NEA/CSNI/R(94)35

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USER EFFECTS ON THE TRANSIENT SYSTEM CODE CALCULATIONS

Final Report

January 1995

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS
OECD NUCLEAR ENERGY AGENCY

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ABSTRACT

Large thermalhydraulic system codes are widely used to perform safety and licensing analyses of nuclear power plants to optimize operational procedures and the plant design itself. Evaluation of the capabilities of these codes are accomplished by comparing the code predictions with the measured experimental data obtained from various types of separate effects and integral test facilities. During these comparisons of the code results, there has been a continuous debate on the way how the code user influences the predicted system behaviour. This rather subjective element might become a crucial point with respect to the quantitative evaluation of the code uncertainties which is essential if the "best estimate codes are used for licensing procedures".

The International Standard Problem Exercises (ISPs) proposed by the OECD-Committee for the Safety of Nuclear Installations (CSNI) and by IAEA (International Atomic Energy Agency) and thermalhydraulic code assessment activity undertaken by USNRC (US Nuclear Regulatory Commission) under International Code Assessment and Application Program (ICAP) demonstrate the large effort put in this framework by organizations all over the world. In recent years, some attempts have been made to establish methodologies to evaluate the accuracy and the uncertainty of the code predictions and consequently judgement on the acceptability of the codes. In none of the methodologies has the influence of the code user on the calculated results been directly addressed. In this paper, the results of the investigations on the user effects for the thermalhydraulic transient system codes will be presented and discussed on the basis of some case studies.

It can be noted that the fundamentals of user effects presented, here, are applicable and indicate the status for severe accident code calulations, e.g. SCDAP/RELAP5. In this respect nothing fundamental could be added to this paper except increasing the number of examples specifically for the severe accident codes.

The general findings of the investigations show that in addition to user effects, there are other reasons that affect the results of the calculations and which are hidden under user effects. Both the hidden factors and the direct user effects will be discussed in detail and general recommendations and conclusions will be presented to control and limit them.

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1 INTRODUCTION

Within the frame of the large international effort on the assessment of thermal-hydraulic system codes used for the safety analysis of Light Water Reactors, there has been a continuous debate on the way how the code user influences the predicted system behaviour. This rather subjective element might become a crucial point with respect to the quantitative evaluation of the code uncertainties which is essential if the "best estimate codes" are used for licensing procedures.

The International Standard Problem Exercises (ISPs) proposed by the OECD-Committee for the Safety of Nuclear Installations (CSNI) and by IAEA (International Atomic Energy Agency) and thermalhydraulic code assessment activity undertaken by USNRC under International Code Assessment and Application Program (ICAP) demonstrate the large effort put in this framework by organizations all over the world. In recent years, some attempts have been made to establish methodologies to evaluate the accuracy and the uncertainty of the code predictions and consequently the judgement on the acceptability of the codes. In none of the methodologies has the influence of the code user on the calculated results been directly addressed. But the user influence on predicted results became evident in most of the recent ISPs and especially in the blind type of ISPs, when different participants using the same code version produced rather different results. The reasons for these differences were mainly attributed to the large number of options available to select appropriate models, correlations or specific multipliers, particularly in the case of the first generation codes which are not any longer the state of the art e.g. RELAP3, RELAP4, RETRAN-02, etc. The major reasons of the necessity of options were a) to compensate for the lack of detailed modelling of complex processes (e.g. thermal non-equilibrium effects),and b) to allow the use of these codes for both conservative type predictions needed for reactor licensing as well as more realistic best-estimate predictions.

With respect to the new generation of advanced computer codes (e.g. TRAC, RELAP5, ATHLET, CATHARE), which are strictly based on two-fluid representation of two-phase flow and "best-estimate" description of complex flow and heat transfer conditions and reflect the state of the art, it was expected that the user effect would be drastically reduced. However, experience with large number of ISPs has shown the dominant influence of the code user on the final results and the goal of reduction of user effects has not been achieved. The definition of "user effects" is very subjective but for the purpose of this paper, the user effects can be defined as: Using the same code and also same specifications(e.g. initial and boundary conditions) the results of the calculations should be similar, otherwise the differences are coming from "the user effects". It should be noted that in this context many elements may usefully be considered user effects, in other arenas e.g. plant calculations some of these elements may be better classified as scale, experimental data etc. uncertainties.

In this paper, the results of investigations of the user effects for the thermalhydraulic transient system codes will be presented and discussed in detail on the basis of some case studies. The code which provide input to this paper are mostly one-dimensional codes and the results of at least one semi-multidimentional code(i.e. TRAC) is also included. Finally, general recommendations and conclusions will be presented to control and limit some of the user effects, based on the case studies presented.

At this point, it is worth to mention that the fundamentals of user effects, which are given in the following sections, are applicable and indicate the status for severe accident code calculations, e.g. SCDAP/RELAP5. Nothing funamental could be added to this paper except increasing number of examples for the severe accident codes.

2 REASONS FOR CODE USER EFFECTS IN RELATION TO INPUT DATA

Some of the main sources by which a code user has influence on the predicted code results are identified and categorized in this Section. Only those effects will be considered which are directly related to code input data. All aspects of changing the code source (code structure, numerical scheme and models), problems related to the code implementation, or the influence resulting from different computer hardware will not be considered here as "code user effect".

2.1 System nodalization

All major existing LWR safety thermal-hydraulics system codes follow the concept of a "free nodalization" which means that the code user must construct a detailed scheme to map the whole system to be calculated into the frame of a predominately one-dimensional thermal-hydraulic network. To do this, the codes offer a number of basic elements like single-volumes, pipes, branches, junctions, heat structures, etc. This approach provides not only sufficient flexibility with respect to different reactor designs, but also allows simulation of both separate effect and integral test facilities that often deviate considerably from the full-size reactor.

As a consequence of this rather "open strategy", a large responsibility is passed to the user of the code to develop an adequate nodalization scheme which makes best use of the various modules and the prediction capabilities of the specific code. Due to the existing code limitations and to economic constraints, the development of such a nodalization represents always a compromise between the desired degree of accuracy (resolution) and an acceptable economic computational effort.

It is not possible here to cover all the aspects of the development of an adequate nodalization diagram, however, two crucial problems will be briefly mentioned that illustrate the basic problem.

Spatial convergency

As has been quite often mis-understood, a continuous refinement of the spatial resolution (e.g. a reduction of the cell sizes) does not automatically improve the accuracy of the prediction.

There are two major reasons for this behaviour:

(1) The large number of empirical constitutive relations used in the codes have been developed on the basis of a fixed (in general coarse) nodalization.

(2) The numerical schemes used in the codes generally include a sufficient amount of artificial viscosity which is needed to provide stable numerical results. A reduction of the cell sizes below a certain threshold value might result in severe non-physical instabilities.

From this it can be concluded that there exists no a priori optimal approach for the nodalization scheme.

Mapping of multi-dimensional effects

Even in relatively small scale integral test facilities, there exist multi-dimensional effects, especially with respect to flow splitting and flow merging processes: e.g. for the connection of the main coolant pipe to the pressure vessel. The problem may become even more complicated due to the presence of additional bypass flows and a large re-distribution of flow during the transient. It is left to the code user to determine how

to map these flow conditions within the frame of a predominately one-dimensional code, using the existing elements like branch components, multiple junction connections or cross-flow junctions.

These two examples show how the limitations in the physical modelling and the numerical method in the codes need to be compensated by an "engineering judgement" of the code user which at best, is based on results of detailed sensitivity of assessment studies. However, in many cases, due to lack of time or lack of appropriate experimental data, the user is forced to make ad-hoc decisions.

2.2 Code options, physical model parameters

Even though the number of user options has been largely reduced in the advanced codes, there still exist various possibilities for the code user to directly influence the physical description of specific phenomena, e.g.

- choice between engineering type models for choking or use of code implicit calculation of critical two-phase flow conditions,
- flow multipliers for subcooled or saturated choked flow,
- the efficiency of separators,
- two-phase flow characteristics of main coolant pumps,
- pressure loss coefficient for pipes, pipe connections, valves, branches etc.

Since in many cases directly measured data are not available or at least not complete, the user is left to his engineering judgement to specify these parameters.

2.3 Input parameters related to specific system characteristics

The assessment of LWR safety codes is mainly performed on the basis of experimental data coming from scaled integral or separate effect test facilities. Typically in these scaled-down facilities specific effects exist, that may be small or even negligible for the full-size reactor case, but are as important as the major phenomena to be investigated in the subscale experiments. Examples are the release of structure heat to the coolant, heat losses to the environment, or small bypass flows. Often, the quality of the prediction depends largely on the correct description of these effects which in turn requires a very detailed representation of structural material and a good approximation of the local distribution of the heat losses. However, many times the importance of these effects are largely underestimated and, consequently, wrong conclusions are drawn from results based on incomplete representation of a small-scale test facility.

2.4 Input parameters needed for specific system components

The general thermal-hydraulic system behaviour is described in the codes by the major code modules based on a predominately one-dimensional formulation of the mass, momentum and energy equations for the separated phases. However, for a number of system components, this approach is not adequate and consequently additional, mainly empirical, models have to be introduced, e.g. for pumps, valves, separators, etc. In general, these models require a large amount of additional code input data, which are often not known since they are largely scale dependent. A typical example is the input data needed for the homologous curves which describe the pump behaviour under single- and two-phase flow conditions which in general are known

only for a few small-scale pumps. In all these cases, the code user must extrapolate from existing data obtained for different designs and scaling factors; this introduces a further ambiguity in the prediction. This extrapolation process will have also user effects which are based partly on engineering estimates of the users of the codes, for the full scale pump performance.

2.5 Specification of initial and boundary conditions

Many of the existing codes do not provide a steady state option. In these cases pseudo-steady state runs must be performed using more or less artificial control systems to drive the code towards the specified initial conditions. The specification of stable initial and boundary conditions and the setting of related controllers require great care and detailed checking. If this is not done correctly, there exist a large risk that even small imbalances in the initial data will overwrite the following transient, especially for slow transients and small break LOCA calculations.

2.6 Specification of state and transport property data

The calculation of state and transport properties is usually done implicitly by the code. However, in some cases, for example in RELAP5, the code user can define the range of reference points for property tables and, therefore, can influence the accuracy of the prediction. This might be of importance especially in more "difficult" regions, e.g. close to the critical point or at conditions near atmospheric pressure.

Another example is in relation to the fuel materials property data. The specification of fuel rod gap conductance (and thickness) is an important parameter, affecting core dryout and rewet occurrences, that must be selected by the user. Usually this assumption, also connected with the actual fuel burnup, is not reported as a user assumption.

2.7 Selection of parameters determining time step sizes

All the existing codes are using automatic procedures for the selection of time step sizes in order to provide convergency and accuracy of the prediction. Experience shows, however, that these procedures do not always guarantee stable numerical results and, therefore, the user might often force the code to take very small time steps to pass through trouble spots. In some cases, if this action is not taken, very large numerical errors can be introduced in the evolution of any transient scenario and are not always checked by the code user.

2.8 Code input errors

To prepare a complete input data deck for a large system, the code user must provide a huge number of parameters (approximately 15 to 20 thousand values) which he must be typed one by one. Even if all the codes provide consistency checks, the probability for code input errors is relatively high and can be reduced only by extreme care following clear quality assurance guidelines.

3 SELECTED TYPICAL EXAMPLES FOR IDENTIFYING USER AND OTHER RELATED EFFECTS ON THE CODE CALCULATIONAL RESULTS

In this section, the results of the investigations on the user effects for the thermal-hydraulic transient system codes will be discussed on the basis of several ISP's and other assessment cases.

3.1 ACHILLES Reflooding Test (ISP-25)

One of the transient tests from the best estimate natural reflood series of experiments (Run Al B105) was selected as ISP-25.

The selected transient simulates the end of the accumulator injection in a postulated LOCA with the nitrogen vessel representing the accumulators, which have emptied of water, venting into the cold leg. The detailed information on ISP-25 transient and facility description can be found in [1,2], together with the initial and boundary conditions. A simplified schematic representation of the main active components of the facility is shown in Figure 1.

Participants of ISP-25 were required to provide a pre-test prediction (blind calculation) with no prior knowledge of the experimental results. In addition, all the participants except those participants from the host institution were modelling the facility first time. The pre-test predictions showed a wide variation in results and, even when similar versions of the same code were used, a number of differences were observed with hydraulics and thermal parameters. Comparisons of calculated and experimental data for two such parameters are shown in Figures 2 and 3, see for example [3]. The hydraulic behaviour and heater rod temperature predictions show significant variations. As examples, the range of peak clad temperature predictions is about 150 K and the range of quench times differs by a factor of two.

The comparison of the RELAP5 calculations highlighted the impact of the code user effect, where large variations in predicted behaviour were observed and as a result CSNI sponsored investigations on code user effects based on ISP-25 calculational results [4]. The results of these investigations will be briefly discussed in this section.

The fact that four participants in ISP-25 used the RELAP5 code did provide an opportunity to investigate so called "user effects", the effect that the code user has on the results of a blind prediction, eventhough, it is accepted that the code versions were not exactly identical. The outcome of this investigation on user effects led to identification and also differentiation of different sources of discrepancies. The general findings show that in addition to code user effects, there are other factors which affect the results of the calculations and are hidden under user effects. These reasons are identified as: The effects due to specific characteristics of experimental facilities, i.e. limitations as far as code assessment is concerned; limitations of the used thermalhydraulic code to simulate certain system behaviour or phenomena; limitations due to interpretation of experimental data by the code users; i.e. interpretation of experimental data base.

A few specific examples will be presented here for each of the identified reasons, as a result of the investigations based on ISP-25 calculational results.

I. The specific characteristics of experimental facilities (i.e. limitations as far as code assessment is concerned):

   1. The analysis of experimental data and the calculations show that the friction loss (K) factors in the ACHILLES test loop were very important. Pressure drop and distribution information were not

sufficiently known to the code users to obtain the specific friction loss factors properly around the loop. This point was considered to be the most important one in the analysis of the experiment.

2. The original intention of the test was to provide a constant pressure as a boundary condition. However, the experimenters were not able to maintain a constant containment pressure with the available control system, during the early phase of the transient. This has an influence on the initial pressure distribution in the test loop and has a significant impact on the early behaviour of the experiment.
3. Liquid carry-over was collected at two points: Weir device at the upper plenum and steam separator (Figure 1).

   The method of steam/water separations was very specific to this test facility. Only the combined flow was measured, as a result it was not possible to determine the ratio of liquid removed at the weir to that at the steam separator. The transient thermalhydraulic codes including RELAP5 have no capability to simulate this type of device at the top of the core.
4. Formation of ice at the outlet of the Nitrogen tank was not foreseen at the time the ISP-25 was proposed and it is known that such conditions could not be handled with present codes.
5. Other limitations are typical of nearly all integral loop experiments e.g. quench front progression measurements (assumed to be one dimensional), minor errors in the flow rate measurements with turbinemeter due to the introduction of the nitroge n into the system (mainly calibration problem).

II. Limitations of the thermal-hydraulic codes to simulate certain system behaviour or phenomena: It should be clearly stated that all the thermalhydraulic codes have their own, specific limitations. Since the versions of the RELAP5 code were used for these investigations, the limitations will be restricted to this code and its applications to ISP-25. Main limitations coming from code modeling are:

1. RELAP5 was not able to deal with non-condensible gases in the system. The numerics in relation to the treatment of non-condensibles appeared to be very poor.
2. RELAP5 calculates the pressure drop on the basis of the defined geometry as input to the code calculation, however, the calculated pressure drop can be quite different, if the loss coefficients and the details of the geometry are not properly supplied.
3. Inverted annular film boiling (IAFB) would probably have occured during the initial surge due to subcooled liquid reaching the quench front. RELAP5 and also the other codes do not model the main aspects of the fast forced and low pressure reflo od conditions as encountered during the initial phases of the transient in ISP-25.
4. There were no specific models in RELAP5 to simulate the effects of the grids.
5. Ice formation, at the outlet piping of the accumulator, due to the nitrogen injection is not modelled in RELAP5 or in other system codes.
6. RELAP5 has no capability for calculating the liquid film formation and flow on wetted surfaces, e.g. at the top of the core and on the shroud vessel.
7. The modelling and calculations of the entrainment and de-entrainment for various geometrical configurations are very limited with RELAP5 and also with the other system codes.

III. Limitations due to interpretation of experimental data by the code user:

The predicted scenario of each of the participants was strongly dependent on typical user choices, e.g. consideration of pressure drop distribution, simulation of the nitrogen vessel, etc. The results of the four RELAP5 users are very different, mostly, due to the different philosophies in performing the calculations to overcome some of the code deficiencies present at the time of the calculations. Some of the specific examples are: One of the code user, due to the deficiencies of the IBM version of the code, was not able to use the "reflooding option" and instead the "blowdown option" with corresponding heat transfer package of the code was used. Some of the code users simulated nitrogen behavior in the accumulator with "saturated steam" or "hydrogen".

In addition to the user choices, interpretation of the boundary conditions by the code users has an important effect on the results. Some typical examples are:

1. Functioning of the capacity vessel was misinterpreted by the code users. The pressure of the capacity vessel as boundary conditions was determined in the experiment by steam and nitrogen coming into the loop. This quantity was assumed as an independent boundary condition in the code calculations. It was believed that this point has an effect only during the first 30 seconds of the transient.
2. Interpretation and use of the friction loss (K) factors which were supplied in the ISP-25 report on Boundary Conditions and Experimental procedure for ACHILLES Run [2] were done differently by different code users. Wide variations of user choices were available as far as the use of the K factors at two different orifices.
3. Differences in relation to the initial conditions in various input decks depended on the fact that the experimental initial conditions were not at true steady state. Therefore different procedures were adopted to establish these conditions by various users.
4. In the experiment, most of the water passed into the steam separator and the steam passing through the orifice, was saturated. This situation was not considered by the code users.

3.2 LOBI Natural Circulation Test

The post-test analysis of LOBI A2-77A natural circulation test has been independently performed by six different users (CENG-Grenoble, CEA-Paris, GRS-Garching, JRC-Ispra, DCMN-Pisa and UKAEA-Winfrith), using five different advanced thermalhydraulic codes (CATHARE 1 V1.3, TRAC-PF1/MOD1, ATHLET/MOD1.0, RELAP5/MOD1-EUR and RELAP5/MOD2 by the last two organizations) [5 and 6]. The detailed information on the natural circulation test A2-77A can be found in [7]. On the basis of these post test analysis results, interaction of code users with the mentioned system codes have been analyzed. The first point to be considered is the comparison of the input decks of different codes. At this stage, it can be identified that the most significant limitation of a current code analysis is the lack of detailed insight on the used input parameters. All these major existing thermal-hydraulic safety codes follow the concept of a "free nodalization". This means that the code user has to build-up a detailed noding diagram which simulates the whole system to be calculated into a frame of a thermal-hydraulic network.

As a consequence of this rather flexible strategy, considerable responsibility is imposed on the user of the code in order to develop an adequate nodalization scheme which makes best use of the various modules and the prediction capabilities of the given code. The final product is a "model" that represents a compromise between the user knowledge of the code performance, of the facility hardware and of the simulated transient scenario. In addition, the existing code capabilities and limitations and the required computer CPU time also play a considerable role in defining the specifications of the input model.

On the basis of the above discussion, and to establish a critical comparison of the nodalisations and specific assumptions, twenty different items related to the input decks are compared among each other, as given in table 1. These have been split into three main groups:

1. The elements characterizing the nodalization details (items 1 to 5 in table I):

   In relation to the number of nodes, on one hand RELAP5 and ATHLET codes, with roughly 150 nodes, on the other hand the CATHARE code, with more than 300 nodes, and the TRAC code, with 250 nodes, can be; distinguished (Figure 4).
   This choice is only partially due to the user; the code numerical structure also plays an important role for establishing the degree of detail of the nodalization model. As an example, RELAP5 code, owing to the Courant limit, needs nodes having length larger than few tens of centimeters, while CATHARE

code does not have such a constraint, allowing a greater degree of freedom .
In principle, the best results for a physical simulation should be given by a nodalization with a number of nodes as large as possible, however, this is not strictly true for the current system codes. Otherwise, an optimal number of nodes can be recognized for each code for a given simulation problem. Directions for the selection of this number are not available in any code manual. Only the user experience can achieve this parameter, considering the phenomena to be analyzed, in line with the available resources (CPU time needed, computers, etc.) and the goals of the study (e.g. sensitivity analyses aiming at the interpretation of physical phenomena, licensing calculations, etc.). It should be noted that a large amount of sensitivity analyses can bring substantial improvements of nodalization parameters; in this way coarse nodalization, with few elements, can produce better results than fine nodalization with much larger number of elements.
Concerning the overall number of heat structure mesh points (item 5 in table I), the dominant influence of this parameter on the heat transfer mechanism must be stressed. In particular, the heat release from structures is strongly affected by the number of meshes (Figure 5).

2. The elements characterizing the "nodalization fidelity" to the actual geometrical data of the facility (items 6 to 11 in table I):
The geometrical fidelity of the nodalization and the system hardware is a specific characteristic of a code input model that should be considered very carefully. Apart from the nodalization detail, which is essentially a user choice, the agreement between input and actual system related parameters is an objective goal to be pursued. With reference to the overall volume of a facility that can be considered the most important parameter in this group, the following approximations or inadequacies affect the agreement between actual system value and code input value:

   - imperfect knowledge of the system or the plant data (drawings inadequacies, etc.);
   - presence of dead ends (nozzles, instrumentation lines, etc.);
   - need to simulate a three dimensional configuration with a one dimensional code modules.

   For these points the required compromises done are based on user knowledge and experiences. The experience demonstrates, for example, the acceptability of few percent error on the nominal value of the overall facility volume.
Another aspect of the nodalization fidelity is related to the active heat transfer areas, i.e. heat sources and sinks. In relation to this, the most important characteristics to be preserved are the total core area and the overall steam generator heat transfer surface. Usually, these parameters are respected with an error less than 1%.
Two further problems, typically encountered by a system code user, arise during the development of a nodalization:

   a) With reference to a PWR typical plant, the choice of the hydraulic channel numbers in the steam generator and in the core (for a BWR plant the same problem may occur in relation to the number of jet pumps and again to the number of core channel [8]). A nodalization with only few "pipes" can preserve the overall thermal energy balance, however cannot represent a nonuniform flow behaviour of the various channels (e.g. nonuniform flow distribution in the steam generator U-tubes, or in the lower plenum of reactor vessel or in the steam generator plena, channel to channel oscillations, etc. [8]);
   b) Passive structures of the plant. The consideration of all the material structures including vessel, piping and internal wall, as well as flanges, valves and pump casings is almost impossible owing to limitations of computer memory. Approximations are needed and are usually done.

3. The elements characterizing the relation between actual hydraulics and geometry of the code input model (items 12 to 20 in table I and Figures 6, 7 and 8):

   This topic refers, essentially, to local and distributed pressure drop coefficients. With reference to the friction factor, a substantial difference among the various basic models implemented in the codes can

be observed, e.g. the dependency of friction factor upon the Reynolds number is not considered in the same way in all codes: for example Colebrook correlation is used in RELAP5/MOD2 and some other special correlations are adopted by TRAC and CATHARE. Roughness is addressed by RELAP , while it has no influence on calculated pressure drops in CATHARE and TRAC. Finally, with regard to the form loss coefficients, items 12 to 18 in table I, the following remarks can be made:

a) there is no theoretical model suitable to calculate this parameter in the wide variety of configurations encountered in modelling a typical nuclear plant or simulator; no relationship gives the dependency of these factors upon Reynolds number and local void fraction;

b) experimental uncertainties are often connected to this parameter, usually derived from pressure drop measurements;

c) loss coefficient values must account for the three-dimensional effects that can not be modelled by a one-dimensional code;

d) some of the thermalhydraulic model deficiencies can be adjusted by use of loss coefficients in an artificial way.

The data reported in table I give an idea of typical variation ranges associated with assumed values of these parameters. It should be noted that "all" the above values lead to "reasonable agreement" with experimental data at least as far as the initial steady state is concerned (Figure 9).

Each code user, depending on the code used, interprets in a subjective way the uncertainties characterizing the experimental data. The rest of the steady state and transient calculations proceed on the basis of these interpretations and assumptions. In order to give an idea of the consequences of the choices discussed above, the calculated flow rates in intact loop during the whole transient are compared with the measured values in Figure 10 as a function of the overall residual mass of the primary side. In general, the codes used capture the basic physics of the involved phenomena, but the quantitative values of the physical variables are not satisfactory. More in depth analyses [9] show that, apart from possible inadequacies of input decks discussed above, there are also some limitations of the thermalhydraulic models, e.g. flooding, stratification in horizontal pipes, etc.

3.3 Additional ISP Calculational Cases

Some of the user effects which have been identified based on the ISP exercises performed recently (ISP-22, ISP-26 and ISP-27) will be summarized and presented, as further examples, in this section.

ISP-22

This ISP was a "double blind" exercise based on a special transient in the SPES facility [10]. The examined test, named SP-FW-02, was initiated by a loss of feedwater in the secondary side of the steam generator in loop one.

A very broad range of results has been obtained by participants using the same code (RELAP5/Mod2) (e.g. Figure 11). Extensive post-test analysis and discussions at a specific workshop [11] demonstrated that two of the main sources of discrepancies were:

(a) approximate consideration of heat losses from primary side with main reference to their distribution: in particular small changes in the pressurizer related value (within experimental uncertainties) shift the sequence of relevant events of thousands seconds, leading, possibly, to different conclusions about the validity of the accident management procedure selected in the experiment;

(b) wrong calculation of initial mass of steam generators secondary side, notwithstanding a known code limitation in calculating the total mass inside a boiler (such as the secondary side of a steam generator). For the post-test analysis, this limitation could be accomodated through proper adjustments of user selected parameters in the nodalization.

Item (a) is a demonstration of the criticality of the interface between the code user and the definition of boundary condition: the code user should fully understand the meaning and the limitations of the boundary conditions available from the experiment. Item (b) demonstrates the need for the code user to know in some detail the basic code limitations, and possibly, to adopt tools suitable to overcome these deficiencies.

The consideration, for one of the participants of both the mentioned aspects led to the comparison between measured and calculated trends shown in Figures 12 and 13.

ISP-26

ISP-26 was an open standard problem based on a 5% cold-leg small break LOCA experiment conducted in the ROSA-IV Large Scale Test Facility (LSTF) [12]. Wide dispersion bands were obtained between the calculated results of the different participants and the experimental data, especially in relation to the prediction of the heater rod surface temperature trends (Figure 14).

The evaluation of data base constituted by experimental and calculated trends led to the identification of four areas connected in some way with the user, that are among those responsible for discrepancies:

1. The modeling of core and steam generator upflow side as well as the different choices for the break flow calculation contributed to the results of the calculations significantly [13].
2. The convergence of the solutions with respect to optimization of the noding was not assured. A "well balanced" nodalization with a relatively fine noding in steam generators and core (as far as practical) may produce better results than an unbalanced nodalization where, as an example, a large number of nodes are used for the core but a coarse noding is used for steam generators.
3. The calculated results are much affected not only by physical options but also by numerical options, i.e., convergence criteria and numerical scheme. These options are selected by each user based on their own criterion. Thus, it would be desirable that the appropriate guidelines and information are provided to users for selecting input options [13]
4. The dead end volumes and the fluid temperatures inside dead ends may affect the overall energy and mass balance during the transient. These were not completely specified by experimentalists.

ISP-27

The ISP-27 was classified as a "double blind" international standard problem. It was based on the BETHSY small-break LOCA test 9. 1 .b. It consists of a 2" cold-leg break experiment in which high pressure safety injection (HPSI) system is assumed unavailable. It belongs to the multiple failure transient category and is addressed to accident management studies. The resulting transient leads to a large core uncovery and fuel heat-up requiring the implementation of an ultimate procedure [14].

Preliminary observations from the comparison Workshop on ISP-27 indicate that the differences between blind calculations and experimental data were mainly attributable to user effects. Most important of these were:

1. Achieving true steady state and overall system balance was specially important for this long transient. This point was overlooked by most of the code users.

2. Nodalization of the BETHSY system should have been established considering the anticipated important phenomena during the transient. User experience has significant influence on this aspect.

3. Considering the specific features of the break nozzle, the experimenters provided the participants with experimental data from a separate effect test facility, using a nozzle similar to those installed in the integral facility.

   A correct use of this data base should have produced critical flowrate values very similar for the various participants as a function of pressure.

   Actually this was not the case due to various reasons (Figure 15), some of these are:

   - errors in interpreting the supplied data base;
   - judgement of low importance of this data for the overall transient evolution in an integral test facility;
   - influence of conditions in the upstream pipe upon the calculated critical flowrate that actually made useless the comparison of data calculated in the integral facility with those measured in the separate effect test facility.

4 SOME SUGGESTED WAYS TO REDUCE THE USER EFFECTS

From what has been mentioned above it is quite clear that, at least for the presently existing codes and their limitations with respect to physical modelling and numerical techniques, there is no chance to completely avoid the influence of the code user on the predicted system behaviour. However, several methods by which the magnitude of the user effect might be reduced are indicated in the following.

4.1 User Training

As has been described above, a large responsibility is imposed on the code user to provide an adequate description of the facility and to prepare the corresponding input data. This task can be fulfilled only if the user is fully aware of the physical modelling and the limitations of the codes, if he has a sufficient knowledge of the facility to be described and if he also has a good understanding of the major phenomena expected to occur during the transient. Therefore, user instruction and training might be the easiest way to improve the quality of the code predictions.

Unfortunately, there has been in the past a tendency to use ISPs as a type of "fast course" in training new code users without giving importance to above mentioned aspects. The rather poor results produced in these cases have largely contributed to the confusion on the user effect and the evaluation of the code capabilities. Based on ISP results, it is evident that a policy should be adopted to require the qualification of code users. In addition, it is also possible, as in the other industry branches, to require that only qualified users should be performing studies having some consequences, e.g. safety analysis.

4.2 Improved User Guidelines

There has been in the past a continuous demand for user guidances which should be based on the results of a systematic code assessment programme. More detailed user guidelines are certainly a way to improve the

quality of code prediction and to avoid larger mistakes and, in this sense may also reduce the user effect. However, to be more realistic, such guidelines cannot give detailed recipes for all existing conditions and, therefore, cannot substitute for a trained and experienced code user.

4.3 User Discipline

Even the best user guideline will not serve a useful purpose if the code user, as often found is keen to invent "tricks" to drive the code prediction towards an experimental result or towards what the user expected to achieve. This does not contest the value of sensitivity studies which are often the only way to better understand code deficiencies. What is meant here is a type of "tuning" of the results by a selection of completely unrealistic input values for physical models related parameters or boundary conditions, or by the extensive use of parallel channel and cross flow junctions to produce some "multi-dimensional" flow calculation that is beyond the code's capability. The result of this "tuning" is at best a compensation of errors which only contributes to confusion on the true prediction capability and, therefore, on the clear identification of code deficiencies and limitations.

4.4 Quality Assurance

The preparation and testing of an input deck for a reactor or a related integral test facility is a tedious work which requires even for a competent code user an effort of about one man-year. A reliable input deck can only be achieved if a clear quality assurance strategy is followed. Often this effort is not allocated (e.g. due to lack of time, money, or competence) and, consequently, incomplete or error-ridden decks are used. A bad habit has been also that, in order to save time, existing decks are shared between different users who then introduce only minor modifications without a complete checking of the major part of the input data and without an understanding for what purpose they have been developed.

4.5 Code Improvement

For a long time perspective, the best way to reduce the user effect would be to improve the code with respect to the physical modelling and the numerical techniques. This might be illustrated in two examples:

- The use of numerical methods which allow an automatic mesh refinement based on actual local flow conditions (e.g. for the representation of tracking mixture levels or quench fronts). This would avoid the code user having to make a prejudgement on the minimum cell or mesh size for a specific system component.
- To include multi-dimensional capabilities for those specific parts of the system where these effects are dominating, even in small-scale test facilities: e.g. for the downcomer (see for example the 2-D downcomer module in CATHARE-2), or for the upper and lower plena in the pressure vessel. This would take from the user the need to make unqualified judgments on the major flow conditions to be expected during the transients.

A possibly less ambitious improvement to the present codes could be the implementation of an improved user interface which make use of modern graphics, window techniques and drop-down menus. This would not only reduce the tedious workload to elaborate code input data sets, it would also reduce the probability for code input errors and, therefore, would contribute to minimize the code user effect.

5 CONCLUSIONS

Experience with some code assessment case studies and also additional ISPs have shown the dominant effect of the code user on the predicted system behaviour. The general findings of the user effect investigations on some of the case studies indicate, specifically, that in addition to user effects, there are other factors which affect the results of the calculations and are hidden under the general title of "user effects". These additional reasons are identified as: The specific characteristics of experimental facilities, i.e. limitations as far as code assessment is concerned; limitations of the used thermal-hydraulic codes to simulate certain system behaviour or phenomena; limitations due to interpretation of experimental data by the code user, i.e. interpretation of experimental data base. It should be noted in this paper that the code users usually obtain their practical experiences for plant calculations from calculations of integral and separate effects tests. The experience gained by the users ultimately concerns the plant calculations. Most of the points raised in the paper are also applicable for the plant calculations but need to be investigated separately. In addition, the fundamentals of user effects presented, here, also indicate the status for severe accident code calculations, e.g. SCDAP/RELAP5.

On the basis of the discussions in this paper, the following conclusions and recommendations can be made:

- More dialogue appears to be necessary with the experimenters in the planning of code assessment calculations, e.g. ISPs.
- User guidelines are not complete for the codes and the lack of sufficient and detailed user guidelines are observed with some of the case studies.
- More extensive user instruction and training, improved user guidelines , or quality assurance procedures may partially reduce some of the subjective user influence on the calculated results.
- The discrepancies between experimental data and code predictions are due both to the intrinsic code limit and to the so called "user effects". There is a worthful need to quantify the percentage of disagreement due to the poor utilization of the code and due to the code itself. This need especially arises for the uncertainty evaluation studies (e.g. [15]) which do not take into account the mentioned user effects.
- A very focused investigation, based on the results of comparison calculations e.g. ISPs, analysing the experimental data and the results of the specific code in order to evaluate the user effects and the related experimental aspects should be integral part of the ISP process. This may also help to quantify the "user effects".

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ITEM	TRAC/PF1 CEA	CAT1 V1.3 CENG	R5/M2 DCMN	ATHLET GRS	R5/M1-EUR JRC	R5/M2 UKAEA	EXP	notes
1. number of nodes	249	331	126	145	177	160	–	
2. number of junctions	40	–	132	163	185	165	–	
3. number of heat structures	151/64 °	212	155	167	216	201	–	°pipe walls, SGU tubes
4. number of core structures	17	42	15	10	12	6	–	
5. overall number of structures mesh points	1355	848	1302	510	1036	1062	–	
6. free total volume of the facility without PRZ (m^3)	0.527	0.522	0.524	0.522	0.522	0.523	0.522	
7. free total volume of IL SG SS (m^3)	0.869	0.750	0.770	0.770	0.770	0.797	0.771	
8. free total volume of BL SG SS (m^3)	0.285	0.260	0.259	0.258	0.257	0.270	0.260	
9. fluid mass in PS (kg)	375	370	373	373	373	370.05	370	without PRZ and UH
10. fluid mass in IL SG SS (kg)	353	310	392	359	228	360	359.5	
11. fluid mass in BL SG SS (kg)	118	110	144	132	77	144.2	133.4	
12. K_f/K_r at free core area	28/28	1.9/0.9	35/35	27/27	2.0/2.0	2.32/2.3	–	
13. K_f/K_r at SG IL inlet of the U-tubes	9/9	0.26/0.26	20/20	12/12	0.36/0.36	1/0.3	–	
14. K_f/K_r at SG BL inlet of the U-tubes	24/24	0.38/0.38	50/50	58/58	0.37/0.37	2.05/0.55	–	
15. K_f/K_r at PU IL inlet	0.25/0.25	3.6/2.6	0.6/0.2	48/49	0.06/0.02	0.291/0.251	–	
16. K_f/K_r at PU BL inlet	0.25/0.25	3.6/2.6	0.3/0.7	7.6/7.5	0.03/0.08	0.16/0.21	–	including HL and CL connections to RPV
17. $\Sigma K_f(\Sigma K_r)$ in IL	37	7	32.2(32.2)	–	68	1.85(1.85)	–	
18. $\Sigma K_f(\Sigma K_r)$ in BL	73	64	173.1(173.1)	–	–	3.95(3.76)	–	
19. friction factor in IL HL	NFF=2 °	–	0.018	0.02	–	–	NA	°TRAC option
20. friction factor in core region	–	–	0.012	0.02	–	–	NA	

PRZ=Pressurizer, IL=Intact Loop, BL=Broken Loop, HL=Hot Leg, CL=Cold Leg, SG=Steam Generator, SS=Secondary Side, PS=Primary System
PU=Pump, UH=Upper Head, RPV=Reactor Pressure Vessel, K_f=Forward Loss Coefficient, K_r=Reverse Loss Coefficient

Table I: Items related to the LOBI-MOD2 natural circulation test input decks.

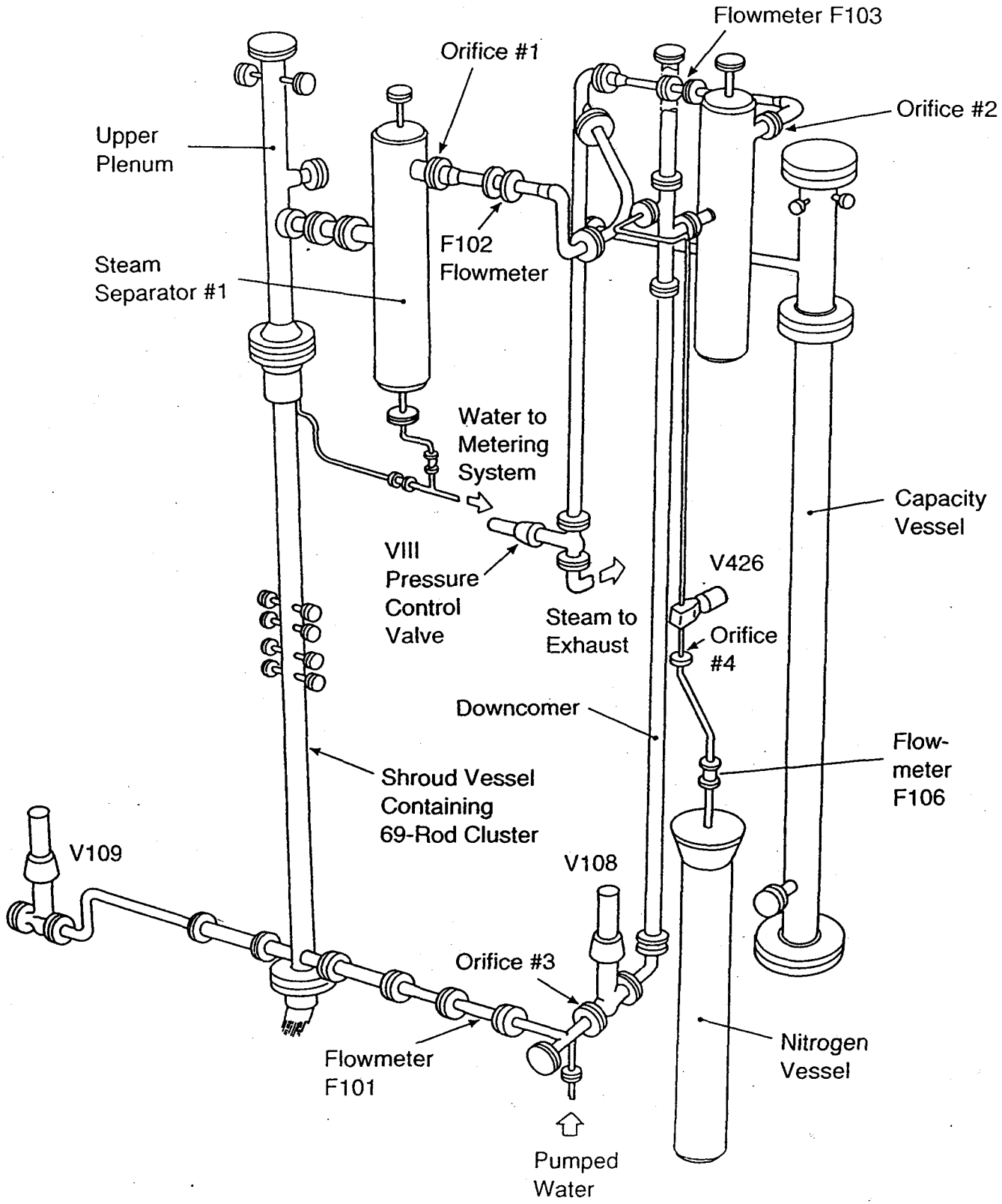

Figure 1: ACHILLES rig configured for best-estimate transients.

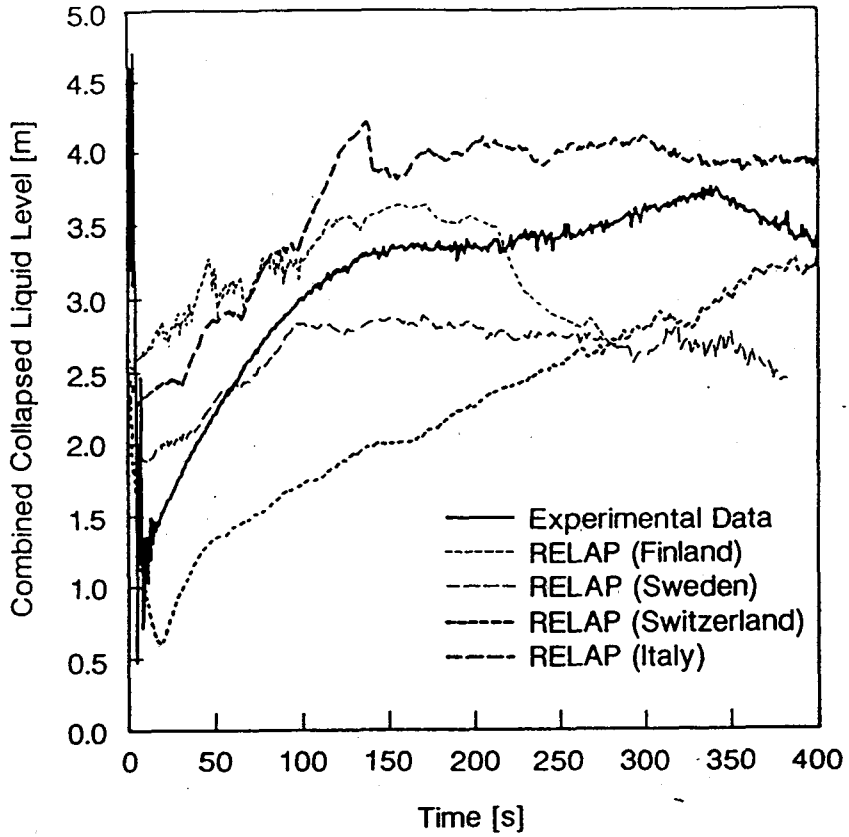

Figure 2: ISP-25 combined downcomer and core collapsed liquid levels. Comparison of experimental and calculated data.

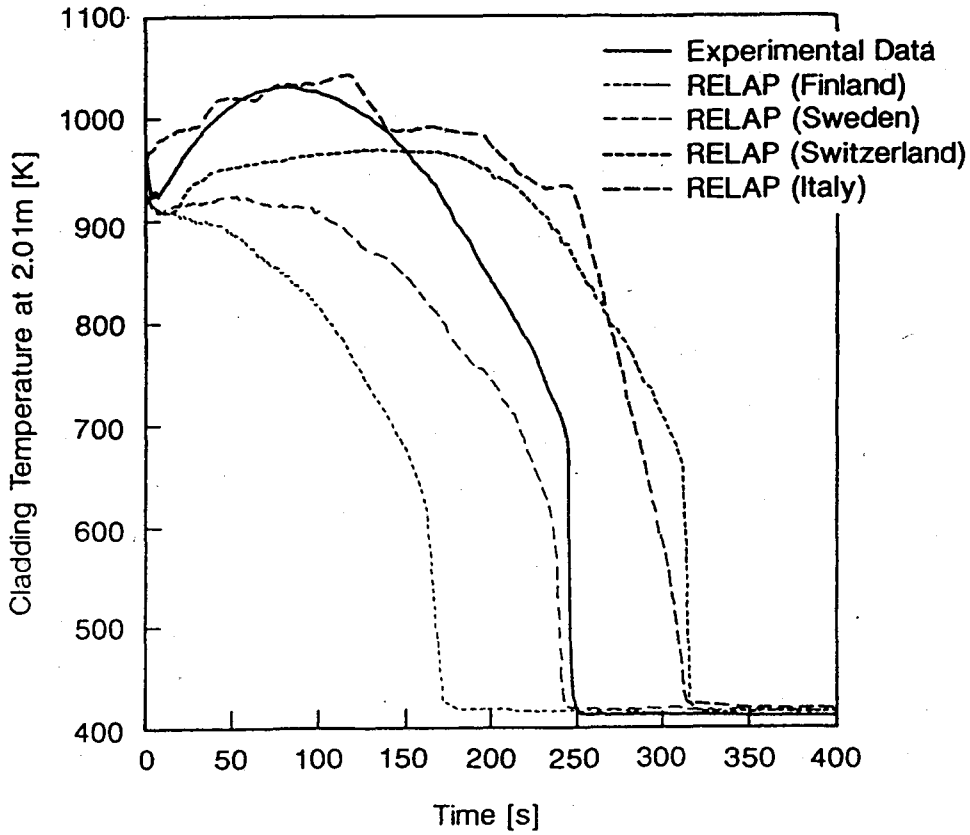

Figure 3: ISP-25, cladding temperature history at 2.01 m elevation. Comparison of experimental and calculated data.

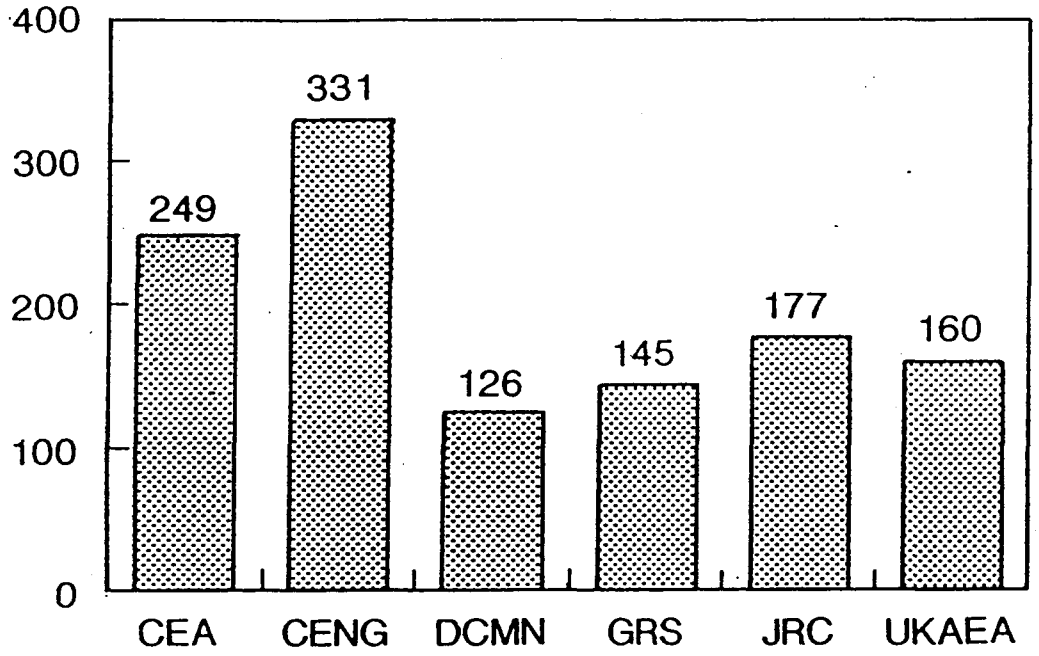

Figure 4: Number of nodes chosen by various users for nodalizing the LOBI facility

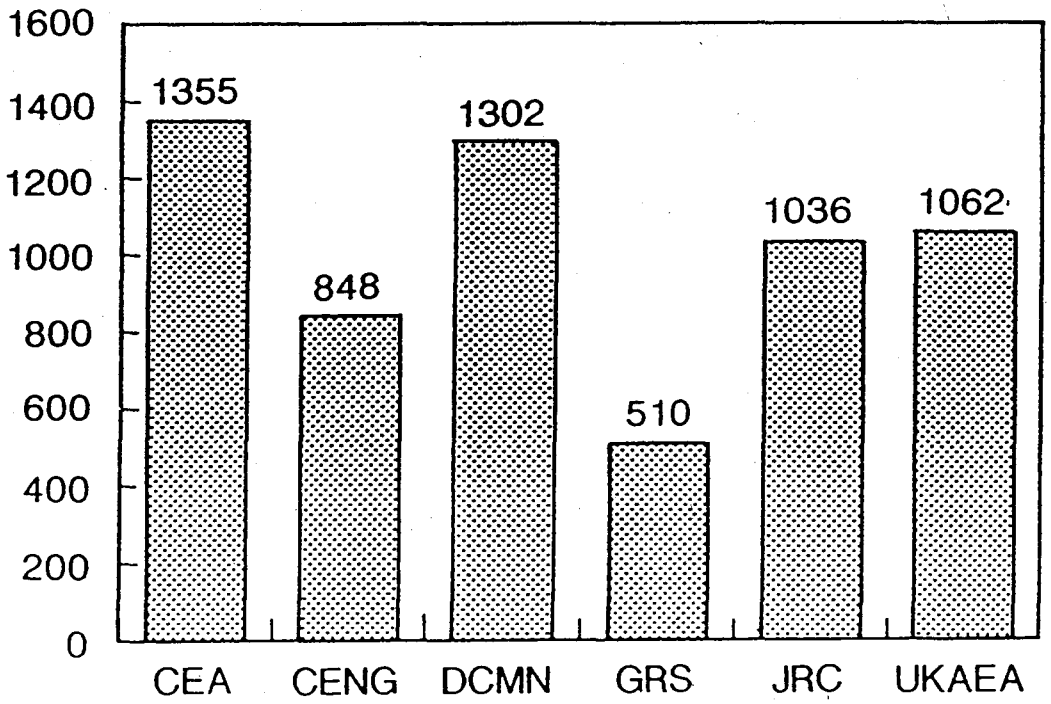

Figure 5: Overall number of structure mesh points chosen by various users for nodalizing the LOBI facility.

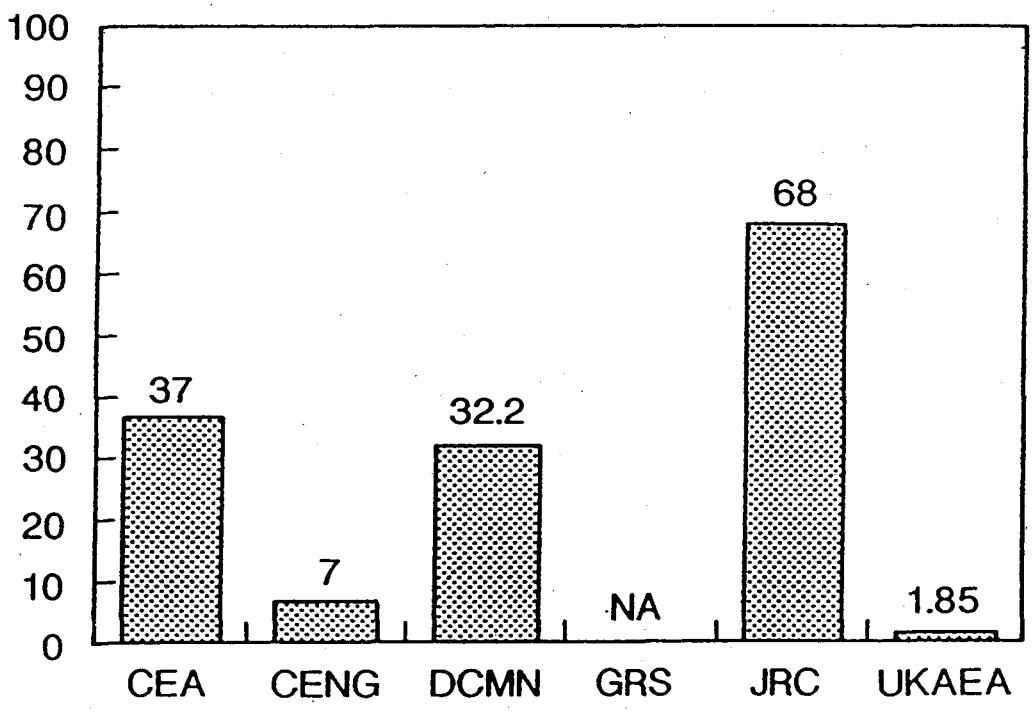

Figure 6: Forward pressure drop coefficient at intact loop connection with pressure vessel of LOBI facility as selected by various users.

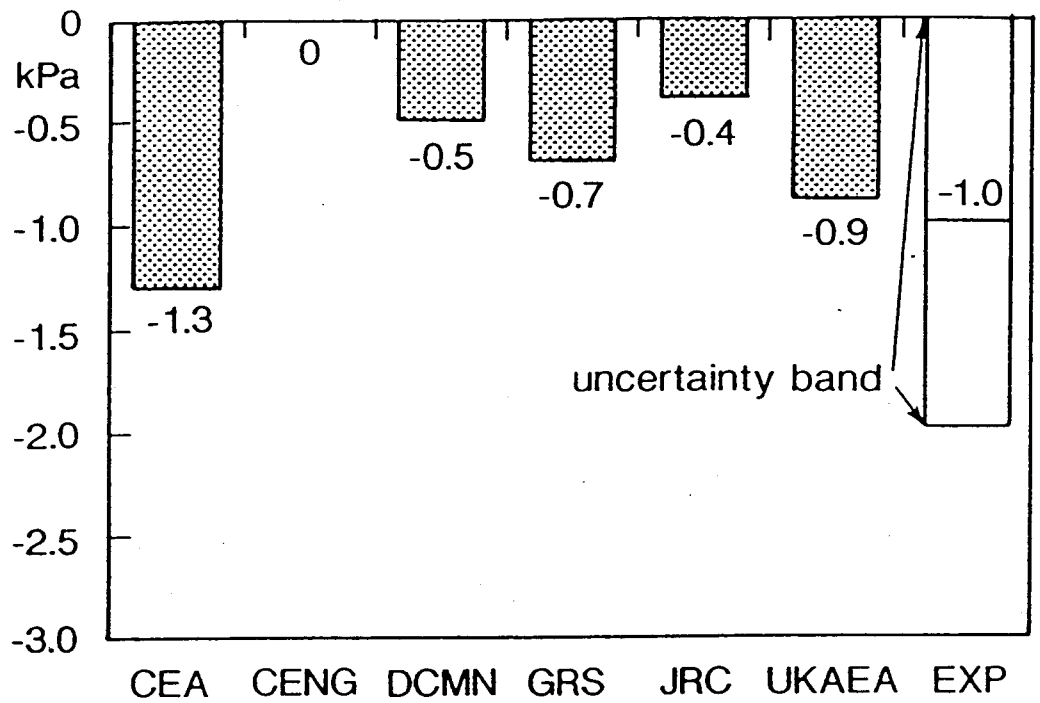

Figure 7: Pressure drop over steam generator intact loop primary side resulting from steady-state calculations for LOBI facility by various users and comparison with experimental data.

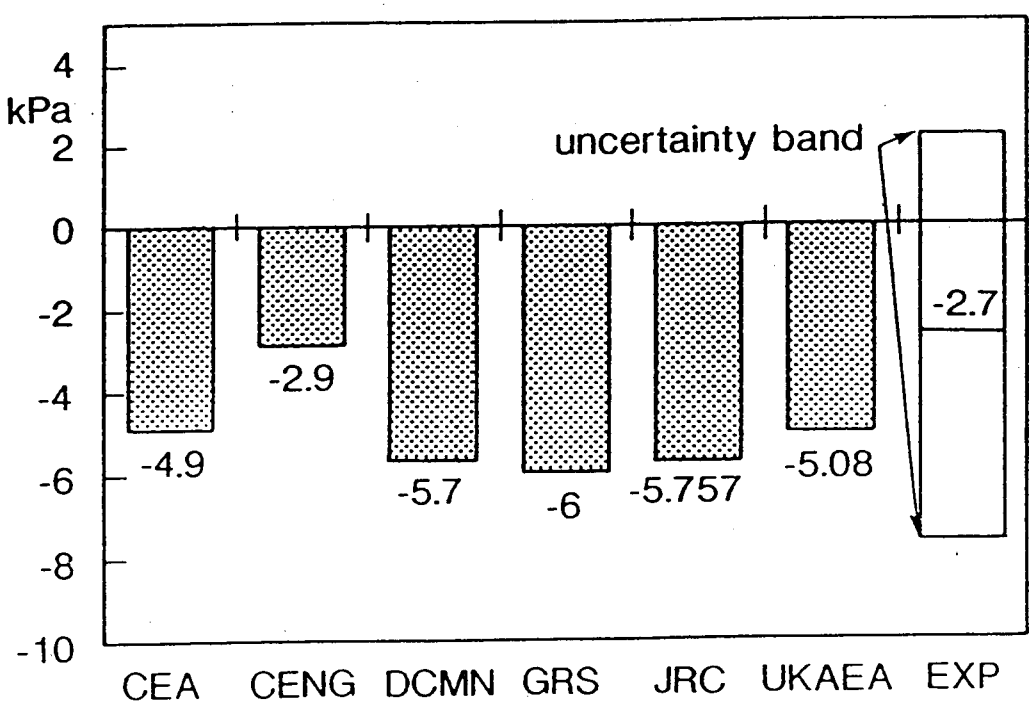

Figure 8: Pressure drop over steam generator broken loop primary side resulting from steady-state calculations for LOBI facility by various users and comparison with experimental data.

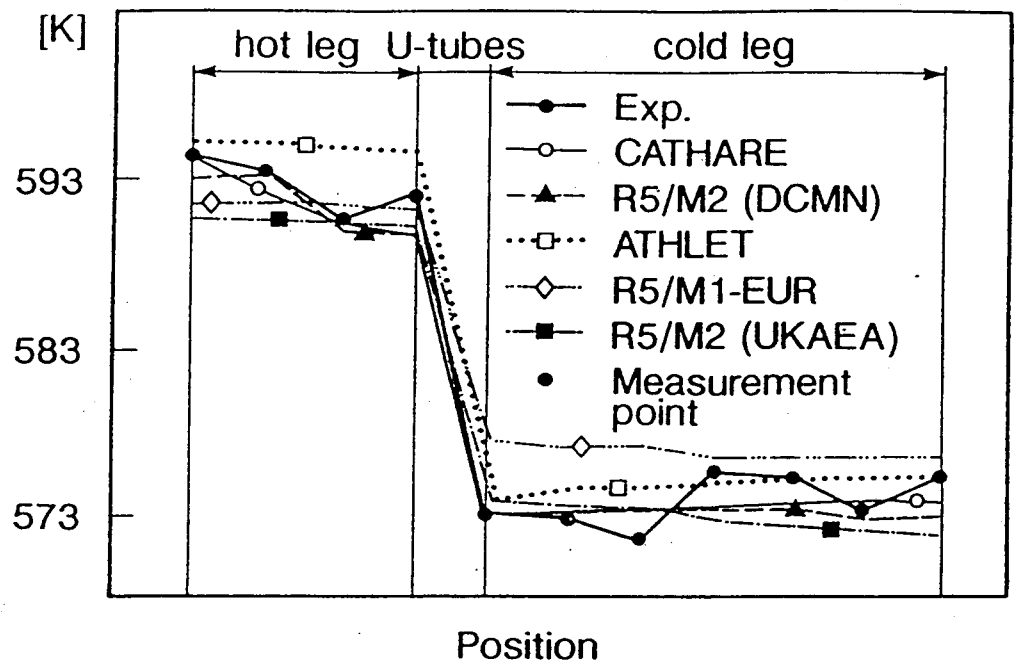

Figure 9: Distribution of fluid temperature along intact loop resulting from steady-state calculation by various users and comparison with experimental data.

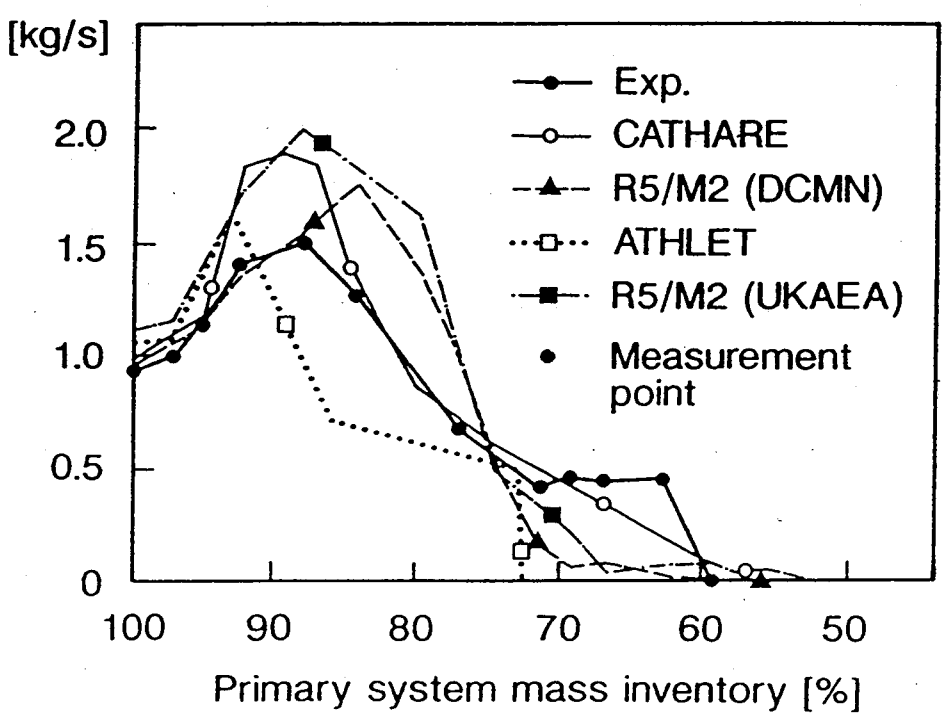

Figure 10: Comparison between measured and calculated trends of steady-state mass flowrate in intact loop during the whole transient as a function of primary

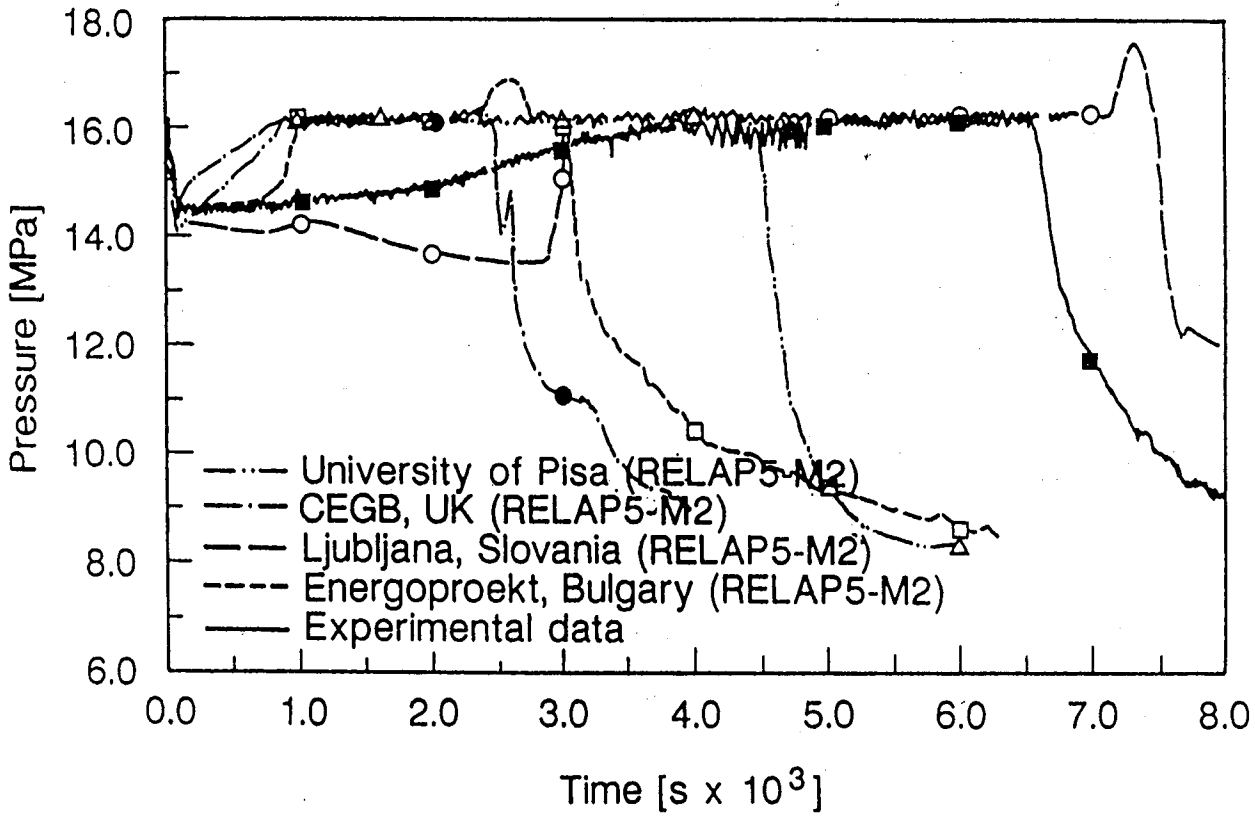

Figure 11: Dispersion of results obtained by participants performing "blind" calculations for ISP-22 (SPES facility) by using RELAP5/Mod2 code.

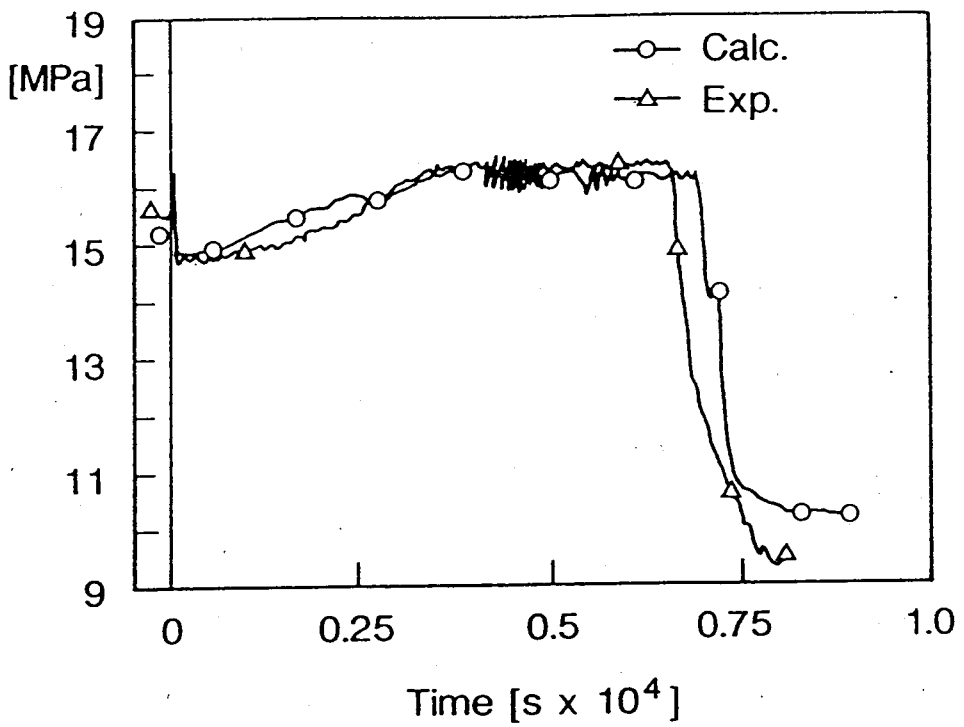

Figure 12: Post-test calculation of a participant for SPES SP-FW-02: Upper plenum pressure.

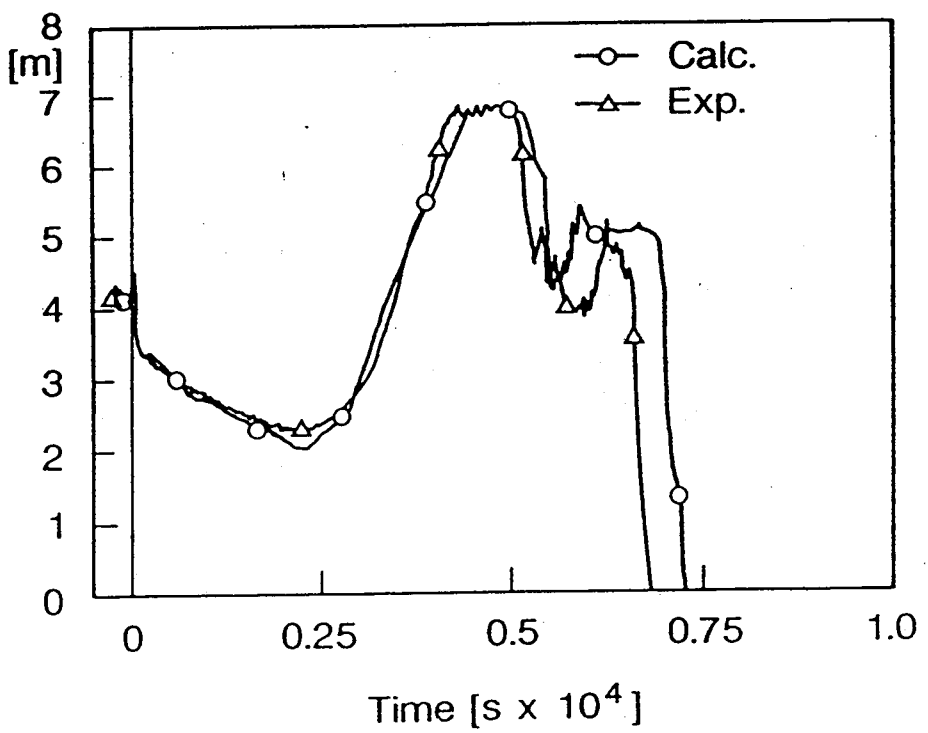

Figure 13: Post-test calculation of a participant for SPES SP-FW-02: Pressurizer level.

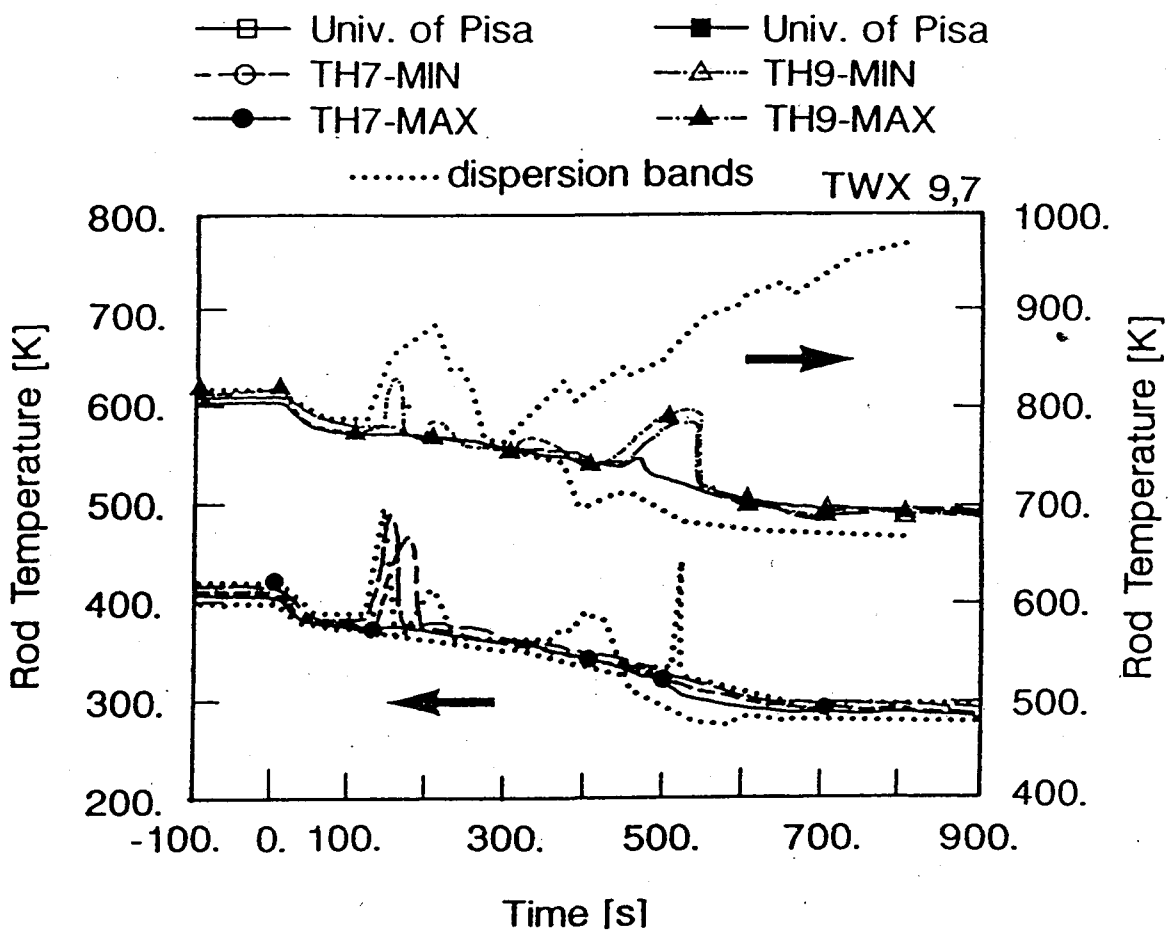

Figure 14: Heater rod surface temperature (maximum): Calculated dispersion bands for RELAP5/Mod2 participants for ISP-26, ROSA-IV-LSTF, open standard problem.

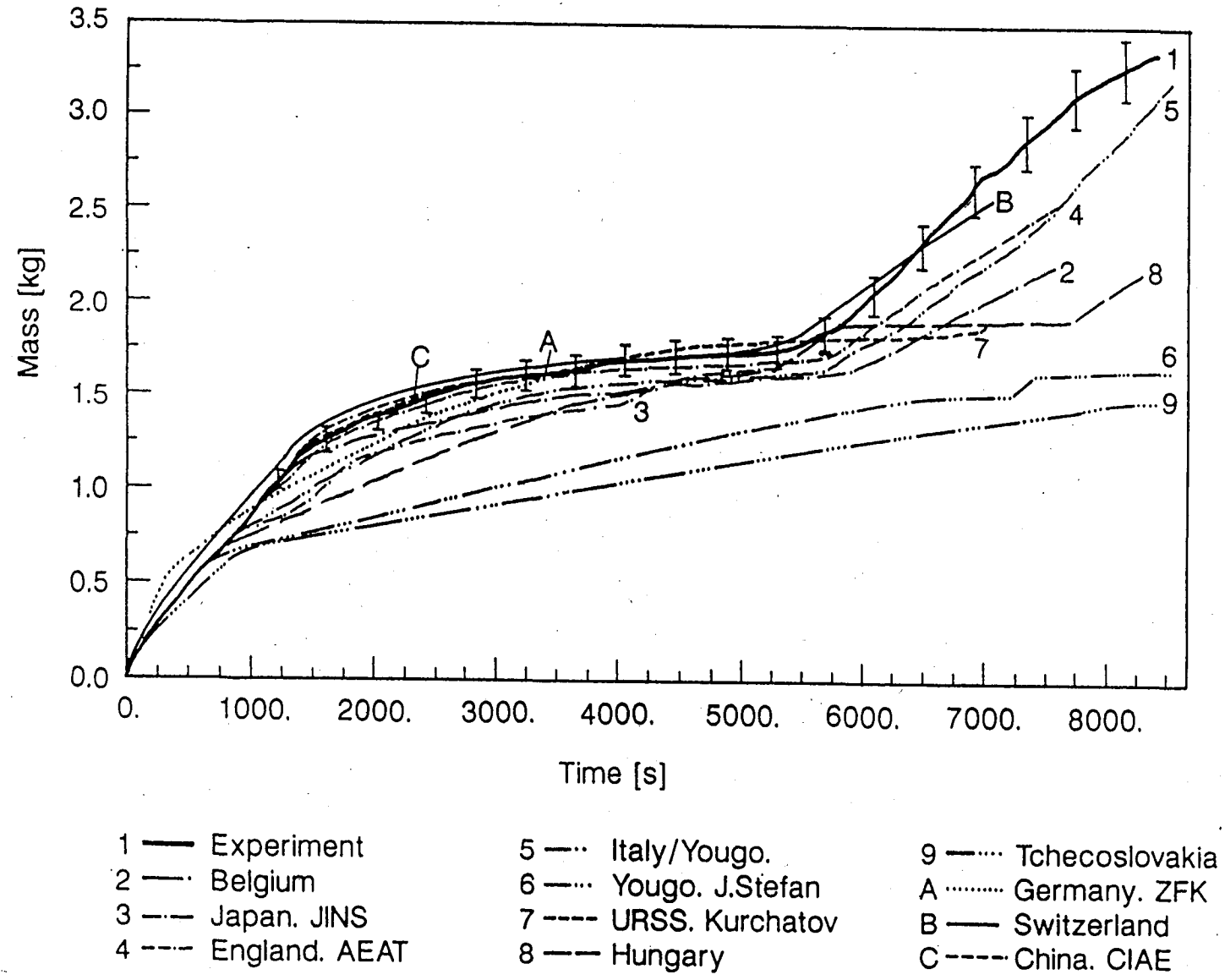

Figure 15: Integrated break mass flow comparisons between experimental data and RELAP5/Mod2 calculations (Blind), for BETHSY (ISP-27).