
11103201  1     4
11103301  0.0   4
```

```
11103401  551.0      5
11103501  100010000  0       1     1    0.220  1
11103502  110010000  10000   1     1    0.144  6
11103503  111010000  1000000 1     1    0.16   8
11103504  115010000  0       1     1    0.170  9
11103505  120010000  10000   1     1    0.200  11
11103506  130010000  0       1     1    0.170  12
11103507  370010000  10000   1     1    0.530  19
11103508  360010000  0       1     1    0.429  20
11103509  205010000  0       1     1    0.220  21
11103510  210010000  0       1     1    0.220  22
11103511  220010000  10000   1     1    0.214  24
11103512  225010000  0       1     1    0.260  25
11103513  230010000  10000   1     1    0.469  33
11103514  235010000  0       1     1    0.160  34
11103515  240010000  10000   1     1    0.250  38
11103516  245010000  0       1     1    0.365  39
11103601  000000000  0       0     1    0.220  1
11103602  -801       00000   3504  1    0.144  2
11103603  -801       00000   3504  1    0.144  3
11103604  -801       00000   3504  1    0.144  4
11103605  -801       00000   3504  1    0.144  5
11103606  -801       00000   3504  1    0.144  6
11103607  -801       00000   3504  1    0.160  7
11103608  -801       00000   3504  1    0.160  8
11103609  -801       0       3504  1    0.170  9
11103610  -801       00000   3504  1    0.200  10
11103611  -801       00000   3504  1    0.200  11
11103612  000000000  0       0     1    0.170  12
11103613  -801       00000   3509  1    0.530  13
11103614  -801       00000   3509  1    0.530  14
11103615  -801       00000   3509  1    0.530  15
11103616  -801       00000   3509  1    0.530  16
11103617  -801       00000   3509  1    0.530  17
11103618  -801       00000   3509  1    0.530  18
11103619  -801       00000   3509  1    0.530  19
11103620  000000000  0       0     1    0.429  20
11103621  000000000  0       0     1    0.220  21
11103622  000000000  0       0     1    0.220  22
11103623  000000000  00000   0     1    0.214  23
11103624  000000000  00000   0     1    0.214  24
11103625  -801       0       3501  1    0.260  25
11103626  -801       00000   3501  1    0.469  26
11103627  -801       00000   3501  1    0.469  27
11103628  -801       00000   3501  1    0.469  28
11103629  -801       00000   3501  1    0.469  29
11103630  -801       00000   3501  1    0.469  30
11103631  -801       00000   3501  1    0.469  31
11103632  -801       00000   3501  1    0.469  32
11103633  -801       00000   3501  1    0.469  33
11103634  000000000  0       0     1    0.160  34
11103635  -801       00000   3506  1    0.250  35
11103636  -801       00000   3506  1    0.250  36
11103637  -801       00000   3506  1    0.250  37
11103638  -801       00000   3506  1    0.250  38
11103639  000000000  0       0     1    0.365  39
11103701  0                  0.0   0.0  0.0    39
11103801  0. 100. 100. 0. 0. 0. 0.  1. 39
*
* core bypass cylindrical
11201000  35    5  2  1  0.01623
11201100  0     1
11201101  4     0.02108
11201201  1     4
11201301  0.0   4
11201401  551.0      5
11201501  145010000  0    1     1    0.2    1
11201502  145020000  0    1     1    0.2    2
11201503  145030000  0    1     1    0.189  3
11201504  145040000  0    1     1    0.189  4
11201505  145050000  0    1     1    0.189  5
11201506  145060000  0    1     1    0.189  6
11201507  145070000  0    1     1    0.189  7
11201508  155010000  0    1     1    0.213  8
11201509  160010000  0    1     1    0.213  9
11201510  160020000  0    1     1    0.213  10
11201511  160030000  0    1     1    0.213  11
11201512  160040000  0    1     1    0.213  12
11201513  160050000  0    1     1    0.213  13
11201514  160060000  0    1     1    0.213  14
11201515  160070000  0    1     1    0.213  15
11201516  160080000  0    1     1    0.213  16
11201517  160090000  0    1     1    0.213  17
11201518  160100000  0    1     1    0.213  18
11201519  165010000  0    1     1    0.2    19
11201520  170010000  0    1     1    0.235  20
11201521  170020000  0    1     1    0.235  21
11201522  170030000  0    1     1    0.235  22
11201523  170040000  0    1     1    0.235  23
11201524  170050000  0    1     1    0.235  24
11201525  170060000  0    1     1    0.235  25
11201526  170070000  0    1     1    0.235  26
11201527  170080000  0    1     1    0.235  27
11201528  170090000  0    1     1    0.235  28
11201529  170100000  0    1     1    0.235  29
11201530  175010000  0    1     1    0.20   30
11201531  180010000  0    1     1    0.17   31
11201532  180020000  0    1     1    0.17   32
11201533  180030000  0    1     1    0.17   33
11201534  180040000  0    1     1    0.17   34
11201535  180050000  0    1     1    0.17   35
11201601  000000000  0    0     1    0.2    1
11201602  000000000  0    0     1    0.2    2
11201603  000000000  0    0     1    0.189  3
11201604  000000000  0    0     1    0.189  4
11201605  000000000  0    0     1    0.189  5
11201606  000000000  0    0     1    0.189  6
11201607  000000000  0    0     1    0.189  7
11201608  000000000  0    2901  1    0.213  8
11201609  000000000  0    2901  1    0.213  9
11201610  000000000  0    2901  1    0.213  10
11201611  000000000  0    2901  1    0.213  11
11201612  000000000  0    2901  1    0.213  12
11201613  000000000  0    2901  1    0.213  13
11201614  000000000  0    2901  1    0.213  14
11201615  000000000  0    2901  1    0.213  15
11201616  000000000  0    2901  1    0.213  16
11201617  000000000  0    2901  1    0.213  17
11201618  000000000  0    2901  1    0.213  18
11201619  000000000  0    2901  1    0.2    19
11201620  000000000  0    2901  1    0.235  20
11201621  000000000  0    2901  1    0.235  21
11201622  000000000  0    2901  1    0.235  22
11201623  000000000  0    2901  1    0.235  23
11201624  000000000  0    2901  1    0.235  24
11201625  000000000  0    2901  1    0.235  25
11201626  000000000  0    2901  1    0.235  26
11201627  000000000  0    2901  1    0.235  27
11201628  000000000  0    2901  1    0.235  28
11201629  000000000  0    2901  1    0.235  29
11201630  000000000  0    2901  1    0.20   30
11201631  000000000  0    0     1    0.17   31
11201632  000000000  0    0     1    0.17   32
11201633  000000000  0    0     1    0.17   33
11201634  000000000  0    0     1    0.17   34
11201635  000000000  0    0     1    0.17   35
11201701  0               0.0   0.0  0.0    35
11201801  0. 100. 100. 0. 0. 0. 0.  1. 35
*
* bottom of heater rods
11405000  2    9   2   1   0.0311
11405100  0    1
11405101  8    0.132
11405201  1    8
11405301  0.0  8
11405401  551.0      9
11405501  135010000  0    1     1    0.2    1
11405502  140010000  0    1     1    0.2    2
11405601  000000000  0    0     1    0.2    2
11405701  0               0.0   0.0  0.0    2
11405801  0. 100. 100. 0. 0. 0. 0.  1. 2
*
* guide tube
11501000  5    5  2  1  0.037
11501100  0    1
11501101  4    0.04
11501201  1    4
11501301  0.0  4
11501401  561.0      5
11501501  150010000  10000  1    1    0.243  5
11501601  000000000  0      0    1    0.243  5
11501701  0                 0.0  0.0  0.0    5
11501801  0. 100. 100. 0. 0. 0. 0.  1. 5
*
* core bypass flanges (in guide tubes)
11502000  3    5  2  1  0.037
11502100  0    1
11502101  4    0.146
11502201  1    4
11502301  0.0  4
11502401  561.0      5
11502501  150010000  0    1    1    0.109  1
11502502  150030000  0    1    1    0.109  2
11502503  150050000  0    1    1    0.109  3
11502601  000000000  0    0    1    0.109  3
11502701  0               0.0  0.0  0.0    3
11502801  0. 100. 100. 0. 0. 0. 0.  1. 3
*
* fuel box wall
11601000  16   5  1  1  0.0
11601100  0    1
11601101  4    0.003
11601201  1    4
11601301  0.0  4
11601401  561.0      5
11601501  200010000  10000  1    1    0.07632  16
11601601  370010000  0      1    1    0.07632  1
11601602  370010000  0      1    1    0.07632  2
11601603  370020000  0      1    1    0.07632  3
11601604  370020000  0      1    1    0.07632  4
11601605  370030000  0      1    1    0.07632  5
11601606  370030000  0      1    1    0.07632  6
11601607  370040000  0      1    1    0.07632  7
11601608  370040000  0      1    1    0.07632  8
11601609  370050000  0      1    1    0.07632  9
11601610  370050000  0      1    1    0.07632  10
11601611  370060000  0      1    1    0.07632  11
11601612  370060000  0      1    1    0.07632  12
11601613  370070000  0      1    1    0.07632  13
11601614  370070000  0      1    1    0.07632  14
11601615  360010000  0      1    1    0.07632  15
11601616  360010000  0      1    1    0.07632  16
11601701  0                 0.0  0.0  0.0      16
11601801  0. 100. 100. 0. 0. 0. 0.  1. 16
11601901  0. 100. 100. 0. 0. 0. 0.  1. 16
*
* bottom unheated length
11651000  2    10  2  1  0.0
11651100  0    1
11651101  3    0.0020
11651102  1    0.0025
11651103  1    0.0035
11651104  1    0.0043
11651105  1    0.0050
11651106  2    0.006115
11651201  2    3
11651202  3    4
11651203  4    5
11651204  5    6
11651205  4    7
```

```
11651206  5    9
11651301  0.0  9
11651401  561.0       10
11651501  000000000  0      0      1         3.2    1
11651502  000000000  0      0      1         1.9    2
11651601  140010000  0      1      1         3.2    1
11651602  135010000  0      1      1         1.9    2
11651701  0                 0.0    0.0       0.0    2
11651901  0. 100. 100. 0. 0. 0. 0.  1. 2
*
* core active length
12001000  14   10  2  1  0.0
12001100  0    1
12001101  3    0.0020
12001102  1    0.0025
12001103  1    0.0035
12001104  1    0.0043
12001105  1    0.0050
12001106  2    0.006115
12001201  2    3
12001202  3    4
12001203  4    5
12001204  5    6
12001205  4    7
12001206  5    9
12001301  0.04 3
12001302  0.0  5
12001303  0.96 6
12001304  0.0  9
12001401  561.0   10
12001501  000000000  0      0         1         4.24   14
12001601  200010000  10000  1         1         4.24   14
12001701  900               0.051724  0.0       0.0    1
12001702  900               0.051724  0.0       0.0    2
12001703  900               0.0689655 0.0       0.0    3
12001704  900               0.0689655 0.0       0.0    4
12001705  900               0.084483  0.0       0.0    5
12001706  900               0.084483  0.0       0.0    6
12001707  900               0.089655  0.0       0.0    7
12001708  900               0.089655  0.0       0.0    8
12001709  900               0.084483  0.0       0.0    9
12001710  900               0.084483  0.0       0.0    10
12001711  900               0.0689655 0.0       0.0    11
12001712  900               0.0689655 0.0       0.0    12
12001713  900               0.051724  0.0       0.0    13
12001714  900               0.051724  0.0       0.0    14
12001901  0. 100. 100.     0.    0.    0.    0.    1.     1
12001902  0. 100. 100.     0.13  0.    0.    0.    1.     2
12001903  0. 100. 100.     0.    0.13  0.    0.    1.     3
12001904  0. 100. 100.     0.13  0.    0.    0.    1.     4
12001905  0. 100. 100.     0.    0.13  0.    0.    1.     5
12001906  0. 100. 100.     0.13  0.    0.    0.    1.     6
12001907  0. 100. 100.     0.    0.13  0.    0.    1.     7
12001908  0. 100. 100.     0.13  0.    0.    0.    1.     8
12001909  0. 100. 100.     0.    0.13  0.    0.    1.     9
12001910  0. 100. 100.     0.13  0.    0.    0.    1.     10
12001911  0. 100. 100.     0.    0.13  0.    0.    1.     11
12001912  0. 100. 100.     0.13  0.    0.    0.    1.     12
12001913  0. 100. 100.     0.    0.13  0.    0.    1.     13
12001914  0. 100. 100.     0.    0.    0.    0.    1.     14
*
$ top unheated length
12002000  2    10  2  1  0.0
12002100  2001
12002401  561.      10
12002501  000000000  0      0      1         3.664  1
12002502  000000000  0      0      1         3.2    2
12002601  200150000  0      1      1         3.664  1
12002602  200160000  0      1      1         3.2    2
12002701  0                 0.0    0.0       0.0    2
12002901  0. 100. 100. 0. 0. 0. 0.  1. 2
*
$ upper tie plate
12051000  1   5  1  1  0.0
12051100  0  1
12051101  4  0.015
12051201  1  4
12051301  0.0 4
12051400  0
12051401  561.0       5
12051501  200160000  0  1  1  9.896e-3  1
12051601  205010000  0  1  1  9.896e-3  1
12051701  0  0.0  0.0  0.0  1
12051801  0. 100. 100. 0. 0. 0. 0.  1. 1
12051901  0. 100. 100. 0. 0. 0. 0.  1. 1
*
% separator walls - flange
12201000  1     5  2  1  0.02745
12201100  0     1
12201101  4     0.1875
12201201  1     4
12201301  0.0   4
12201401  561.        5
12201501  220030000  0      1      1    0.086  1
12201601  000000000  0      0      1    0.086  1
12201701  0                 0.0    0.0  0.0    1
12201801  0. 100. 100. 0. 0. 0. 0.  1. 1
*
% separator wall
12202000  19    5  2  1  0.02745
12202100  0     1
12202101  4     0.03015
12202201  1     4
12202301  0.0   4
12202401  561.        5
12202501  220030000  00000  1      1    0.2345  1
12202502  220040000  00000  1      1    0.1915  2
12202503  220040000  00000  1      1    0.043   3
12202504  220050000  10000  1      1    0.2345  19
12202601  225010000  0      1      1    0.2345  1
12202602  225010000  0      1      1    0.1915  2
12202603  230010000  0      1      1    0.043   3
12202604  230010000  0      1      1    0.2345  4
12202605  230010000  0      1      1    0.2345  5
12202606  230020000  0      1      1    0.2345  6
12202607  230020000  0      1      1    0.2345  7
12202608  230030000  0      1      1    0.2345  8
12202609  230030000  0      1      1    0.2345  9
12202610  230040000  0      1      1    0.2345  10
12202611  230040000  0      1      1    0.2345  11
12202612  230050000  0      1      1    0.2345  12
12202613  230050000  0      1      1    0.2345  13
12202614  230060000  0      1      1    0.2345  14
12202615  230060000  0      1      1    0.2345  15
12202616  230070000  0      1      1    0.2345  16
12202617  230070000  0      1      1    0.2345  17
12202618  230080000  0      1      1    0.2345  18
12202619  230080000  0      1      1    0.2345  19
12202701  0                 0.0    0.0  0.0     19
12202801  0. 100. 100. 0. 0. 0. 0.  1. 19
12202901  0. 100. 100. 0. 0. 0. 0.  1. 19
*
* sd horizontal pipes
12501000  10    5  2  1  0.0368
12501100  0     1
12501101  4     0.047
12501201  1     4
12501301  0.0   4
12501401  561.        5
12501501  250010000  10000  1      1    0.279  5
12501502  255010000  10000  1      1    0.279  10
12501601  000000000  0      0      1    0.279  10
12501701  0                 0.0    0.0  0.0    10
12501801  0. 100. 100. 0. 0. 0. 0.  1. 10
*
* sd horizontal pipes flanges
12502000  5     5  2  1  0.0368
12502100  0     1
12502101  4     0.1335
12502201  1     4
12502301  0.0   4
12502401  561.        5
12502501  250010000  0      1      1    0.109  1
12502502  250050000  0      1      1    0.109  2
12502503  255010000  0      1      1    0.109  3
12502504  255030000  0      1      1    0.109  4
12502505  255050000  0      1      1    0.109  5
12502601  000000000  0      0      1    0.109  5
12502701  0                 0.0    0.0  0.0    5
12502801  0. 100. 100. 0. 0. 0. 0.  1. 5
*
* sd and udc pipe
12601000  17    5  2  1  0.0427
12601100  0     1
12601101  4     0.0508
12601201  1     4
12601301  0.0   4
12601401  561.        5
12601501  260010000  10000  1      1    0.25   4
12601502  265010000  00000  1      1    0.246  5
12601503  270010000  00000  1      1    0.247  6
12601504  275010000  10000  1      1    0.362  10
12601505  280010000  00000  1      1    0.3    11
12601506  285010000  10000  1      1    0.3    17
12601601  000000000  00000  0      1    0.25   4
12601602  000000000  00000  0      1    0.246  5
12601603  000000000  00000  0      1    0.247  6
12601604  000000000  00000  0      1    0.362  10
12601605  000000000  00000  0      1    0.3    11
12601606  -801       00000  3502   1    0.3    17
12601701  0                 0.0    0.0  0.0    17
12601801  0. 100. 100. 0. 0. 0. 0.  1. 17
*
* dc flanges
12602000  10    5  2  1  0.0427
12602100  0     1
12602101  4     0.146
12602201  1     4
12602301  0.0   4
12602401  561.        5
12602501  260010000  0      1      1    0.08   1
12602502  260010000  0      1      1    0.08   2
12602503  265010000  0      1      1    0.08   3
12602504  270010000  0      1      1    0.08   4
12602505  285060000  0      1      1    0.08   5
12602506  300010000  0      1      1    0.08   6
12602507  310010000  0      1      1    0.08   7
12602508  320150000  0      1      1    0.08   8
12602509  325010000  0      1      1    0.08   9
12602510  330010000  0      1      1    0.08   10
12602601  000000000  0      0      1    0.08   10
12602701  0                 0.0    0.0  0.0    10
12602801  0. 100. 100. 0. 0. 0. 0.  1. 10
*
* ssa-dc connection
12901000  4     5  2  1  0.02
12901100  0     1
12901101  4     0.0211
12901201  1     4
12901301  0.0   4
12901401  561.        5
12901501  290010000  10000  1      1    0.3    2
12901502  295010000  10000  1      1    0.35   4
12901601  000000000  0      0      1    0.3    1
12901602  000000000  0      0      1    0.3    2
12901603  000000000  0      0      1    0.35   3
12901604  000000000  0      0      1    0.35   4
12901701  0                 0.0    0.0  0.0    4
12901801  0. 100. 100. 0. 0. 0. 0.  1. 4
```

```
* ssa-dc connection flanges
12902000  4      5  2  1  0.02
12902100  0      1
12902101  4      0.0595
12902201  1      4
12902301  0.0  4
12902401  561.          5
12902501  290010000  10000  1      1      0.070  2
12902502  295010000  10000  1      1      0.070  4
12902601  000000000  0      0      1      0.070  1
12902602  000000000  0      0      1      0.070  2
12902603  000000000  0      0      1      0.070  3
12902604  000000000  0      0      1      0.070  4
12902701  0                 0.0    0.0    0.0    4
12902801  0. 100. 100. 0. 0. 0. 0.  1. 4
*
* lower downcomer
13001000  26     5  2  1  0.0368
13001100  0      1
13001101  4      0.0445
13001201  1      4
13001301  0.0  4
13001401  551.0         5
13001501  300010000  0      1      1      0.275  1
13001502  305010000  10000  1      1      0.28   9
13001503  310010000  0      1      1      0.26   10
13001504  320010000  10000  1      1      0.275  24
13001505  325010000  0      1      1      0.27   25
13001506  330010000  0      1      1      0.27   26
13001601  000000000  0      0      1      0.275  1
13001602  -801       00000  3503   1      0.28   9
13001603  000000000  0      0      1      0.26   10
13001604  000000000  00000  0      1      0.275  24
13001605  000000000  0      0      1      0.27   25
13001606  000000000  0      0      1      0.27   26
13001701  0                 0.0    0.0    0.0    26
13001801  0. 100. 100. 0. 0. 0. 0.  1. 26
*
* jet pump
13151000  15     5  2  1  0.0133
13151100  0      1
13151101  4      0.0167
13151201  1      4
13151301  0.0  4
13151401  551.0         5
13151501  315010000  10000  1      1      0.273   14
13151502  315150000  0      1      1      0.1     15
13151601  320010000  10000  1      1      0.273   14
13151602  320150000  0      1      1      0.1     15
13151701  0                 0.0    0.0    0.0     15
13151801  0. 100. 100. 0. 0. 0. 0.  1. 15
13151901  0. 100. 100. 0. 0. 0. 0.  1. 15
*
* lower plenum hor
13351000  7      5  2  1  0.0244
13351100  0      1
13351101  4      0.028
13351201  1      4
13351301  0.0  4
13351401  551.0         5
13351501  335010000  10000  1      1      0.25   4
13351502  345010000  10000  1      1      0.12   7
13351601  000000000  0      0      1      0.25   4
13351602  000000000  0      0      1      0.12   7
13351701  0                 0.0    0.0    0.0    7
13351801  0. 100. 100. 0. 0. 0. 0.  1. 7
*
* lp hor flanges
13352000  3      5  2  1  0.0244
13352100  0      1
13352101  4      0.1335
13352201  1      4
13352301  0.0  4
13352401  551.0         5
13352501  335010000  0      1      1      0.1    1
13352502  335040000  0      1      1      0.1    2
13352503  345010000  0      1      1      0.1    3
13352601  000000000  0      0      1      0.1    3
13352701  0                 0.0    0.0    0.0    3
13352801  0. 100. 100. 0. 0. 0. 0.  1. 3
*
* lp pipe
13353000  2      5  2  1  0.01905
13353100  0      1
13353101  4      0.02413
13353201  1      4
13353301  0.0  4
13353401  551.0         5
13353501  345040000  10000  1      1      0.25   2
13353601  110020000 -10000  1      1      0.25   2
13353701  0                 0.0    0.0    0.0    2
13353801  0. 100. 100. 0. 0. 0. 0.  1. 2
13353901  0. 100. 100. 0. 0. 0. 0.  1. 2
*
* ic pipe external
15000000  10     5  2  1  0.009
15000100  0      1
15000101  4      0.010               * 0.013
15000201  1      4
15000301  0.0  4
15000401  551.0         5
15000501  500010000  10000  1      1      0.38   5
15000502  500060000  10000  1      1      0.212  9
15000503  500100000  00000  1      1      0.112  10
15000601  -801              00000  3507   1      0.38   1
15000602  -801              00000  3507   1      0.38   2
15000603  -801              00000  3507   1      0.38   3
15000604  -801              00000  3507   1      0.38   4
15000605  -801              00000  3507   1      0.38   5
15000606  -801              00000  3507   1      0.212  6
15000607  -801              00000  3507   1      0.212  7
15000608  -801              00000  3507   1      0.212  8
15000609  -801              00000  3507   1      0.212  9
15000610  -801              00000  3507   1      0.112  10
15000701  0                       0.0    0.0  0.0    10
15000801  0. 100. 100. 0. 0. 0. 0.  1. 10
*
* ic exit piping
15010000  27     5  2  1  0.009
15010100  0      1
15010101  4      0.010               * 0.013
15010201  1      4
15010301  0.0  4
15010401  551.0         5
15010501  540010000  10000  1      1      0.35   2
15010502  540030000  10000  1      1      0.472  22
15010503  540230000  0      1      1      0.4    23
15010504  540240000  0      1      1      0.3    24
15010505  540250000  10000  1      1      0.35   27
15010601  000000000  00000  0      1      0.35   1
15010602  000000000  00000  0      1      0.35   2
15010603  -801       00000  3508   1      0.472  22
15010604  000000000  00000  0      1      0.4    23
15010605  000000000  00000  0      1      0.3    24
15010606  000000000  00000  0      1      0.35   25
15010607  000000000  00000  0      1      0.35   26
15010608  000000000  00000  0      1      0.35   27
15010701  0                 0.0    0.0    0.0    27
15010801  0. 100. 100. 0. 0. 0. 0.  1. 27
*
* ic pipe internal flanges
15100000  2      30  2  1  0.095
15100100  0      1
15100101  29     0.125
15100201  1      29
15100301  0.0  29
15100401  551.0         30
15100501  510010000  00000  1      1      0.10   1
15100502  520010000  00000  1      1      0.10   2
15100601  562010000  00000  1      1      0.10   1
15100602  560080000  00000  1      1      0.10   2
15100701  0                 0.0    0.0    0.0    2
15100801  0. 100. 100. 0. 0. 0. 0.  1. 2
15100901  0. 100. 100. 0. 0. 0. 0.  1. 2
*
* ic heat exchanger 12 tubes
15150000  5      10  2  1  0.00811
15150100  0      1
15150101  9      0.01098
15150201  1      9
15150301  0.0  9
15150401  551.0         10
15150501  515010000  10000  1      1      0.758  5
15150601  561010000  00000  1      1      0.758  1
15150602  560120000  00000  1      1      0.758  2
15150603  560110000  00000  1      1      0.758  3
15150604  560100000  00000  1      1      0.758  4
15150605  560090000  00000  1      1      0.758  5
15150701  0                 0.0    0.0    0.0    5
15150801  0. 100. 100. 0. 0. 0. 0.  1. 5
15150901  0.005 100. 100. 0. 0. 0. 0.  1. 5
*
* ic heat exchanger - bottom exit single tube
15250000  14     10  2  1  0.0104
15250100  0      1
15250101  9      0.0134
15250201  1      9
15250301  0.0  9
15250401  551.0         10
15250501  525010000  00000  1      1      0.1      1
15250502  525020000  10000  1      1      0.07875  9
15250503  525090000  10000  1      1      0.104    14
15250601  560070000  00000  1      1      0.1      1
15250602  560060000  00000  1      1      0.07875  2
15250603  560050000  00000  1      1      0.07875  3
15250604  560040000  00000  1      1      0.07875  4
15250605  560030000  00000  1      1      0.07875  5
15250606  560020000  00000  1      1      0.07875  6
15250607  560010000  00000  1      1      0.07875  7
15250608  552010000  00000  1      1      0.07875  8
15250609  551010000  00000  1      1      0.07875  9
15250610  551010000  00000  1      1      0.104    14
15250701  0                 0.0    0.0    0.0      14
15250801  0. 100. 100. 0. 0. 0. 0.  1. 14
15250901  0. 100. 100. 0. 0. 0. 0.  1. 14
*
* ic tank - to consider heat loss to envir.
15600000  16     5  2  1  0.4750
15600100  0      1
15600101  4      0.478
15600201  1      4
15600301  0.0  4
15600401  551.0         5
15600501  551010000  00000  1      1            0.07875  1
15600502  652010000  00000  1      1            0.07875  2
15600503  660010000  10000  1      1            0.07875  8
15600504  660070000  10000  1      1            0.1      10
15600505  660090000  10000  1      1            0.0632   14
15600506  661010000  00000  1      1            0.0632   15
15600507  562010000  00000  1      1            0.1      16
15600601       -801  0      3505   1            0.07875  1
15600602       -801  0      3505   1            0.07875  2
15600603       -801  0      3505   1            0.07875  3
15600604       -801  0      3505   1            0.07875  4
15600605       -801  0      3505   1            0.07875  5
15600606       -801  0      3505   1            0.07875  6
15600607       -801  0      3505   1            0.07875  7
15600608       -801  0      3505   1            0.07875  8
15600609       -801  0      3505   1            0.1      9
15600610       -801  0      3505   1            0.1      10
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15600611       -801  0       3505   1       0.0632  11
15600612       -801  0       3505   1       0.0632  12
15600613       -801  0       3505   1       0.0632  13
15600614       -801  0       3505   1       0.0632  14
15600615       -801  0       3505   1       0.0632  15
15600616       -801  0       3505   1       0.1     16
15600701  0                  0.0    0.0     0.0     16
15600801  0. 100. 100. 0. 0. 0. 0.  1. 16
*
* ic tank external pipes - for heat losses
15630000  22     5  2  1  0.02625
15630100  0     1
15630101  4     0.0295
15630201  1     4
15630301  0.0  4
15630401  551.0       5
15630501  563010000  10000  1       1       0.11    4
15630502  563050000  10000  1       1       0.07875 11
15630503  563120000  10000  1       1       0.1     13
15630504  563140000  10000  1       1       0.0632  18
15630505  563190000  10000  1       1       0.11    22
15630601       -801  0       3508   1       0.11    4
15630602       -801  0       3508   1       0.07875 11
15630603       -801  0       3508   1       0.1     13
15630604       -801  0       3508   1       0.0632  18
15630605       -801  0       3508   1       0.11    22
15630701  0                  0.0    0.0     0.0     22
15630801  0. 100. 100. 0. 0. 0. 0.  1. 22
*
* ic tank external pipes - for heat losses
15640000  22     5  2  1  0.02625
15640100  0     1
15640101  4     0.0295
15640201  1     4
15640301  0.0  4
15640401  551.0       5
15640501  564010000  10000  1       1       0.03    4
15640502  564050000  10000  1       1       0.07875 11
15640503  564120000  10000  1       1       0.1     13
15640504  564140000  10000  1       1       0.0632  18
15640505  564190000  10000  1       1       0.03    22
15640601       -801  0       3508   1       0.03    4
15640602       -801  0       3508   1       0.07875 11
15640603       -801  0       3508   1       0.1     13
15640604       -801  0       3508   1       0.0632  18
15640605       -801  0       3508   1       0.03    22
15640701  0                  0.0    0.0     0.0     22
15640801  0. 100. 100. 0. 0. 0. 0.  1. 22
*
* ic tank internal baffle
16600000  14     5  2  1  0.35
16600100  0     1
16600101  4     0.353
16600201  1     4
16600301  0.0  4
16600401  551.0       5
16600501  552010000  00000  1       1       0.07875 1
16600502  560010000  10000  1       1       0.07875 7
16600503  560070000  10000  1       1       0.1     9
16600504  560090000  10000  1       1       0.0632  13
16600505  561010000  00000  1       1       0.0632  14
16600601  652010000  00000  1       1       0.07875 1
16600602  660010000  10000  1       1       0.07875 7
16600603  660070000  10000  1       1       0.1     9
16600604  660090000  10000  1       1       0.0632  13
16600605  661010000  00000  1       1       0.0632  14
16600701  0                  0.0    0.0     0.0     14
16600801  0. 100. 100. 0. 0. 0. 0.  1. 14
16600901  0. 100. 100. 0. 0. 0. 0.  1. 14
*
*
*-------------------------------------------------------------*
* material tables
*-------------------------------------------------------------*
*
*
20100100  tbl/fctn   1  1    * stainless steel
20100200  tbl/fctn   1  1    * copper
20100300  tbl/fctn   1  1    * nickel
20100400  tbl/fctn   1  1    * boron nitride
20100500  tbl/fctn   1  1    * inc. 600
20100600  tbl/fctn   1  1    * filler (ceramics)
*-------------------------------------------------------------*
*          conduttivita'   acciaio
*-------------------------------------------------------------*
20100101     1.0     15.16
20100102   123.0     15.16
20100103   173.0     15.16
20100104   223.0     15.16
20100105   273.0     15.16
20100106   293.0     15.16
20100107   323.0     15.62
20100108   373.0     16.37
20100109   423.0     17.09
20100110   473.0     17.81
20100111   523.0     18.50
20100112   573.0     19.20
20100113   623.0     19.85
20100114   673.0     20.50
20100115   723.0     21.13
20100116   773.0     21.77
20100117   823.0     22.36
20100118   873.0     22.95
20100119   923.0     23.53
20100120   973.0     24.12
20100121  1023.0     24.68
20100122  1073.0     25.25
20100123  1123.0     25.81
20100124  1173.0     26.38
20100125  1223.0     26.94
20100126  1273.0     27.50
20100127  1323.0     28.05
20100128  1373.0     28.60
20100129  1423.0     29.15
20100130  1473.0     29.70
20100131  1523.0     30.25
20100132  1573.0     30.80
*-------------------------------------------------------------*
*  calore specifico dell' acciaio
*-------------------------------------------------------------*
20100151     1.0     3.58249e6
20100152   123.0     3.58249e6
20100153   173.0     3.58249e6
20100154   223.0     3.58249e6
20100155   273.0     3.58249e6
20100156   293.0     3.58249e6
20100157   323.0     3.69720e6
20100158   373.0     3.85678e6
20100159   423.0     3.99345e6
20100160   473.0     4.10800e6
20100161   523.0     4.21070e6
20100162   573.0     4.29602e6
20100163   623.0     4.37028e6
20100164   673.0     4.43980e6
20100165   723.0     4.50300e6
20100166   773.0     4.56225e6
20100167   823.0     4.62308e6
20100168   873.0     4.68470e6
20100169   923.0     4.75185e6
20100170   973.0     4.82295e6
20100171  1023.0     4.91380e6
20100172  1073.0     5.03230e6
20100173  1123.0     5.18398e6
20100174  1173.0     5.37200e6
20100175  1223.0     5.60110e6
20100176  1273.0     5.88155e6
20100177  1323.0     6.16200e6
20100178  1373.0     6.44245e6
20100179  1423.0     6.72290e6
20100180  1473.0     7.00335e6
20100181  1523.0     7.28380e6
20100182  1573.0     7.56425e6
*-------------------------------------------------------------*
* conduttivita' mat.-2- rame *
*-------------------------------------------------------------*
20100201  293.2   386.1
20100202  373.2   376.8
20100203  573.2   366.3
20100204 1000.0   366.3
20100205 2000.0   366.3
*-------------------------------------------------------------*
* calore spec. mat. -2-          *
*-------------------------------------------------------------*
20100251  293.2   3.4496e6
20100252  373.2   3.56608e6
20100253  573.2   3.7184e6
20100254 1000.0   3.7184e6
20100255 2000.0   3.7184e6
*-------------------------------------------------------------*
* conduttivita' mat. -3- ni  *
*-------------------------------------------------------------*
20100301  293.2   71.18
20100302  573.2   58.62
20100303  773.2   58.62
20100304 1073.2   48.15
20100305 2000.0   48.15
*-------------------------------------------------------------*
* calore spec. mat. -3-          *
*-------------------------------------------------------------*
20100351  293.2   4.05384e6
20100352  573.2   4.05384e6
20100353  773.2   4.05384e6
20100354 1073.2   4.05384e6
20100355 2000.0   4.05384e6
*-------------------------------------------------------------*
* conduttivita' mat. -4- bn-s*
*-------------------------------------------------------------*
20100401  293.0   23.0
20100402  400.0   23.0
20100403  500.0   22.5
20100404  600.0   22.0
20100405  700.0   21.5
20100406  800.0   20.9
20100407  900.0   20.5
20100408 1000.0   20.1
20100409 1100.0   19.8
20100410 1200.0   19.4
20100411 1300.0   19.1
20100412 2000.0   19.1
*-------------------------------------------------------------*
* calore spec.mat. -4-          *
*-------------------------------------------------------------*
20100451  293.0   1.5029e6
20100452  400.0   2.0121e6
20100453  500.0   2.4035e6
20100454  600.0   2.698e6
20100455  700.0   2.9127e6
20100456  800.0   3.097e6
20100457  900.0   3.268e6
20100458 1000.0   3.3972e6
20100459 1100.0   3.4941e6
20100460 1200.0   3.5891e6
20100461 1300.0   3.6537e6
20100462 1400.0   3.7183e6
20100463 1500.0   3.7506e6
20100464 2000.0   3.7506e6
*-------------------------------------------------------------*
* conduttivita' mat.-5- i/600 *
*-------------------------------------------------------------*
20100501  294.3   14.86
```

```
20100502  366.5   15.72
20100503  477.6   17.45
20100504  588.8   19.19
20100505  699.9   20.92
20100506  811.0   22.79
20100507  922.0   24.81
20100508 1033.2   26.83
20100509 1144.3   28.85
20100510 2000.0   28.85
*-------------------------------------------------------------*
* calore spec. mat. -5-       *
*-------------------------------------------------------------*
20100551  294.3   3.74292e6
20100552  366.5   3.91995e6
20100553  477.6   4.09698e6
20100554  588.8   4.274e6
20100555  699.9   4.451e6
20100556  811.0   4.66179e6
20100557  922.0   4.93998e6
20100558 1033.2   5.11701e6
20100559 1144.3   5.26032e6
20100560 2000.0   5.26032e6
*-------------------------------------------------------------*
* conduttivita' mat.-6- fil. *
*-------------------------------------------------------------*
20100601  294.2   0.9304
20100602 2000.0   0.9304
*-------------------------------------------------------------*
* calore spec. mat. -6-       *
*-------------------------------------------------------------*
20100651  294.2   1.92975e6
20100652 2000.0   1.92975e6
*
*
*-------------------------------------------------------------*
*   general tables
*-------------------------------------------------------------*
*
*
* heat removal by cooling coil from sd (max 200 kw)/ heat losses
po-ic-2
20250100  htc-t  507
20250101    -1.0  0.0
20250102     0.0  0.0
20250103     1.0  -1. *15.
20250104    450.  -1. *15.
20250105    451.  -4. *15.
20250106    600.  -4. *15.
20250107    601.  -1. *15.
20250108    1.e6 -1. *15.
*
* heat removal by cooling coil from udc (max 40 kw)/ heat losses
po-ic-2
20250200  htc-t  508
20250201    -1.0          0.0
20250202     0.0          0.0
20250203     1.0  -1. *20.
20250204    450.  -1. *20.
20250205    451. -15. *20.
20250206    600. -15. *20.
20250207    601.  -1. *20.
20250208    1.e6  -1. *20.
*
* heat removal by cooling coil from mdc (max 10 kw) (heta losses
po-ic-2)
20250300  htc-t  509
20250301    -1.0          0.0
20250302     0.0          0.0
20250303     1.0           20.
20250304     1.e6          20.
*
* heat removal by cooling coil from  lp (max 50 kw)
20250400  htc-t  510
20250401    -1.0         0.0
20250402     0.0         0.0
20250403     1.0         323.
20250404     1.e6        323.
*
* heat losses from ic tank
20250500  htc-t  580
20250501    -1.0         0.0
20250502     0.0         0.0
20250503     1.0         50.
20250504     1.e6        50.
*
* heat losses from steam dome top (utilized for po-sd-8)
20250600  htc-t  582
20250601    -1.0         0.0
20250602     0.0         0.0
20250603     1.0         80.
20250604     1.e6        80.
*
* heat losses from ic line
20250700  htc-t  581
20250701    -1.0         0.0
20250702     0.0         0.0
20250703     1.0         50.  *
20250704     982.        50.
20250705     1.e6        50.
*
* heat losses from ic tank external pipes & ic line liquid
20250800  htc-t  580
20250801    -1.0         0.0
20250802     0.0         0.0
20250803     1.0         50.  *
20250804     1.e6        50.
*
* heat losses from core region (external vessel)
20250900  htc-t  583
20250901    -1.0         0.0
20250902     0.0         0.0
20250903     1.0          5. *
20250904     1.e6         5.
*
*   heat exchange between sd, udc, mdc and lp slabs with cooling
coil
*       - assigned environment temperature value -
20280100  temp   511
20280101    -1.0         0.0
20280102     0.0         0.0
20280103     1.0         303.
20280104     1.e6        303.
*
* core power
20290000  power  513
20290001    -1.0         0.0
20290002     0.0         0.0
20290003     5.0         0.0416e6
20290004    438.0        0.0416e6
20290005    440.7        0.004e6
20290006    586.1        0.004e6
20290007    588.         0.07047e6
20290008    590.         0.07330e6
20290009   1086.         0.07330e6
20290010   1088.         0.0
20290011     1.e6        0.
*
* bypass heaters
20290100  htrnrate   515
20290101    -1.    0.00
20290102     0.    0.00
20290103    1.99   0.00
20290104    2.0   -2.65e3
20290105    200.  -2.65e3
20290106    201.   0.
20290107    1.e6   0.
*
* power loss from fuel box -lower part-  fb1
20290200  htrnrate   516
20290201    -1.    0.00
20290202     0.    0.00
20290203    0.01   5.90e4
20290204    30.    5.90e4
20290205    50.    5.90e4
20290206    70.    5.90e4
20290207    100.   5.90e4
20290208    201.   7.90e4
20290209    202.   7.90e4
20290210    400.  10.90e4
20290211   1003.  10.90e3
20290212    1.e6  10.90e3
*
* power loss from fuel box -upper part- fb2
20290300  htrnrate   517
20290301    -1.    0.00
20290302     0.    0.00
20290303    0.01   0.450e3
20290304    100.   0.650e3
20290305    360.   0.650e3
20290306    650.   0.450e3
20290307   1002.   5.650e4
20290308   1003.   0.450e3
20290309    1.e6   0.450e3
*
*-------------------------------------------------------------*
*     control variables
*-------------------------------------------------------------*
*
* dc lvl annular part1
20500100  dc.lvl1           sum      1.   0.   1
20500101  0.    0.1         voidf    320150000
20500102        0.273       voidf    320140000
20500103        0.273       voidf    320130000
20500104        0.273       voidf    320120000
20500105        0.273       voidf    320110000
20500106        0.273       voidf    320100000
20500107        0.273       voidf    320090000
20500108        0.273       voidf    320080000
20500109        0.273       voidf    320070000
20500110        0.273       voidf    320060000
20500111        0.273       voidf    320050000
20500112        0.273       voidf    320040000
20500113        0.273       voidf    320030000
20500114        0.273       voidf    320020000
20500115        0.273       voidf    320010000
*
* dc lvl   part 2
20500200  dc.lvl2           sum      1.   0.   1
20500201  0.    0.325       voidf    310010000
20500202        0.281       voidf    305080000
20500203        0.281       voidf    305070000
20500204        0.281       voidf    305060000
20500205        0.281       voidf    305050000
20500206        0.281       voidf    305040000
20500207        0.29        voidf    305030000
20500208        0.29        voidf    305020000
20500209        0.29        voidf    305010000
20500210        0.283       voidf    300010000
*
* dc lvl   part 3
20500300  dc.lvl3           sum      1.   0.   1
20500301  0.    0.300       voidf    285060000
20500302        0.300       voidf    285050000
20500303        0.300       voidf    285040000
20500304        0.300       voidf    285030000
20500305        0.300       voidf    285020000
20500306        0.300       voidf    285010000
20500307        0.300       voidf    280010000
20500308        0.362       voidf    275040000
20500309        0.362       voidf    275030000
```

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20500310          0.362          voidf          275020000
20500311          0.362          voidf          275010000
20500312          0.247          voidf          270010000
*
* dc lvl jet pump region
20500400    dc.lvl4              sum            1.   0.   1
20500401    0.    0.273          voidf          315150000
20500402          0.273          voidf          315140000
20500403          0.273          voidf          315130000
20500404          0.273          voidf          315120000
20500405          0.273          voidf          315110000
20500406          0.273          voidf          315100000
20500407          0.273          voidf          315090000
20500408          0.273          voidf          315080000
20500409          0.273          voidf          315070000
20500410          0.273          voidf          315060000
20500411          0.273          voidf          315050000
20500412          0.273          voidf          315040000
20500413          0.273          voidf          315030000
20500414          0.273          voidf          315020000
20500415          0.273          voidf          315010000
*
* dc lvl total annular region
20501000    dc.lvl.a             sum            1.   0.   1
20501001    0.    1.        cntrlvar       001
20501002          1.        cntrlvar       002
20501003          1.        cntrlvar       003
20501004          0.246     voidf          265010000
20501005          0.25      voidf          260010000
20501006          0.25      voidf          260020000
20501007          0.25      voidf          260030000
20501008          0.25      voidf          260040000
*
* dc lvl total jet pump region
20501100    dc.lv.jp             sum            1.   0.   1
20501101    0.    1.        cntrlvar       002
20501102          1.        cntrlvar       003
20501103          1.        cntrlvar       004
20501104          0.327          voidf          325010000
20501105          0.185          voidf          330010000
20501106          0.246     voidf          265010000
20501107          0.25      voidf          260010000
20501108          0.25      voidf          260020000
20501109          0.25      voidf          260030000
20501110          0.25      voidf          260040000
*
* lp lvl vertical
20501500    lp.lvl               sum            1.   0.   1
20501501    0.    0.30           voidf          100010000
20501502          0.25           voidf          110010000
20501503          0.25           voidf          110020000
20501504          0.1443         voidf          110030000
20501505          0.1443         voidf          110040000
20501506          0.1114         voidf          110050000
20501507          0.1615         voidf          111010000
20501508          0.1600         voidf          112010000
20501509          0.1745         voidf          115010000
20501510          0.2            voidf          120010000
20501511          0.2            voidf          120020000
20501512          0.176          voidf          130010000
20501513          0.2            voidf          135010000
20501514          0.2            voidf          140010000
*
* core level
20501600    core.lvl             sum            1.   0.   1
20501601    0.    0.265          voidf          200010000
20501602          0.265          voidf          200020000
20501603          0.265          voidf          200030000
20501604          0.265          voidf          200040000
20501605          0.265          voidf          200050000
20501606          0.265          voidf          200060000
20501607          0.265          voidf          200070000
20501608          0.265          voidf          200080000
20501609          0.265          voidf          200090000
20501610          0.265          voidf          200100000
20501611          0.265          voidf          200110000
20501612          0.265          voidf          200120000
20501613          0.265          voidf          200130000
20501614          0.265          voidf          200140000
20501615          0.229          voidf          200150000
20501616          0.2            voidf          200160000
*
* upper plenum level
20501700    up.lvl               sum            1.   0.   1
20501701    0.    0.22           voidf          205010000
20501702          0.22           voidf          210010000
*
* up-sep  level
20501800    upse.lvl             sum            1.   0.   1
20501801    0.    0.214          voidf          220010000
20501802          0.214          voidf          220020000
20501803          0.2345         voidf          220030000
20501804          0.2345         voidf          220040000
20501805          0.2345         voidf          220050000
20501806          0.2345         voidf          220060000
20501807          0.2345         voidf          220070000
20501808          0.2345         voidf          220080000
20501809          0.2345         voidf          220090000
20501810          0.2345         voidf          220100000
20501811          0.2345         voidf          220110000
20501812          0.2345         voidf          220120000
20501813          0.2345         voidf          220130000
20501814          0.2345         voidf          220140000
20501815          0.2345         voidf          220150000
20501816          0.2345         voidf          220160000
20501817          0.2345         voidf          220170000
20501818          0.2345         voidf          220180000
20501819          0.2345         voidf          220190000
20501820          0.2345         voidf          220200000
*
* co lvl total in the core region
20502000    dc.lv.jp             sum            1.   0.   1
20502001    0.    1.        cntrlvar       015
20502002          1.        cntrlvar       016
20502003          1.        cntrlvar       017
20502004          1.        cntrlvar       018
*
* core bypass  level   part 1
20502500    by.lvl1              sum            1.   0.   1
20502501    0.    0.2468         voidf          150010000
20502502          0.2468         voidf          150020000
20502503          0.2468         voidf          150030000
20502504          0.2468         voidf          150040000
20502505          0.2468         voidf          150050000
20502506          0.223          voidf          155010000
20502507          0.2133         voidf          160010000
20502508          0.2133         voidf          160020000
20502509          0.2133         voidf          160030000
20502510          0.2133         vpidf          160040000
20502511          0.2133         voidf          160050000
20502512          0.2133         voidf          160060000
20502513          0.2133         voidf          160070000
20502514          0.2133         voidf          160080000
20502515          0.2133         voidf          160090000
20502516          0.2133         voidf          160100000
20502517          0.2015         voidf          165010000
*
* core bypass  level   part 2
20502600    by.lvl2              sum            1.   0.   1
20502601    0.    0.235          voidf          170010000
20502602          0.235          voidf          170020000
20502603          0.235          voidf          170030000
20502604          0.235          voidf          170040000
20502605          0.235          voidf          170050000
20502606          0.235          voidf          170060000
20502607          0.235          voidf          170070000
20502608          0.235          voidf          170080000
20502609          0.235          voidf          170090000
20502610          0.235          voidf          170100000
20502611          0.2075         voidf          175010000
*
* by lvl total from by bot
20503000    dc.lv.jp             sum            1.   0.   1
20503001    0.    1.        cntrlvar       025
20503002          1.        cntrlvar       026
*
* sep annulus  level
20503500    sep.annl             sum            1.   0.   1
20503501    0.    0.34           voidf          225010000
20503502          0.512          voidf          230010000
20503503          0.469          voidf          230020000
20503504          0.469          voidf          230030000
20503505          0.469          voidf          230040000
20503506          0.469          voidf          230050000
20503507          0.469          voidf          230060000
20503508          0.469          voidf          230070000
20503509          0.469          voidf          230080000
*
* core power
20504000    core.po              sum        1. 0. 1
20504001    0.        0.162907   htrnr      200100101
20504002              0.162907   htrnr      200100201
20504003              0.162907   htrnr      200100301
20504004              0.162907   htrnr      200100401
20504005              0.162907   htrnr      200100501
20504006              0.162907   htrnr      200100601
20504007              0.162907   htrnr      200100701
20504008              0.162907   htrnr      200100801
20504009              0.162907   htrnr      200100901
20504010              0.162907   htrnr      200101001
20504011              0.162907   htrnr      200101101
20504012              0.162907   htrnr      200101201
20504013              0.162907   htrnr      200101301
20504014              0.162907   htrnr      200101401
*
* ext fuel box level
20505000    ext.fblv             sum            1.   0.   1
20505001    0.    0.53           voidf          370010000
20505002          0.53           voidf          370020000
20505003          0.53           voidf          370030000
20505004          0.53           voidf          370040000
20505005          0.53           voidf          370050000
20505006          0.53           voidf          370060000
20505007          0.53           voidf          370070000
20505008          0.429          voidf          360010000
*
* heat exchange ic
20506000    ic.ht                sum            1.   0.   1
20506001    0.    1.             q              510010000
20506002          1.             q              515010000
20506003          1.             q              515020000
20506004          1.             q              515030000
20506005          1.             q              515040000
20506006          1.             q              515050000
20506007          1.             q              520010000
*
*  heat exchange ic  exit pipe (in the tank)
20506100    ic.tube              sum            1.   0.   1
20506101    0.    1.             q              525010000
20506102          1.             q              525020000
20506103          1.             q              525030000
20506104          1.             q              525040000
20506105          1.             q              525050000
20506106          1.             q              525060000
20506107          1.             q              525070000
20506108          1.             q              525080000
20506109          1.             q              525090000
20506110          1.             q              525100000
20506111          1.             q              525110000
20506112          1.             q              525120000
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20506113          1.          q          525130000
20506114          1.          q          525140000
*
* ht ic total
20506200  ic.ht.to            sum        1.    0.    1
20506201  0.     -1.          cntrlvar   060
20506202         -1.          cntrlvar   061
*
*  environment heat loss from ic tank
20506300  ic.t.hl             sum        1. 0. 1
20506301  0.      0.235       htrnr      560000101
20506302          0.235       htrnr      560000201
20506303          0.235       htrnr      560000301
20506304          0.235       htrnr      560000401
20506305          0.235       htrnr      560000501
20506306          0.235       htrnr      560000601
20506307          0.235       htrnr      560000701
20506308          0.235       htrnr      560000801
20506309          0.298       htrnr      560000901
20506310          0.298       htrnr      560001001
20506311          0.188       htrnr      560001101
20506312          0.188       htrnr      560001201
20506313          0.188       htrnr      560001301
20506314          0.188       htrnr      560001401
20506315          0.188       htrnr      560001501
20506316          0.298       htrnr      560001601
*
*  heat exchange from ic tank ext pipe vertical (longer)
20507100  ic.tav1             sum        1.    0.    1
20507101  0.      1.          q          563050000
20507102          1.          q          563060000
20507103          1.          q          563070000
20507104          1.          q          563080000
20507105          1.          q          563090000
20507106          1.          q          563100000
20507107          1.          q          563110000
20507108          1.          q          563120000
20507109          1.          q          563130000
20507110          1.          q          563140000
20507111          1.          q          563150000
20507112          1.          q          563160000
20507113          1.          q          563170000
20507114          1.          q          563180000
*
*  heat exchange from ic tank ext pipe vertical (short)
20507200  ic.tav2             sum        1.    0.    1
20507201  0.      1.          q          564050000
20507202          1.          q          564060000
20507203          1.          q          564070000
20507204          1.          q          564080000
20507205          1.          q          564090000
20507206          1.          q          564100000
20507207          1.          q          564110000
20507208          1.          q          564120000
20507209          1.          q          564130000
20507210          1.          q          564140000
20507211          1.          q          564150000
20507212          1.          q          564160000
20507213          1.          q          564170000
20507214          1.          q          564180000
*
*  heat exchange from ic tank ext pipe all four horizontal
20507300  ic.tav3             sum        1.    0.    1
20507301  0.      1.          q          563010000
20507302          1.          q          563020000
20507303          1.          q          563030000
20507304          1.          q          563040000
20507305          1.          q          563190000
20507306          1.          q          563200000
20507307          1.          q          563210000
20507308          1.          q          563220000
20507309          1.          q          564010000
20507310          1.          q          564020000
20507311          1.          q          564030000
20507312          1.          q          564040000
20507313          1.          q          564190000
20507314          1.          q          564200000
20507315          1.          q          564210000
20507316          1.          q          564220000
*
* ht tank external total
20507500  tank.htt            sum        1.    0.    1
20507501  0.      1.          cntrlvar   063
20507502          1.          cntrlvar   071
20507503          1.          cntrlvar   072
20507504          1.          cntrlvar   073
*
*
.
/*
*
```

APPENDIX 6:

Overview of the scaling analysis

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QUALITATIVE ANALYSIS OF SCALING EFFECTS IN ISOLATION CONDENSER BEHAVIOUR WITH RELAP5/MOD3.1 THERMALHYDRAULIC CODE

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ABSTRACT

This paper deals with the attempt to analyse, with the Relap5/Mod3.1 code, the scaling effects in the behaviour of Isolation Condenser taking as reference the PO-IC-02 experiment performed in the PIPER-ONE facility available at Pisa University.

The PIPER-ONE is an experimental facility simulating a General Electric BWR-6 with volume and height scaling ratio of 1/2200 and 1/1, respectively. The facility was properly modified to test the thermalhydraulic caracteristics of an isolation condenser-type system.

The isolation condenser-type system consists of a once-through heat exchanger immersed in a pool with water at ambient temperature and installed at about 10 m above the core.

Several calculations have been performed with Relap5/Mod3/7j and Relap5/Mod3.1 codes, and the capabilities of code to simulate the behaviour of the isolation condenser component have been assessed. The results obtained cannot be extrapolated to the plant because of the different scaling of isolation condenser system with respect to the other components of the facility.

In this paper the effects of "scaling" changes in the facility nodalization are analysed with the use of Relap5/Mod3.1 code.

The following parameters are considered in the analysis of scaling effects:

1) Elevation of isolation condenser relative to the top of active fuel (TAF);
2) Length of Isolation Condenser tubes;
3) Diameter of Isolation condenser tubes;
4) Heat exchange area of Isolation condenser;
5) Inlet flow area of Isolation condenser;

A final calculation including all the modifications has also been performed.

1. INTRODUCTION

Innovative reactors, (essentially AP-600 and SBWR) are characterized by simplification in the design and by the presence of passive systems. Experimental and theoretical research are needed to qualify the new components and to characterize the new thermal-hydraulic scenarios expected during accidents. Available system codes have to be validated in order to be used for evaluating the thermal-hydraulic performances of the new systems, especially in case of long lasting transients evolving at low pressure (D'Auria et. al, 1992a).

In the frame of the activities carried out at University of Pisa related to the analysis of thermal-hydraulic situations of interest to the mentioned reactors (e.g. D'Auria et. al, 1992b and Andeuccetti et al., 1991), three series of experiments have been carried out utilizing the PIPER-ONE facility. These were aimed at the experimental investigation of the behaviour of systems simulating the main features of the Gravity Driven Cooling System (GDCS, first series of experiments, Bovalini et al., 1991a) and of the reactor pressure vessel Isolation Condenser (IC, second and third series of experiments, Bovalini et al., 1992a, D'Auria et. al, 1993, Bovalini et al., 1992b, and D'Auria et. al, 1994a, respectively). At the same time Relap5/Mod2 and Mod3 codes (Carlson et al., 1990) have been extensively applied as best estimate tools to predict the transient scenarios of both SBWR and AP-600 reactors (see also D'Auria et. al, 1994b, and Barbucci et al., 1993).

The object of this paper is to evaluate the possibilities to use Relap5/Mod 3.1 code (Carlson et al., 1990) for extrapolating the behaviour of PIPER-ONE facility. In order to achieve this, a qualified Relap5/Mod3.1 nodalization (Bovalini et al., 1995) of the PIPER-ONE has been used and the considered modifications have been implemented step-by-step to investigate the single effects of each parameter in the scaling process (D'Auria et al., et al., 1992c)

2. EXPERIMENTAL FACILITY

The simplified sketch of the apparatus is shown in Fig. 1: it includes the main loop, the ECCS simulators (LPCI/CS,

	QUANTITY	UNIT	PIPER-ONE	SBWR (°)	RATIO(+) PIPER-ONE/ SBWR	IDEAL (+) VALUE OF THE RATIO PIPER-ONE/SBWR
1	Primary system volume	m^3	0.199	595.	1/2990	1/2990
2	Core height	m	3.710	2.743	1.35/1	1/1
3	Maximum nominal core power	MW	0.320	2000.	1/6200	1/2990
4	Value of 3% core power	MW	0.041 (-)	60.	1/1463	1/2990
5	Ratio (3% core power) /primary system volume	MW/m^3	0.206	0.1	2.06/1	1/1
6	Isolation condenser heat transfer area (++)	m^2	0.301	184	1/610	1/2990
7	Isolation condenser heat transfer area over primary system volume	m^{-1}	1.512	0.31	4.9/1	1/1
8	Isolation condenser volume	m^3	0.0015	2.334	1/1556	1/2990
9	Isolation condenser volune over primary system volume	-	0.0075	0.0038	1.97/1	1/1
10	Isolation condenser heat transfer area over 3% core power	m^2/kW	7.341	3.066	2.39/1	1/1
11	Height of isolation condenser top related to bottom of active fuel	m	8.64	24.75	1/2.86	1/1
12	Diameter of a single tube	m	0.020	0.0508	1/2.54	1/1
13	Thickness of a single tube	m	0.0023	0.0023	1/1	1/1

(+) non-dimensional (°)IC data have been taken from reference /15/ (++)only tube bundles (-)related to BWR6

Tab. 1 - Comparison between isolation condenser related data in PIPER-ONE and in SBWR.

HPCI/CS) and the systems simulating ADS, SRV and steam line, as well as the blow-down line. Ten zones can be identified in the main loop: lower plenum, core, core bypass (outside the core), guide tube region, upper plenum, region of separators and dryers, steam dome, upper down comer, lower down comer and jet pump region.

The volume scaling factor is about 1/2200, while the core cell geometry and the piezometric heads acting on the lower core support plate are the same in the model and in the reference plant.

The heated bundle consists of 16 (4x4) indirectly heated electrical rods, whose height, pitch and diameter are the same as in the reference plant (Fig. 2). The maximum available power is 320 kW, corresponding to about 25% of scaled full power of the reference BWR.

As already mentioned, the facility hardware was modified by inserting the ICS loop, which can operate at the same pressure as the main circuit.

The main component of Isolation Condenser loop is a heat exchanger consisting of a couple of flanges that support 12 pipes, 22 mm outer diameter and 0.4 m long; it is immersed in a tank of 1 m^3 volume, containing stagnant water, located at 4th floor of the PIPER-ONE service structure. The heat exchanger is connected at the top and at the bottom respectively with the steam dome and the lower plenum of the main loop. In order to enhance natural convection inside the pool, a sort of shroud has been installed that divides the pool into two parts; a hot one and a cold one, the former encompassing the IC as can be seen in Fig. 4.

The Isolation Condenser loop is instrumented with a turbine flow-meter and a differential pressure transducer on the hot side and a series of almost 30 thermocouples in various position of the IC and of the pool as can be derived from Fig. 2.

Hardware restrictions preclude the possibility to have a system correctly scaled with respect to those provided for the new generation nuclear reactors, particularly the GE SBWR. In particular, the heat transfer area of Isolation Condenser in PIPER-ONE is roughly five times larger than the ideal value (Tab.1) . The distance between bottom of the active fuel and the Isolation Condenser and the height of the core itself, are two of the most important parameters differentiating PIPER-ONE from SBWR. These essentially prevent any possibility of extrapolating PIPER-ONE experimental data to SBWR.

3. EXPERIMENT

The experiment comprises two phases characterized by different values of heating power (about 40 and 75 kW, respectively), later indicated as phases A and the B of the test. They correspond to the scaled value of the core decay power and to the capability of heat removal by the IC device,

PARAMETER	SIGN	UNIT	VALUE
LP pressure	PA-LP-1	MPa	5.1
LP fluid temperature	TF-LP-1	K	262.5
Core level	LP-CC-1	m	11.9
Down comer level	LP-LD-1	m	10.7
IC line fluid temperature	TF-IC-1	K	17.5
IC pool fluid temperature	TF-SC-1	K	17.5

Tab. 2- PIPER-ONE test PO-IC-2: initial conditions

PARAMETER OR EVENT	TIME (s)
Test initiation	0.0
IC top valve opens	4.0
IC bottom valve opens	32.0
IC top valve closes	508.0
IC top valve opens again	602.0
IC top and bottom valve close	1106.0
End of test	1184.0

Tab. 3- PIPER-ONE test PO-IC-2: boundary conditions

determined from the previous test PO-SD-8 (Bovalini et al., 1992b).

As usual for the experiments carried out in the PIPER-ONE facility, the test was designed on the basis of pre-test calculations performed by Relap5/Mod3 code.

The test specifications foresaw constant heating power for 5/10 minutes for both experimental phases, in such a way that quasi-steady state conditions could be reached by the main thermal-hydraulic quantities (pressure, flow rates, collapsed levels, etc.).

In the test, the primary circuit was pressurized at the specified value by single-phase natural circulation; the heat source was provided by the core simulator and the structure heating system. Then, liquid was drained from the primary circuit for establishing the test specified liquid levels, roughly at the steam separator top elevation. After some hundreds seconds of steady conditions, with heat losses compensated by the heating cables, the test started by supplying power to the core simulator and opening the valves of the IC loop.

The initial and boundary conditions measured during the test PO-IC-02 are given in Tabs. 2 and 3.

The most significant results measured during the phases A and B are reported in the Figures 3 to 6.

Figure 5 shows the different phases of the transient; when the core power is around 40 kW, the primary pressure decreases (0.3 MPa/min), demonstrating that the power exchanged through the Isolation Condenser is greater than the supplied power. Roughly a steady condition is reached at around 75 kW (phase B), with a decrease of primary pressure of only 0.02 MPa/min. According also to the results of the test PO-SD-8, the overall power removed by the Isolation Condenser is of the order of 80 kW, corresponding to an average heat flux of about 200 kW/m^2 in the considered conditions. The condensate mass flow rate, registered at the drain line (Fig. 4), appears quite constant along the two phases of the test (the turbine transducer was initially blocked, but started to operate with about 3 minutes of delay from the opening of the IC valve).

In Fig. 5, the fluid temperatures measured in three positions along the Isolation Condenser heat exchanger are compared with the steam temperature at the IC inlet (equal to the saturation temperature corresponding to the primary system pressure); in particular, the bottom curve gives an idea of the sub cooled conditions attained by the liquid exiting from the heat exchanger.

Finally, the curves in Fig. 6 essentially show the strong fluid temperature stratification in the pool: in the upper zone, the temperature increases up to about boiling conditions at the test end, while the bottom part of the pool remains at ambient temperature during all the test (fluid temperature less than 20 °C).

4. SCALING METHOD AND INPUT DECK MODIFICATIONS

4.1 The scaling method

The adopted scaling methodology is organised in the following steps (Fig. 7):

1) set-up of nodalization of considered facility and calculation of a transient to qualifying the nodalization itself. This input deck is used for the "base calculation" (D'Auria et al., 1995).

2) identification of relevant parameters for the considered transient: this step defines which parameters in the facilities have to be properly scaled to represent the reference plant behaviour.

3) consideration of the value of above parameters in the facility and scaling to the reference plant.

Parameter	Identifier	Scaling factor	Facility actual value	Facility scaled value	Reference value (Plant)
Elevation of Isolation Condenser from the core	**TOIC-TAF**	1/1	4.7 m	22.7 m	22.7 m
Isolation Condenser Heat exchange area	**IC HTA**	1/2990	0.23 m^2	0.061 m^2	184 m^2
Isolation Condenser Tubes Equivalent Diameter	**IC TDH**	1/1	0.02 m	0.05 m	0.05 m
Isolation Condenser Tube length	**IC TL**	1/1	0.314 m	2.4 m	2.4 m
Isolation Condenser flow area	**IC TFA**	1/2990	0.0037 m^2	0.00102 m^2	3.05 m^2

Tab. 4: Modified parameter for scaling analysis

Input deck	Parameter changed	Nodalization modifications	Remark:
POGONLY1	elevation of IC (same as SBWR)	-add of a MSV to connect the old MSV to the new position of IC (30 volumes) -add a 35 volumes to the IC outlet line connecting the IC to the DC.	The dimension of added tubes and heat structures are the same as the preesistent componenets. No heat losses are applied to these new volumes.
POGONLY2	heat transfer area scaled to SBWR	change of heat slab dimensions and inner and outer cilindrical shell representing the IC tube wall to have a scaled heat transfer area nad the same values of heat slab radius as reference plant.	
POGONLY3	tube diameter of IC (same as SBWR)	change of hydraulic diameter of IC tubes in the volume representing the bundle in the nodalization	
POGONLY4	Length of IC tubes same as SBWR	change of length of IC tube and pool dimension. Te position of IC relatively to the pool is kept constant as in the base case nodalization.	
POGONLY5	IC flow area (scaled to the SBWR)	the flow area of pipe stack representing the IC bundle has been scaled to the SBWR plant.	

Table 5: List of modifications made to the nase nodalization for parameter influence evaluation in the scaling activity.

4) set-up of individual facility nodalizations adopting the scaled values from the previous step.

5) set-up of the final nodalization with all the modifications; comparison of the results with the experimental data.

6) test calculation of a different transient adopting the scaled input deck, and comparison with plant calculation results (base case can be considered). This step has not been dealt with in the present paper.

4.2 Relevant modification to the base input deck

The standard IBM RISC version of Relap5/Mod3.1 has been adopted.

The base nodalization of the PIPER-ONE facility has been previously developed for PO-IC-2 experiment analysis (Bovalini et al., 1995)

The list of modified parameters is given in Tab. 4. For each parameter different calculations have been performed, including sensitivities and use of different codes.

In Tab. 5 the different nodalizations and the modifications introduced are summarized.

The following constraints have been considered:

a) the overall facility volume has been kept nearly constant (overall modifications increase the total volume of 2 %), because it was already scaled to the plant;

b) the additional volumes are thermally insulated.

5. RESULTS OF CODE APPLICATION

5.1 Output relevant parameters

For evaluating the calculation results the following parameters have been used:

- System pressure;
- IC mass flowrate;
- IC fluid temperature jump from inlet to outlet ;

- Core level;
- Downcomer level;
- Temperature jump from IC fluid to inner pool fluid;
- IC exchanged power;
- Temperature jump from inner to outlet pool fluid.

Some results are given in Figs. 8 to 15. The complete evaluation of results can be found in D 'Auria et al., 1995.

5.2 One-step analysis

The results of single parameter variations are given in Figs. 8 from 11. Detected differences are related to the experimental data:

PON1 (Elevation of IC same as in the SBWR plant) : Large difference in the pressure trend of primary system are due to the high flow rate in the IC (higher driving force) and consequent high heat transfer between IC tubes and pool. Higher values of fluid temperature in the IC tubes (>50 K) give a lower fluid temperature jump along the IC tubes (150 K lower than in the exp. case). No relevant modifications in the phenomenological description of the transient.

PON2 (Heat transfer area scaled to SBWR): No significant differences in the overall scenario were calculated. In the IC tubes the calculated fluid temperature was 100 K lower than in the experiment. To be noted that the calculation was stopped after 800 s. due to code failure in the calculation of water properties.

PON3 (Tube diameter of IC same as in the SBWR): The calculation showed similar results as in previous case, with some differences in the primary system pressure, owing to the higher value of fluid temperature in the IC tubes (around 250 K) and at the IC outlet.

PON4 (Length of IC tubes same as SBWR): Lower values of IC tubes fluid temperature than in previous calculations have been calculated. The length of tubes allows more cooling of IC fluid from IC pool, so that the values of subcooling at the IC outlet is higher than in previous cases and also higher than experimental and base calculation values.

PON5 (IC flow area scaled to the SBWR): Similar results as PON3 calculation.

5.3 Global Effect analysis

The different modifications to the base input deck previous analysed have been considered togheter to evaluate the global effects in the transient. The Figs. 12 to 15 show the results.

System pressure: the elevation of IC with respect to the core mostly contributes to the different trend of pressure, lower than experimental value of 0.5-0.8 MPa (Fig. 12). This effect is due mainly to the increase of mass flow rate (Fig. 13) through the IC and the higher power exchanged (Fig. 14) in the IC itself.

Mass flow rate: the average value of mass flow rate through the IC is nearly twice (0.05 Kg/s instead of 0.025 Kg/s) than in the experimental and base case. This also affects the exchanged power, higher than in the experimental case.

Fluid temperature in IC tubes: the value of IC tubes fluid temperature is 50 K higher than in the experimental case (Fig. 15). Moreover, the temperature jump between IC inlet and outlet is 150 K lower than the experimental results. This effect is connected with the pressure trend.

6. CONCLUSIONS

With the above described scaling method the following main results have been achieved:

- the relevant phenomenological aspect of PO-IC-2 experiment (i.e. the constant value of power exchanged in IC bundle depending on downcomer level) have been also calculating by the modified (scaled-up) nodalization; so, the measured scenario can be considered applicable to the SBWR, though the experimental apparatus was not properly scaled.

  The adopted method seem to be capable to handle the main phenomenological aspect of transient, and might also predict some aspects that are expected but not obtained due to limitation of facility design.

In addition, it can be noted that there is no substantial disagreement in the overall evaluation of parameters considered as reference to evaluate the scaled nodalization: the system pressure decreases, following an increment of mass flow rate of IC and the related increment of power exchanged. The subcooling is also is than in experimental case, according with the low level of energy stored in the system (low value of system pressure). Some additional interesting effects can be noted in the calculation performed with this modified nodalization : along the inner pool there is no strong thermal stratification as in the experimental case (Fig. 16) and the calculated mass flow rate through the internal pool (Fig. 17) is higher than the base value. These effects can be directly connected with the modifications of input deck, especially with the new position of Isolation Condenser with respect to the core.

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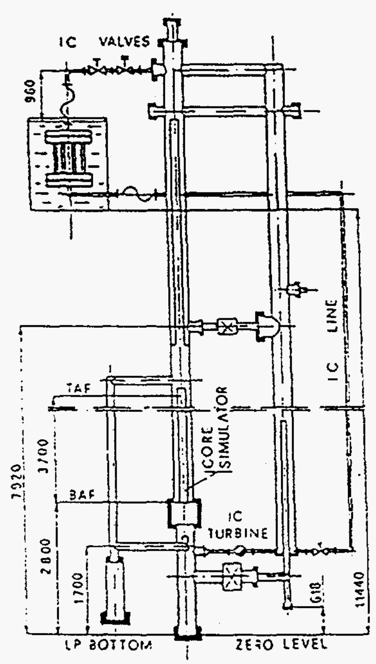

Fig. 1 - Sketch of PIPER-ONE

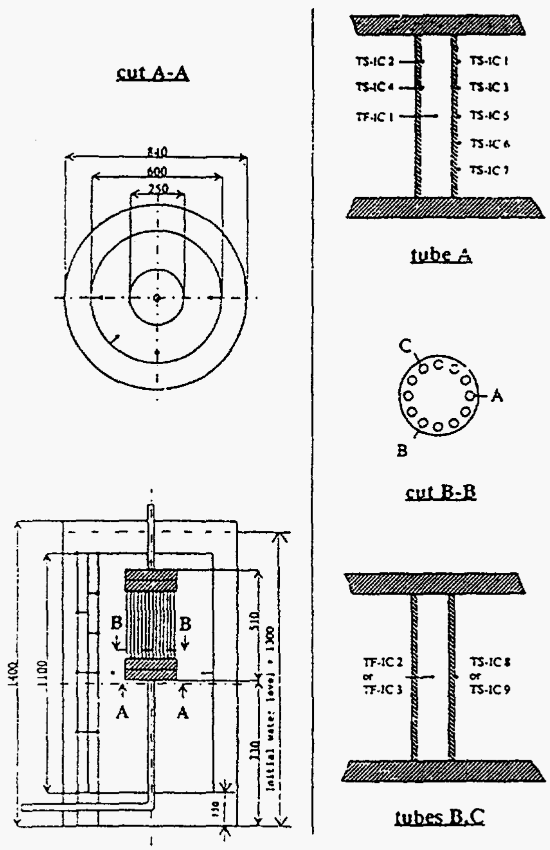

Fig. 2 - Sketch of isolation condenser pool with temperature measurement locations

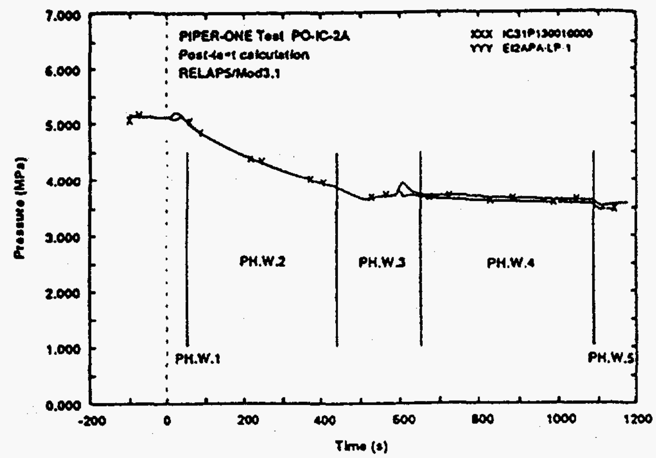

Fig. 3 - Phases of experimental transient

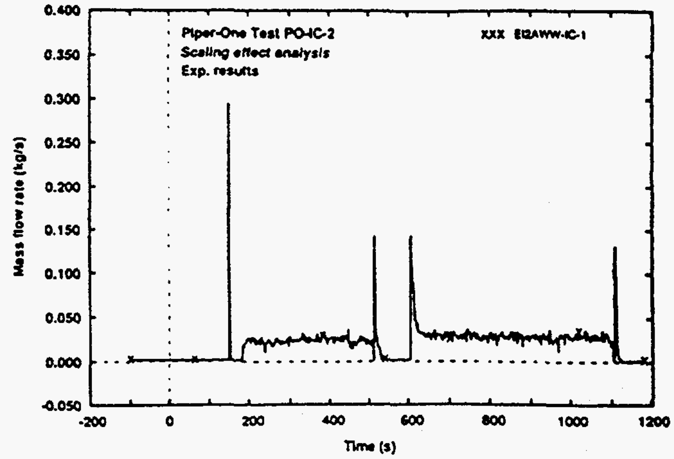

Fig. 4 - Condensate mass flow rate

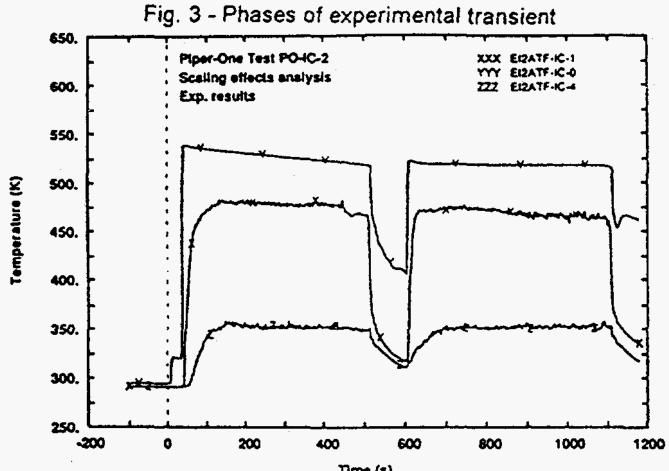

Fig. 5 - Fluid temperature along Isolation Condenser tubes

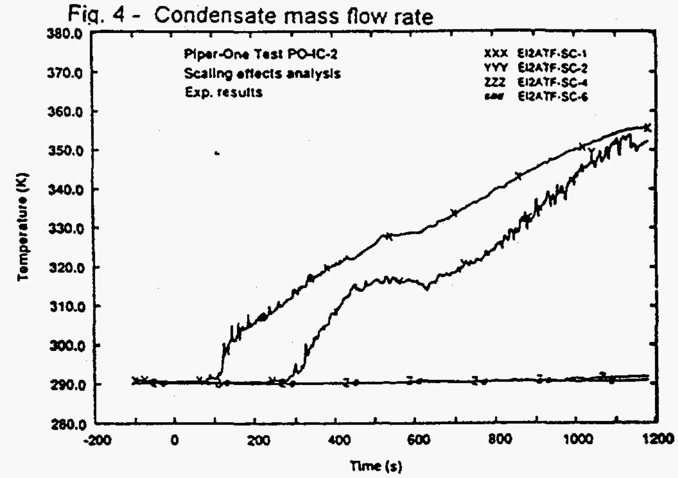

Fig 6 - Fluid temperature along the pool

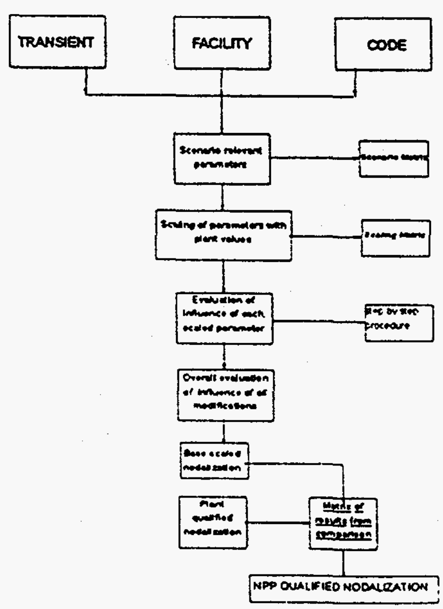

Fig. 7 - Flow chart of scaling method adopted

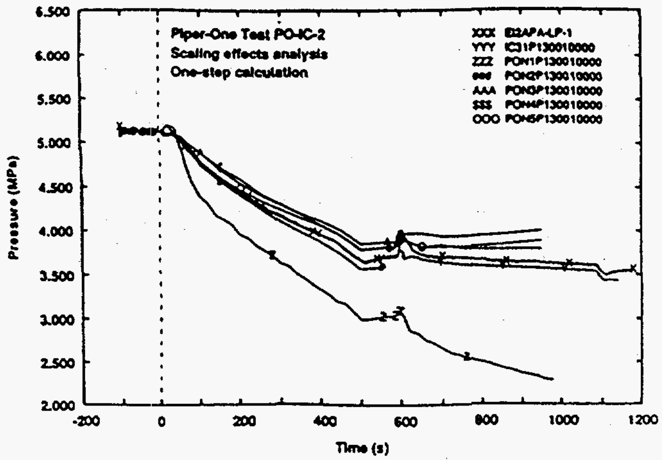

Fig. 8 - Scaling results: system pressure, one step analysis

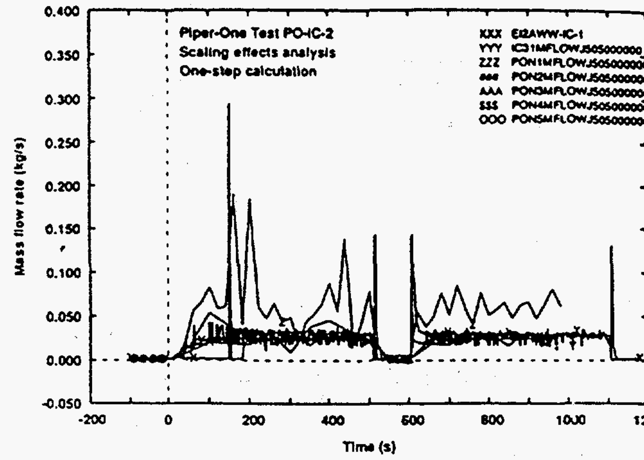

Fig. 9- Scaling results: IC mass flow rate,one step analysis

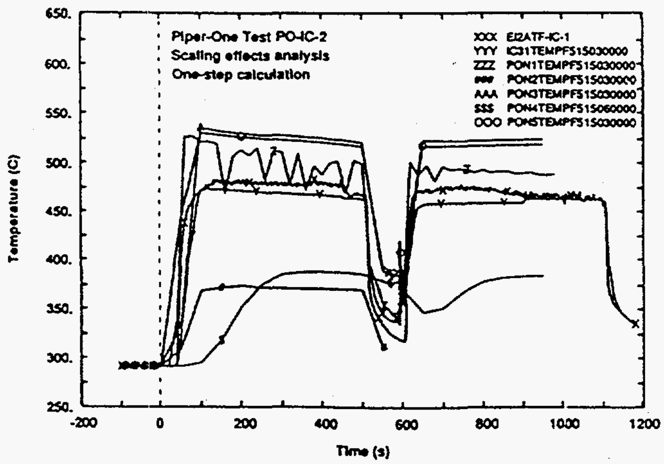

Fig. 10 - Scaling results: IC middle level tube fluid one step analysis

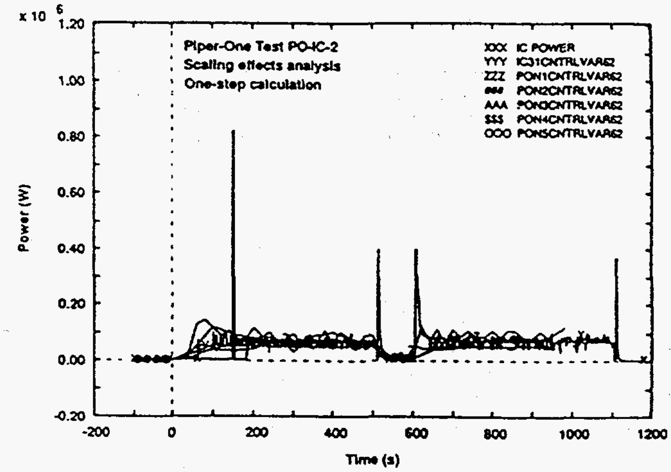

Fig. 11 - Scaling results: IC power exchanged one step analysis

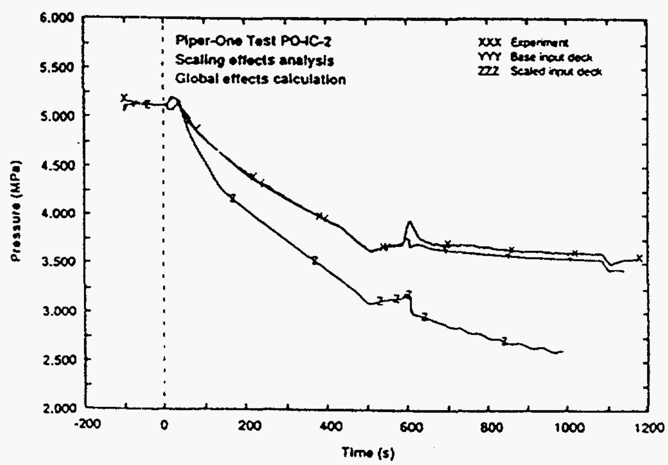

Fig. 12 - Scaling results: system pressure, global effects analysis

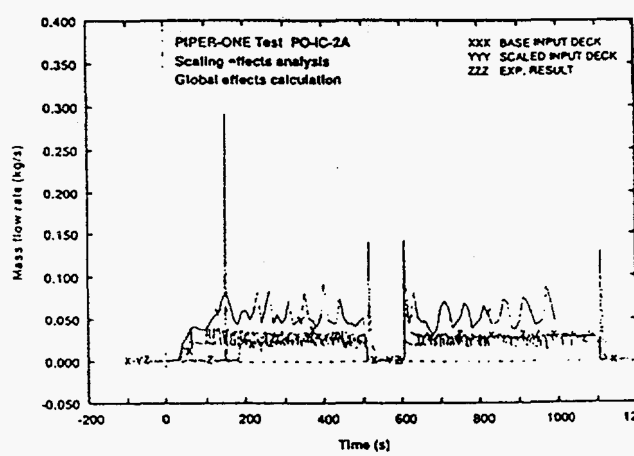

Fig. 13 - Scaling results: IC mass flowrate effects analysis

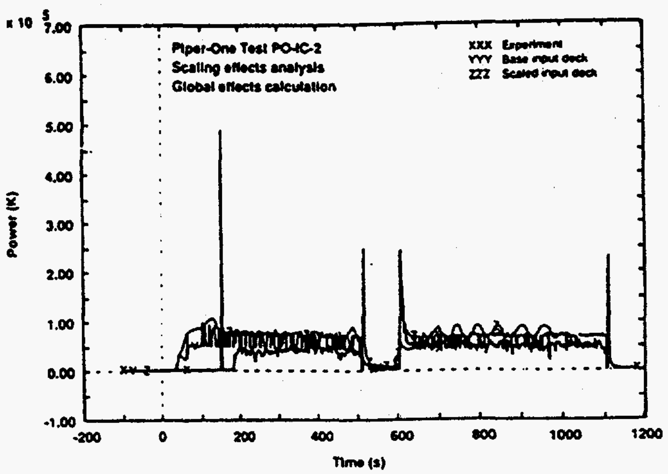

Fig. 14 - Scaling results: IC exchanged power global effects analysis

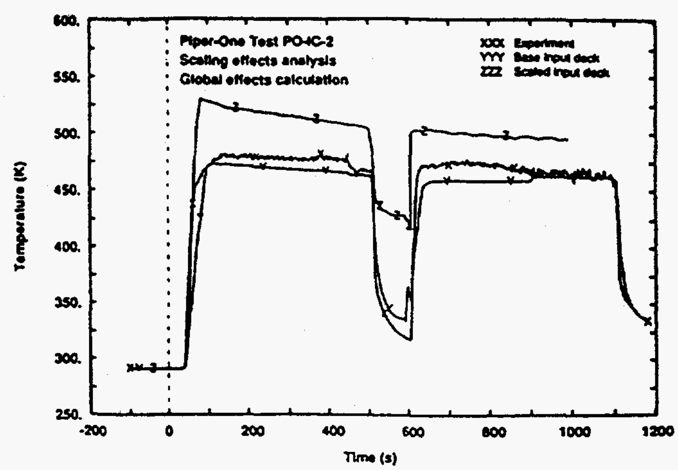

Fig. 15 - Scaling results:middle level tube fluid temperature,global effects analysis

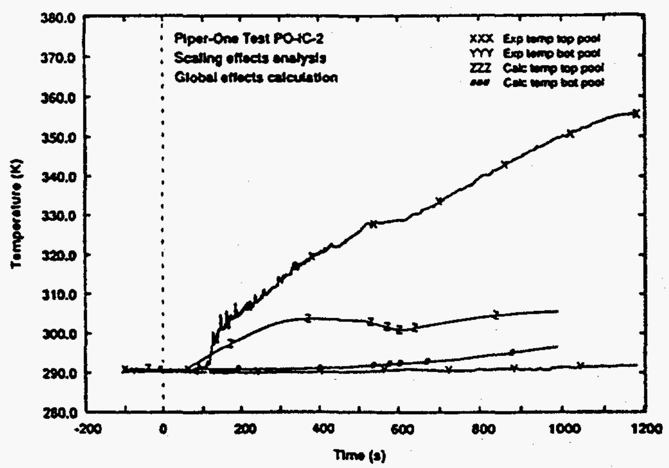

Fig. 16 - Scaling results: thermal stratification along the pool,global effects analysis

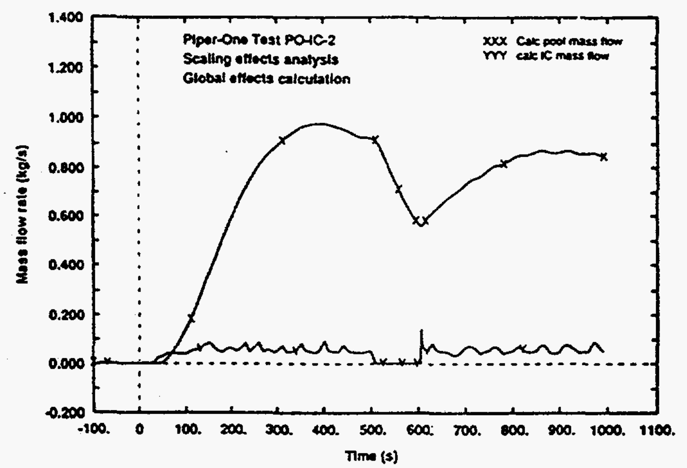

Fig. 17 - Scaling results:calculated circulation flow along the pool,global effects analysis