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The Findings from the OECD/NEA/CSNI UMS (Uncertainty Method Study)

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Abstract

Within licensing procedures there is the incentive to replace the conservative requirements for code application by a "best estimate" concept supplemented by an uncertainty analysis to account for predictive uncertainties of code results. Methods have been developed to quantify these uncertainties. The Uncertainty Methods Study (UMS) Group, following a mandate from CSNI (Committee on the Safety of Nuclear Installations) of OECD/NEA (Organization for Economic Cooperation and Development / Nuclear Energy Agency), has compared five methods for calculating the uncertainty in the predictions of advanced "best estimate" thermal-hydraulic codes.

Most of the methods identify and combine input uncertainties. The major differences between the predictions of the methods came from the choice of uncertain parameters and the quantification of the input uncertainties, i.e. the wideness of the uncertainty ranges. Therefore, suitable experimental and analytical information has to be selected to specify these uncertainty ranges or distributions.

After the closure of the Uncertainty Method Study (UMS) and after the report was issued comparison calculations of experiment LSTF-SB-CL-18 were performed by University of Pisa using different versions of the RELAP 5 code. It turned out that the version used by two of the participants calculated a 170 K higher peak clad temperature compared with other versions using the same input deck. This may contribute to the differences of the upper limit of the uncertainty ranges. A 'bifurcation' analysis was also performed by the same research group also providing another way of interpreting the high temperature peak calculated by two of the participants.

1. Introduction

Some computer codes that model reactor accidents contain deliberate pessimisms and unphysical assumptions. It is then argued that the overall predictions are worse than reality (for example, calculated fuel temperatures are higher than reality). These conservative evaluation models, for example, were provided to satisfy US licensing requirements for such pessimistic calculations up to 1988, ref. [1] (see below for a historical outline of the subject).

The other approach is to design a code to model all the relevant processes in a physically realistic way with the intention that the predictions are not biased either in a pessimistic or optimistic direction (”best estimate”). The main motivations for the development of advanced best estimate thermal hydraulic codes were:

- To describe the physical behavior realistically without individual conservative assumptions. This should calculate the mean of the data rather than providing a bound to the data.
- To obtain more economical operation of reactors by relaxing technical specifications and core operating limits set by conservative evaluation model calculations. This might include prolonging fuel cycles, up-rating power and justifying the continued operation of some reactors against modern safety standards.
- To develop effective accident management measures based on realistic analysis.

These realistic computer codes can approximate the physical behavior with more or less accuracy. The inaccuracies are stated during the usual code validation process. Agreement of calculated results with experimental data is often obtained by choosing specific code input options or by changing parameters in the model equations. These selected parameters usually have to be changed again for different experiments in the same facility or a similar experiment in a different facility in order to obtain agreement with data. A single “best estimate” calculation with an advanced realistic code would give results of one code run of unknown accuracy. To make such results useful, for example if they are to be compared with limits of acceptance, the uncertainty in the predictions then has to be calculated separately. Uncertainty analysis methods therefore had to be developed to estimate safety to justify reactor operation. A particular stimulus was the U.S. Nuclear Regulatory Commission (USNRC) revision of its regulations in 1989 to permit the use of realistic models with quantification of uncertainty in licensing submissions for Emergency Core Cooling Systems, ref. [2]. This kind of approach to the licensing is identified as BEPU (Best Estimate Plus Uncertainty) and requires the application of qualified Uncertainty methods.

In addition uncertainty analysis can be used to assist research prioritization. It can help to identify models that need improving and areas where more data are needed. It can make code development and validation more cost-effective.

The Uncertainty Methods Study (UMS) compares different methods to estimate the uncertainty in predictions of advanced best estimate thermal hydraulic codes by applying the methods to a particular experiment. This paper summarizes the comparison reported in ref. [3] and includes a discussion from more recent evaluations of the results. An outline of the milestones for the application of BEPU is given in advance.

2. A Historic Outline for Accident Analyses

Accidents and related scenarios in nuclear power plants were considered to demonstrate the safety of NPP in the ‘50s when computers did not exist. Experiments, pioneering thermal-hydraulics models and engineering evaluations (this can be expressed as engineering judgment, consideration of lack of knowledge, introducing conservative safety margins, etc.) were the basis of the reactor safety analyses accepted by regulators at the time.

More systematic thermal-hydraulic studies and experiments were conducted in the ‘60s, noticeably concerning individual ‘physical’ phenomena like Two-Phase Critical Flow, Critical Heat Flux, Depressurization/Blow-down, etc. New findings from those researches were considered in reactor safety and licensing documents.

Massive use of computers for nuclear reactor safety started in the ‘70s. The accident analysis could also benefit of primitive numerical codes and of results of lately called integral-system experiments. The nuclear regulatory point-of-view was well established with the publication of the ‘Interim Acceptance Criteria for ECCS’, by the USNRC (US AEC at the time), ref. [4]. This triggered a wide variety of researches aimed at the evaluation of safety margins focusing on the estimation of the maximum temperature on the surface of fuel rods following Large Break Loss of Coolant Accident (LB-LOCA). The Appendix K to the paragraph 10-CFR-50.46 of the Code of Federal Regulation, followed (i.e. the 'Interim Criteria') in 1974, ref. [1], basically confirming the structure of the document by USNRC, 1971 (10 CFR 50, including the Appendixes, is a continuously updated document). 'Conservatism' is the key-word which characterizes the application of Appendix K in licensing analyses. During the same decade, the WASH-1400 or the "Rasmussen Report" was issued addressing the relevance of PSA also producing significant results from the execution of probabilistic analyses, see ref. [5].

Robust, user-friendly versions of lately called system-thermal-hydraulic codes (or computational tools) were available in the '80s. The importance of V & V (Verification and Validation), soon became clear (see e.g. ref. [6]) as a mandatory process to be completed before application of those computational tools to safety and licensing. In this context, the bases were set for addressing the scaling issue, e.g. see ref. [7], for a summary status on the subject. International activities were conducted at CSNI (Committee on the Safety of Nuclear Installations of OECD/NEA, Organization for Economic Cooperation and Development / Nuclear Energy Agency) to propose viable ways for V & V, e.g. refs. [8], [9] and [10], also involving the evaluation of the user effect, ref. [11], and the recognition of the role of the input deck (or nodalization) and qualification, e.g. ref. [12]. Appendix K to 10 CFR 50.46 continued to be used during the decade for licensing purposes.

The need for uncertainty methods suitable for predicting unavoidable errors to be added to the results of calculations performed by system thermal-hydraulic codes became clear at the beginning of '90s (or even at the end of '80s). Working approaches were proposed, e.g. by USNRC, ref. [13] 1989, by GRS, ref. [14] and by University of Pisa, ref. [15]. Research and Development (R & D) activities started to have robust (e.g. with results independent of the user) and qualified uncertainty methods, e.g. ref. [3] (the UMS report concerned in the present paper). The US NRC issued the Regulatory Guide (RG) 1.157, ref. [16]: the application of system thermal-hydraulic codes was envisaged, even though recommending the use of selected conservative models. Those models should be applied in phenomenological areas where the knowledge was not considered satisfactory. Requirements in the RG 1.157 gave guidelines how to perform uncertainty analysis when using best estimate codes in licensing. 10 CFR 50.46 opened the possibility to use best estimate codes for LOCA analyses in licensing, however, in that case uncertainty analysis is required. The acronym BEPU for "best estimate plus uncertainty" started to circulate.

Applications of BEPU approaches in licensing processes definitely started in the '00s. The following key events (not an exhaustive list, not in the order of importance) give an idea of the technology development in the area:

a) AREVA proposed a BEPU methodology to analyze the LBLOCA for the licensing of Angra-2 NPP in Brazil, ref. [17] (the method is noticeably different from what is described by Martin and O'Dell, in ref. [18]). The submission was analyzed by the Regulatory Authority of Brazil which also requested the application of different uncertainty methods by assessors independent from AREVA, e.g. see refs. [19] and [20].

b) USNRC issued the RG 1.203, ref. [21], and opening for the possibility of adopting the BEPU approach in licensing.

c) CSNI launched and completed the six-year project BEMUSE, e.g. ref. [22]. The general aim of BEMUSE was to demonstrate the maturity of uncertainty methods and approaches with main concern to LBLOCA applications. The objective was basically achieved, but differences in the results by participants mainly in predicting reflood time caused the need for a careful interpretation of results. The difficulty in harmonizing, from the side of applicants of uncertainty methods, the choice of input uncertainty parameters and the related ranges of variations was an outcome from the project.

d) Two key documents were issued by IAEA, i.e. refs. [23] and [24]. The former (Safety Report Series, SRS 52) deals with the description of workable uncertainty approaches and methods. The latter (Specific Safety Guide, SSG-2 on deterministic safety analysis) proposes the BEPU approach in licensing as consistent with the technological state of art in the area of accident analysis.

e) Best Estimate (BE) conferences (BE-2000 and BE-2004) were held under the auspices of the American Nuclear Society (ANS) in 2000 and 2004, i.e. refs. [25] and [26]. The series of conferences was continued by V & V Workshops held in Idaho Falls and in Myrtle Beach, i.e. refs. [27] and [28], respectively. The importance given by the international community to BEPU methods was evident from those conferences.

f) A variety of BEPU applications all over the world during the concerned decade, mostly within the license renewal framework, are summarized in ref. [29].

Definitely, the first decade of the current millennium is characterized by the breakthrough for the use of BEPU methods in licensing of NPP. The '10s decade started with the submission of Chapter 15 of the FSAR of the Atucha-II NPP to the Regulatory Authority in Argentina, by the NA-SA utility. In this case, the entire FSAR is based on the BEPU and the approach itself was submitted in advance (and endorsed by the Regulatory Body), e.g. ref. [30]. In this case the adopted uncertainty method was the CIAU (Code with capability of Internal Assessment of Uncertainty), ref. [31]. The approval process from the side of the Regulatory Authority at the time of the present paper is still on-going.

3. Objectives of UMS

The CSNI Task Group on Thermal Hydraulic System Behaviour held a Workshop to discuss the different uncertainty methods in 1994. The Workshop recommended that there should be an international comparison exercise between the available uncertainty analysis methods with the objectives, ref. [32]:

1. To gain insights into differences between features of the methods by:
   - comparing the different methods, step by step, when applied to the same problem;
   - comparing the uncertainties predicted for specified output quantities of interest;
   - comparing the uncertainties predicted with measured value;
   - and so allowing conclusions to be drawn about the suitability of methods.
2. To inform those who will take decisions on conducting uncertainty analyses, for example in the light of licensing requirements.

The CSNI approved the Uncertainty Methods Study (UMS) at its meeting in December 1994, with these objectives. The UK was given the task of leading the study. The study was performed from May 1995 through June 1997.

4. Uncertainty Methods applied

The methods compared in the UMS are summarized in Table 1. The methods (and those discussed at the 1994 Workshop) may be divided into three groups according to their basic principles, refs. [3], [33] and [34]:

- The University of Pisa method, the Uncertainty Method based on Accuracy Extrapolation (UMAE), extrapolates the accuracy of predictions from a set of integral experiments to the reactor case or experiment being assessed (e.g. see also ref. [15]).

The other methods rely on identifying uncertain models and data and quantifying and combining the uncertainties in them. They fall into two kinds:

- The AEA Technology method that characterises the uncertainties by “reasonable uncertainty ranges” and attempts to combine these ranges with a bounding analysis.
- Methods which assign probability distributions to uncertainty ranges for uncertain input parameters and sample the resulting probability density at random in the space defined by the uncertainty ranges. In the UMS, the GRS, IPSN and ENUSA methods are of this kind; so also is the Code Scaling Applicability and Uncertainty Evaluation (CSAU) Method as demonstrated in ref. [35]. The probability used here is due to imprecise knowledge and is not probability due to stochastic or random variability.

Table 1. Summary of Methods Compared in the UMS Study.

Participant	Code Version Used	Method Name and Type
AEA Technology, UK	RELAP5/MOD3.2	AEAT Method. Phenomena uncertainties selected, quantified by ranges and combined.
University of Pisa, Italy	RELAP5/MOD2 cycle 36.04, IBM version CATHARE 2 version 1.3U rev 5	Uncertainty Method based on Accuracy Extrapolation (UMAE). Accuracy in calculating similar integral tests is extrapolated to plant.
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Germany	ATHLET Mod 1.1 Cycle A	GRS Method. Phenomena uncertainties quantified by ranges and probability distributions (PDs) and combined.
Institut de Protection et de Sûreté Nucléaire (IPSN), France	CATHARE 2 version 1.3U rev 5	IPSN Method. Phenomena uncertainties quantified by ranges and PDs and combined.
Empresa Nacional del Uranio, SA (ENUSA), Spain	RELAP5/MOD 3.2	ENUSA Method. Phenomena uncertainties quantified by ranges and PDs and combined.

5. Experiment used for UMS

The participants and the Task Group of Thermal Hydraulic System Behavior agreed that the International Standard Problem (ISP) 26 experiment, LSTF SB-CL-18, should be used. LSTF SB-CL-18 is a 5% cold leg small break LOCA experiment conducted in the ROSA-IV Large Scale Test Facility (LSTF). The LSTF is located at the Tokai Research Establishment of JAERI and is a 1/48 volumetrically scaled, full height, full pressure simulator of a Westinghouse type 3423 MWth pressurized water reactor. The experiment simulates a loss of off-site power, no high pressure injection (HPIS), the accumulator system initiates coolant injection into the cold legs at a pressure of

4.51 MPa, the low pressure injection system initiates at 1.29 MPa. Thus, the experiment considers a beyond design basis accident. Because of the ISP the experiment was already well documented. Much helpful information has been provided by Y. Kukita of the Japan Atomic Energy Research Institute (JAERI).

Although ISP 26 was an open ISP participants in the UMS have not used experimental measurements from the test, for example the break flow or the secondary pressure. In the same way other experiments performed in the LSTF were not used. This means not allowing the related measurements to influence the choice of input uncertainty ranges and probability distributions of the input uncertainties. Submissions included a written statement of the justification used for input uncertainty ranges and distributions used and were reviewed at workshops. All other assumptions made were listed and reviewed.

Two dry-out situations at different timing (see below) characterize the ISP 26 experiment: this makes challenging the application of uncertainty methods.

6. Comparison of the uncertainty methods

A detailed description of the methods is given in refs. [3], [33] and [34], see also ref. [36]. An excerpt from comparison tables provided in those documents is given in Table 2. In this way a step by step comparison is performed and the main similarities and differences between the methods are characterized.

Table 2. Comparison between the uncertainty methods adopted in UMS: an excerpt from comprehensive tables (refs. [3], [33], [34] and [36]).

Feature	AEA Technology	University of Pisa	Statistic methods - GRS, IPSN, ENUSA
Characterization of uncertainties	Reasonable uncertainty ranges	Accuracy: difference between prediction and measurement	Ranges and probability distributions
Selection of important uncertainties	Yes (9 and 7 in two demonstration studies)	No	GRS, IPSN: No (52 and 25 here) ENUSA: PIRT (25)
Combination and propagation of uncertainties	Analyst explores uncertainty space and decides when to stop	Measured accuracy can be extrapolated to plant if: - criteria on integral test data satisfied - data, nodalization, users are qualified - relevant thermal hydraulic aspects are in data base - measured/calculated ratio scattered about 1.0;	Uncertainty space sampled at random according to combined probability distribution
Number of code runs	22 and 50 in two studies	One for each test in the data base and one for the plant	For one sided 95%/95% tolerance/confidence limit: 59; for two-sided interval: 93
Use of specific data for scaling	During code validation	Yes	During code validation
Use of response surface to approximate result	No	No	No
Use of biases on results	No	Possibly	No

The results from the comparison among the methods can be summarized as follows:

a) Three of the methods (i.e. GRS, IPSN and ENUSA) are based upon the approach ‘propagation of input uncertainties’; one method (i.e. UMAE) is based upon the approach ‘extrapolation of output error’ (this classification was introduced about one decade after the end of the UMS, i.e. see ref. [23]). All these methods make use of statistics at different levels.

b) One method (i.e. AEAT), based on the approach ‘propagation of input uncertainties’, is fully based upon the control by analysts at each step of the adopted procedure and makes no use of statistics. It is an unfortunate situation that this method has no (openly available) application other than the UMS.

c) Engineering judgment is needed by all methods; however, in the case of UMAE engineering judgment is used in the development phase and in the case of other methods this is needed for each application. The expert judgment in setting up an input deck can be checked by applying acceptance criteria by use of the Fast Fourier Transform in the UMAE method.

d) Experimental data are used for validation of computer codes selected for uncertainty evaluation. However, in the case of UMAE experimental data are strictly needed to derive uncertainty. A similar statement can be applied in relation to the scaling issue: indirectly, all methods require the consideration of scaling, but in the case of UMAE, the availability of scaled data from experiments is mandatory to derive uncertainty. However, the gap between integral test facilities to reactor size is significant.

e) Among the methods which use statistics, see item a), the GRS method takes benefit of a theoretical derivation (i.e. the Wilks formula, ref. [37]) to identify the number of needed calculations (or code runs). Vice-versa expert judgment at various extents is needed by the AEAT method for each application, except in the case of UMAE where only one calculation is needed (actually, more code runs may be needed in the cases when ‘biases’ are concerned, ref. [15]), and to optimize the nodalization.

f) All methods which are based on the approach ‘propagation of input uncertainties’ have to identify proper input uncertainty parameters and related ranges of variation (see also the conclusions and the PREMIUM - Post BEMUSE REflood Models Input Uncertainty Methods - project). For those methods, the propagation of uncertainty occurs by code calculations varying the identified input uncertainties. In the case of UMAE, either an unqualified code or nodalization is causing large uncertainty bands. However, the extrapolation of accuracy to get the uncertainty requires a specific qualification process.

7. Comparison of results from the application of the methods

Results from the UMS comparison project are comprehensively described in ref. [3] and summarized in ref. [38]. In the following, a synthesis of the discussion in ref. [38] is presented.

The participants were asked to make uncertainty statements, based on their calculation results, for:

1 Functions of time:

- Pressurizer pressure.
- Primary circuit mass inventory.
- Rod surface temperature for one assigned position

2 Point quantities:

- First peak clad temperature.
- Second peak clad temperature.
- Time of overall peak clad temperature (the higher of the two).
- Minimum core pressure difference at an assigned position.

As a result of the short time-scale of the UMS project and of limited funding, some of the uncertainty ranges adopted for methods following the ‘propagation of input uncertainty’ approach may have been less well defined and, as a consequence, wider than would have been the case, for example, if the calculations were for a plant safety analysis. This had consequences to the AEAT and the ENUSA uncertainty predictions.

7.1 Results for the time functions

The uncertainty ranges calculated for the point quantities and for the functions of time, i.e. pressurizer pressure, primary system mass inventory and hot rod surface temperature for the assigned location are given in graphical form in refs. [3] and [38]. Here, results are discussed only in relation to the rod surface temperature, Fig. 1.

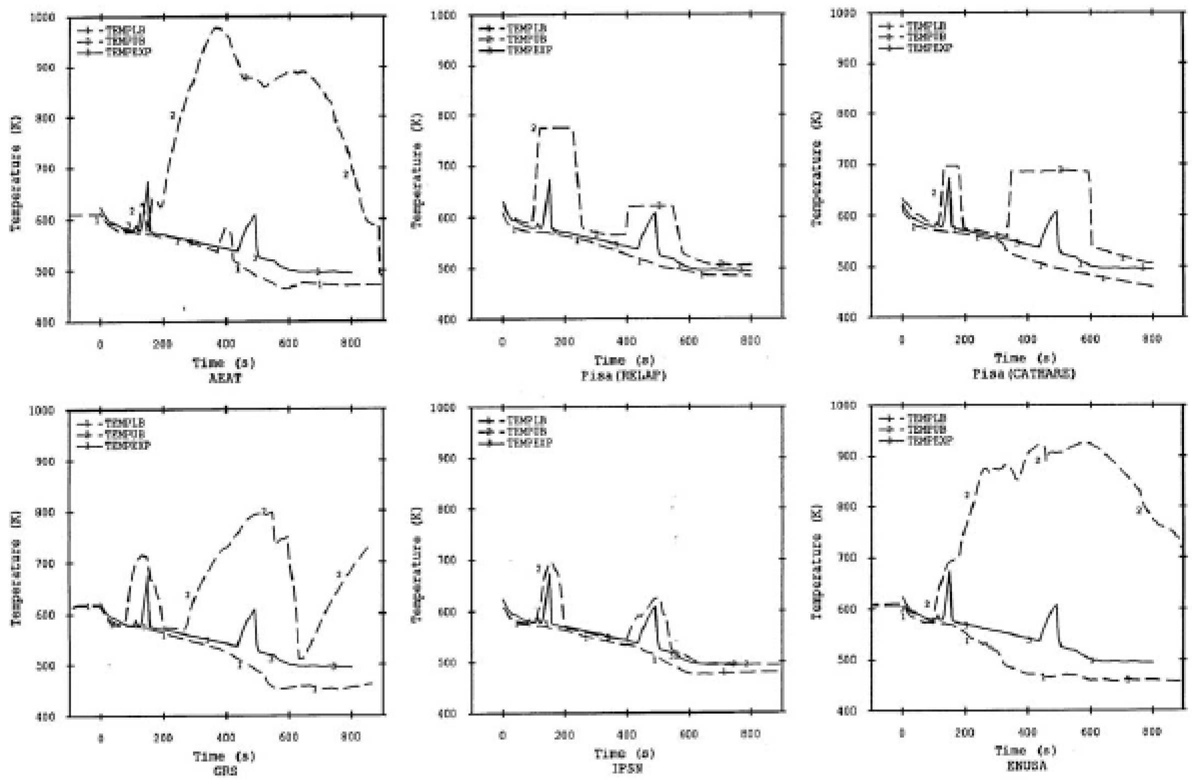

Fig. 1 – UMS results related to rod surface temperature.

7.1.1 Overall evaluation

The AEAT and ENUSA predictions are remarkably similar. The same code (RELAP5), the same base input deck and mostly the same input uncertainties were used. However, they applied different methods, i.e. bounding (AEAT) versus probabilistic treatment (ENUSA) of the uncertainties, and the numbers of adopted input uncertainty parameters are different (7 by AEAT and 25 by ENUSA).

The two applications of the Pisa (UMAE) method using different computer codes (RELAP and CATHARE) are broadly similar. The clad temperature ranges for the second dry-out are similar. Those ranges for the first dry-out calculated by CATHARE gave a narrower range because the base case calculation did not predict the dry-out (ref. [38]).

Of the probabilistic methods, IPSN gave the narrowest ranges. This is attributed to the choice of parameters made and to the narrow ranges adopted for the input uncertainty parameters. The characterization of input uncertainty parameters, of the number of those parameters and of the related ranges of variation could not be optimized owing to the time constraints of the UMS project. An actuation of the CCFL option in the CATHARE code (at the upper core plate and at the inlet plena of the steam generators) was needed to predict the first dry-out.

The large uncertainty ranges for clad temperature calculated by AEAT, ENUSA and GRS prompted discussion among the participants about the reasons for them.

In the case of AEAT and ENUSA this may be due to unrealistically large uncertainty ranges for CCFL parameters, agreed upon in order to complete the study on time (as already mentioned). Another contribution may come from the used RELAP5 version MOD 3.2, as discussed in chapter 8.

The measured maximum clad temperature during the second heat-up is well below that of the first one. In the GRS calculations, many of the calculated time histories exhibit the contrary, namely a maximum during the second heat-up. The uncertainty of the maximum temperature during the second heat-up is about double of that during the first. In some code runs a partial dry-out occurs due to fluid stagnation in the rod bundle which causes an earlier second heat-up, and as a consequence, a larger increase of the clad temperature.

The large uncertainty is striking, and the sensitivity measures indicate which of the uncertainties are predominantly important. These sensitivities are presented in Volume 2 of ref. [3]. Main contributions to uncertainty come from the critical discharge model and the drift in the heater rod bundle. Other contributions that are worth mentioning come from the bypass cross section upper down-comer - upper plenum. As a consequence, improved state of knowledge about the respective parameters would reduce the striking uncertainty of the computed rod surface temperature in the range of the second core heat-up most effectively.

7.1.2 Adding details to the evaluation

Problems were identified in predicting the first dry-out by AEAT, by the UMAE application with CATHARE and by IPSN: this is due to the physical phenomenon of loop seal filling and clearing. Proposed solutions when performing the uncertainty analyses had minor impact on the overall results.

The occurrence of late quench times predicted for the upper uncertainty band, up to about 600 s (see Fig. 1) was questioned since the issuing of the report ref. [3]. AEAT analyzed cases where quench times at the concerned rod surface location was calculated after 570 s. This occurred when:

- there was a third dry-out, or
- when loop seal B (broken loop) does not clear (or clears late) which is associated with low break flow or modeling the off-take at the top of the cold leg, or
- when loop seal A (intact loop) did not clear combined with CCFL parameters maximize the hold-up of water in the Steam Generator (SG) and SG inlet plenum, or
- in cases where the CCFL parameters that maximize the hold-up of water were used in the SG and SG inlet plenum combined with relative low break flow.

Namely, in 17 out of the 50 cases reported by AEAT a third dry-out was detected. The third dry-out leads to relatively small temperature transients which are localized at the top of the core. This is not correlated with high peak clad temperatures.

The third dry-out conditions were also calculated by ENUSA and GRS. GRS found a third dry-out in 2 out of 99 calculations. They were associated with high bypass flow cross section and high condensation. High condensation keeps the pressure low so the accumulators inject continuously. However the accumulator water is discharged through the break. Although the input uncertainties leading to these cases differ from those found by AEAT, they also do not calculate clearance of the broken loop seal. Some other GRS calculations without loop seal clearance do not predict a third dry-out, however.

8. ‘Post-UMS’ evaluations

The information provided in chapters 3 to 7 above considers the original summary of UMS in ref. [3], and the key evaluations from refs. [33], [34], [36] and [38]. In the following, results from computational activities with regard to UMS, and performed after the end of the UMS project, are outlined.

8.1 Use of different code versions at UNIPI

University of Pisa performed comparison calculations of experiment LSTF-SB-CL-18 using different versions of the RELAP 5 code as reported in Fig. 2, i.e. MOD 2 (old code in Fig. 2), MOD 3.2 (intermediate code in Fig. 2) and MOD 3.2.2 (new code in Fig. 2), ref. [39]. The MOD 2 code version was used by the University of Pisa and MOD 3.2 by AEA Technology as well as by ENUSA in the UMS. It turned out that MOD 3.2 calculated a 170 K higher peak clad temperature compared with MOD 2 and MOD 3.2.2 using the same input deck. This may contribute to the relative high upper limit of the uncertainty ranges calculated by AEAT and ENUSA. That explanation is also in agreement with the AEAT peak clad temperature of 787 K at 300 s for their reference calculation using nominal values for the input parameters, without calculating the first heat-up. The measured second peak is 610 K at 500 s.

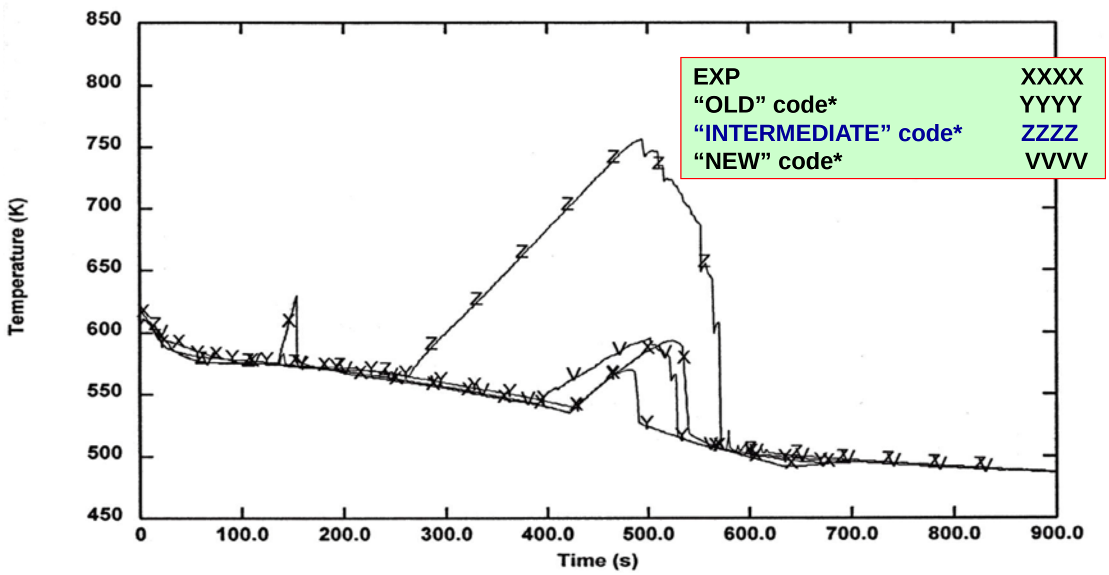

Fig. 2 – UNIPI UMS reference calculation performed with different versions of the Relap5 code.

8.2 New GRS calculation

A new application of the GRS method to the UMS problem was performed by GRS using revised probability distributions for the most important uncertain parameters. These were identified by sensitivity measures in the original UMS analysis: contraction coefficient of critical discharge flow and drift in the heater rod bundle. A newer ATHLET version Mod 1.2, cycle A was used instead of Mod 1.1, Cycle A. The result was a shorter duration of the second heat-up and lower peak clad temperatures during the second heat-up, as shown in Fig. 3. More details can be found in ref. [40].

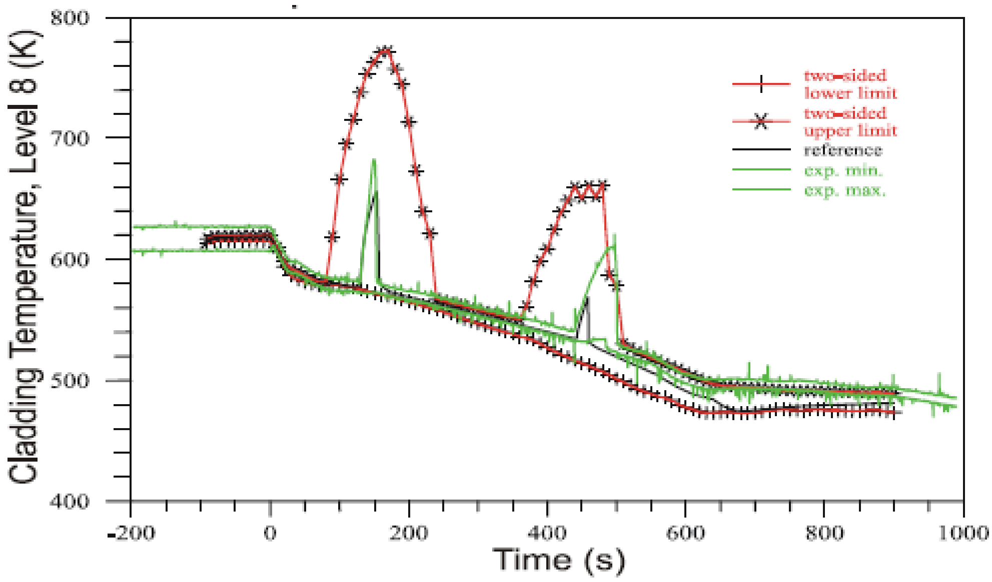

Fig. 3 – GRS UMS revised calculated uncertainty range compared with measured minimum and maximum values of rod clad temperature.

8.3 Bifurcation analysis performed at UNIPI

Thermal-hydraulic transient scenarios in NPP can occur when bifurcations bring the transient evolution far from the best-estimate deterministic prediction, thus invalidating the original uncertainty evaluation. Therefore a bifurcation analysis may be necessary. The related results should be intended to be 'outside' the 95% confidence level which characterizes the results from the 'normal' uncertainty analysis.

An activity was completed at University of Pisa as discussed in ref. [41]. The selected reference transient for the analysis is the same experiment (and related calculation) as for UMS.

Starting points for the bifurcation analysis are:

- The identification of type '1' and type '2' bifurcations.
- The knowledge of the uncertainty characterizing the parameters which affect the bifurcation.

Namely, type '1' and type '2' bifurcations are associated with the actuation of any system during the concerned transient (e.g. scram, valve opening-closure, pump-trip, accumulator intervention, etc.) and with the occurrence of cliff-edge type thermal-hydraulic phenomena (primarily CHF occurrence), respectively. Furthermore, the knowledge of the uncertainty characterizing the parameters which affect the bifurcation is the result of the uncertainty study.

For instance, in the case of accumulator intervention, let us consider the diagram pressure versus time where upper and lower uncertainty lines are reported. Then, the accumulator start may come at any time identified by the intercepts defined by the horizontal line drawn at the nominal accumulator pressure and the upper and the lower pressure boundary curves. Similarly, the actuation of a steam relief valve, e.g. in the secondary side of SG, having reached the opening pressure, may occur during a time interval depending upon the width of the uncertainty bands for SG pressure.

Once 'n' possible bifurcation points have been identified on the boundaries of the uncertainty bands, 'n' new calculations are performed starting from the initial conditions: by properly fixing input parameters the 'n' bifurcation points are reached. Branches are calculated starting from each of the 'n' points, thus creating a bifurcation tree. More details can be found in ref. [41].

In the case of the UMS test scenario, the envelope of the bifurcation calculations can be seen in Fig. 4: the bifurcation envelope ‘resembles’ the AEAT and the ENUSA upper uncertainty boundaries in Fig. 1, thus supporting the conclusion that those boundaries are ‘conservative’.

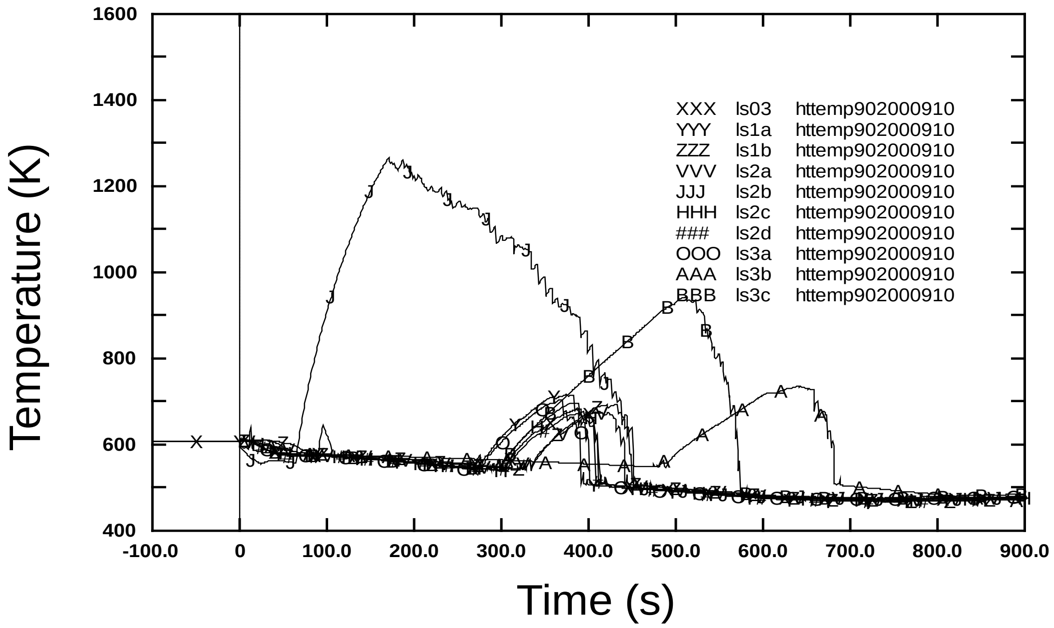

Fig. 4 – UNIPI bifurcation analysis performed in relation to UMS reference calculation.

8.4 Application of CIAU

The CIAU procedure, see chapter 2 and refs. [23] and [31], has been applied to the UMS task producing the results in Fig. 5. Predicted uncertainty bands appear similar to those predicted by the UMAE in Fig. 1 and by the GRS method in Fig. 3.

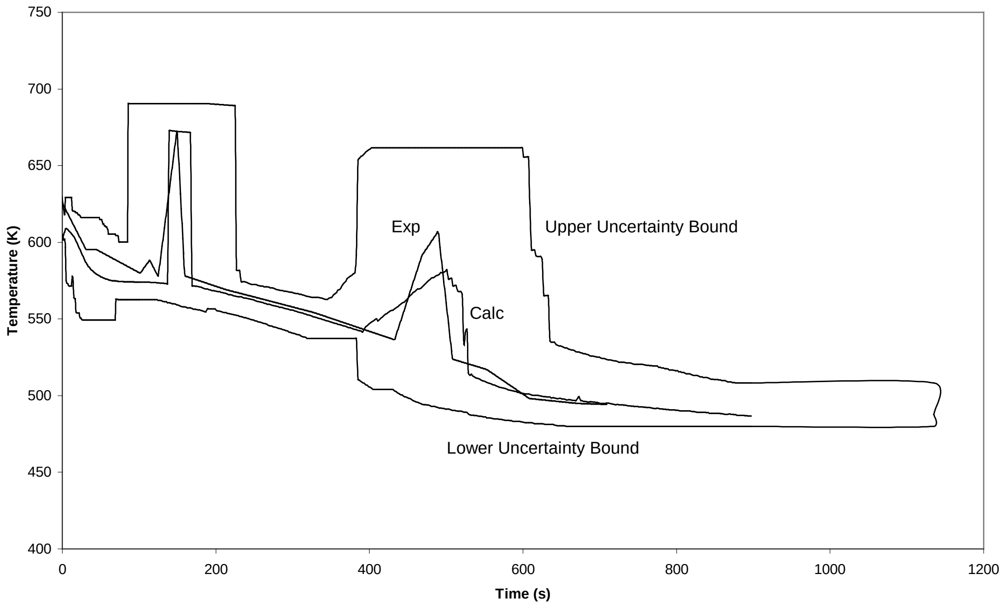

Fig. 5 – UNIPI CIAU application to UMS.

9. Conclusion

Five uncertainty methods for advanced best estimate thermal hydraulic codes have been compared. Most of the methods identify and combine input uncertainties. Three of these, the

GRS, IPSN and ENUSA methods, use probability distributions and one, the AEAT method, performs a bounding analysis. One of the methods, the University of Pisa method, is based on accuracy extrapolation from integral experiments. To use this method, stringent criteria on the code and experimental data base must be met.

Firstly, the basis and the characteristics of the methods were compared within UMS, secondly, the uncertainty predictions obtained with these methods applied to the LSTF small break LOCA test SB-CL-18 were compared.

Three (out of 5) methods, GRS, ENUSA and IPSN follow the approach 'propagation of code input uncertainty'. The selection of input uncertainty parameters and related range of variations constitutes a challenge for those methods. One method, AEAT, is based on a number of steps controlled by the analyst: the challenges in this case are the availability of suitable expertise and the reproducibility of results. One method, UMAE proposed by University of Pisa, follows the approach later on identified as 'extrapolation of code output error'. The method is based upon processing of the error in calculating experimental transient scenarios which are relevant to the specific application. The challenges are the availability of suitable experimental data and the demonstration that those data are actually 'relevant' to the specific application.

The presented uncertainty bands for the concerned transient predicted by the different methods and users leads to the following conclusions:

a) Differences in calculating the wideness of the time-dependent uncertainty bands by the various methods are significant and may cause misleading conclusion by a reader (of the UMS report) not familiar with the (UMS) activity.

b) Large band wideness is calculated by AEAT and ENUSA which may raise concerns related to the capability of codes and their applicability to the prediction of NPP transients.

c) In contrast to the above large bands, a very small band wideness is calculated by IPSN: those bands are small compared with the spread of results observed in the conduct of ISP 26 where several qualified participants calculated the same transient applying state-of-the-art qualified codes.

d) The set of results calculated by UMAE (2 applications within UMS), by GRS (post-UMS calculation) and by CIAU (post-UMS calculation) show similar results and are consistent with the current capabilities of codes. These might be considered as reference results from the UMS.

Explanations have been provided and can be found or can be evaluated from the various reports (see the list of references) in relation to items a) to c). These may be synthesized as follows:

- Resources (man-power) invested in the UMS analysis is not consistent with the needed resources.
- Too much judgement applied for determining the input uncertain parameters and the related ranges of variation without sufficient use of validation experience. Mainly, too much conservatism was introduced to the ranges of uncertain input parameters (except in the IPSN application).
- Use of a 'non-frozen' or not sufficiently verified version of one code.

As a follow-up of UMS, the OECD/CSNI BEMUSE project was promoted and has recently been completed. The inadequacy related to input uncertainty parameters, 2nd bull item above, was also identified in BEMUSE. Then, the OECD/CSNI PREMIUM project has just been launched addressing the issues of selection of input uncertain parameters and determining (possibly by an analytical approach) the related ranges of variation.

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