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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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BEST ESTIMATE METHODS IN THERMAL HYDRAULIC SAFETY ANALYSIS

Summary and Conclusions of an OECD/CSNI Seminar
29 June - 1 July, 1998
Ankara, Turkey

Compiled by N. Aksan
Paul Scherrer Institut, Switzerland

English text only

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

– to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
– to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
– to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and the Republic of Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 27 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

– to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers. It was set up in 1973 to develop and co-ordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries.

CSNI constitutes a forum for the exchange of technical information and for collaboration between organisations which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of its programme of work. It also reviews the state of knowledge on selected topics of nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus in different projects and International Standard Problems, and assists in the feedback of the results to participating organisations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups and organisation of conferences and specialist meeting.

The greater part of CSNI's current programme of work is concerned with safety technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment and severe accidents. The Committee also studies the safety of the fuel cycle, conducts periodic surveys of reactor safety research programmes and operates an international mechanism for exchanging reports on nuclear power plant incidents.

In implementing its programme, CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

OECD/CSNI Seminar on "Best Estimate Methods in Thermal Hydraulic Safety Analysis" Ankara (Turkey), June 29 – July 1, 1998

Summary and Conclusions

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OECD/CSNI Seminar on "Best Estimate Methods in Thermal Hydraulic Safety Analysis" Ankara (Turkey), June 29 – July 1, 1998

SUMMARY AND CONCLUSIONS

1. Introduction

1.1 Sponsorship

The CSNI Seminar on Best Estimate Methods in Thermal Hydraulic Safety Analysis, held on 29 June – 1 July 1998 in Ankara, Turkey, was sponsored by the Committee on the Safety of Nuclear Installations (CSNI) of the OECD Nuclear Energy Agency (NEA). It was organized in collaboration with Turkish Atomic Energy Authority (TAEK).

1.2 Background and Objectives

In the spring of 1992 an OECD Specialist Meeting on Transient Two-Phase Flow ("Current issue in system thermal-hydraulics", April 6-8, 1992) was held in Aix-en-Provence, France. Next, there was an OECD Workshop on Transient Thermal-Hydraulic and Neutronic Codes Requirements (Annapolis, USA, November 5-8, 1996). The issues raised during the meetings indicated strongly a need for well established best estimate methodology for the use in plant safety analysis. A number of other CSNI activities addressed status of codes validation and related issues of codes uncertainties.

Discussions within the CSNI have led to the conclusion that the time is ripe to organize an international seminar to review the insights from and the status of utilization of the Best Estimate methods in plant safety analysis.

The scope of this Seminar is limited to safety analysis needed in support of licensing process. Therefore, the workshop did not specifically address issues related to code development and physical models.

The objectives of the meeting were:

- to exchange information on the Member countries' methodologies used and/or required in the licensing process, and
- to discuss the licensing issues associated with uncertainties and evaluation of T/H safety margins in conservative and BE approaches.
- to provide information to Turkish hosts on the use of Best Estimate methods in support of licensing.

The Seminar was structured into the following sessions:

1. Keynote presentations
2. Overview of past and current CSNI Thermal-Hydraulics activities
3. Best Estimate Methodologies and associated uncertainties (2 Sessions)
4. Selected Issues of Thermal-Hydraulics Safety Analyses
5. Final Discussion

A Program Committee was nominated by the CSNI to evaluate the abstracts of proposed papers, to select the papers for presentation, to organize the sessions and to develop the final program of the workshop, appoint Session Chairman, etc. Its members were:

– Mr. Nusret AKSAN, PSI, Switzerland, (Chairman)
– Mr. Yilmaz BEKTUR, TAEA, Turkey
– Mr. N.A.J. (Nick) Butt, Nuclear Electric, UK
– Dr. Farouk ELTAWILA, NRC, USA
– Dr. V.S. (Krish) KRISHNAN, AECL, Canada
– Dr. Michel REOCREUX, IPSN, France
– Mr. Victor TESCHENDORFF, GRS, Germany
– Mr. Andre DROZD, NEA (secretary)

The meeting was attended by 68 participants from 16 OECD countries, OECD/NEA and IAEA. The list of participants is given at the end of the proceedings.

It should be noted that, at the time this Seminar was organized, it was not intended to publish the presentations in a proceeding. After receiving the presentations and papers during the Seminar, Program Committee (PC) agreed that the presented papers are high quality and valuable for research and licensing organizations. Consequently, PC decided to publish the proceedings of the Seminar.

2. General remarks

The safety limits of the existing plants are currently not reached. Even more, some "better" analyses reveal existence of additional safety margins. There are many possible approaches to best-estimate analysis. It is known that the current conservative approach to LBLOCA is "overly conservative" but that may not be so conservative for the other break sizes ,caution need to be exercised in such cases. As the keynote speakers indicated, the use of BE methods is a "fact of life" regardless of what the regulators may decide about it. Currently only Siemens is using uncertainty analysis in the licensing process. It has been noted, that regulators are usually "evaluating" safety analysis rather than performing full scope analysis. The uncertainty methodologies exist, but need improvement in the direction of simplified usability.

The studies of beyond design basis accident (BDBA) and severe accident (SA) scenarios are very important to evaluate a level of "enhanced" plant safety. As it is difficult to calculate exactly the BDBA and SA scenarios, the "trends" of accident progressions need to be predicted as realistic as possible. Also there is a need for better coupling of thermal-hydraulic computer codes with neutronic, mechanical, containment and PRA analyses. In general, best-estimate codes are being used in a "conservative mode".

Some specific points made during the sessions:

- The safety limits are not going to be changed. Rather, the use of BE codes will change in a direction of establishing the limits and "measure" the margins,
- In the U.S.A., the "old" criteria are still used by the applicants, but BE methods are allowed supported by a PRA evaluation,
- A "common approach" of France and Germany differs in details, e.g., in France one code is used by both regulator and utilities, while in Germany different codes are used to have a better chance to uncover common cause failure,
- Public scrutiny of regulators forces to keep conservative criteria, but BE evaluation may be used ,
- Assessment of codes against validation matrices helps to estimate uncertainties,
- So far, the performed comparisons between CFD and 1-D codes lead to no conclusions,
- With strong emphasis on physics, the use of computer codes may give some valuable input and support to decision making and licensing, in addition to the use of the available research results in a distilled form,
- Nodalization is equally important as modeling. A course nodalization may give a correct average, but leads to incorrect estimate of local conditions (classic examples: void and two-phase flow regimes).

Points made regarding uncertainties studies:

- German paper on uncertainties shows that fuel related uncertainties are the most important, and that confirms the original CSAU studies done by US.NRC,
- If the established safety limits are "truly conservative", a plant should be permitted to operate as close to limits as possible,
- There are many sources of uncertainties. The most basic are the use of approximate codes solved by approximate methods, and the use of questionable correlations,
- Currently there is a good understanding of similarities and differences between the uncertainty analysis methods as provided by the UMS study.
- There is no "single" parameter that describes plant safety but there are many,

- Elements of Canadian approach to uncertainty analysis consists of PUA-RUA-CUA, i.e. Plant (how well we know), Representation (how well we model), and Codes(how well we "do" code analysis),
- When codes are coupled (e.g., thermal-hydraulic to neutronic) there is a "transfer of uncertainties". These type of uncertainties should be addressed and they can be addressed. There are already some plans to investigate a demonstration case with the available methods, presently.

Additional recommendations for uncertainty analysis in DBA and BDBA:

Improve knowledge on sensitive input uncertainties;

Work on algorithm to obtain uncertain input parameter distributions from comparison of calculation results and experimental data (some work performed in USA, work is going on in France and Germany);

Check conservatism of input parameter uncertainty ranges and distributions; choose only experiments as a basis for uncertainty specification which are appropriate for the plant scenario under investigation;

Minimize need for expert judgment as far as practicable;

Uncertainty data base should be set up to store information on parameter uncertainties; although this information is partly code and application dependent, valuable information can be obtained;

A new generation of codes could provide an „internal assessment of uncertainty“;

Improve the sensitive models in thermal hydraulic codes in order to reduce code uncertainties (e.g. critical flow, interfacial shear in the core region, counter-current flow).

Some answers to the general terms of the Seminar:

BDBA evaluation is necessary in the German licensing process since 1 January 1994 to ensure that even extremely unlikely events involving core melt-down would not require radical actions to ensure protection against the damaging effects of ionising radiation outside the fence of the installation site.

No limit of safety margins is specified, a licensing limit is sufficient. It has to be assured that a given plant will not exceed the licensing limits. The purpose of using a best estimate code and performing an uncertainty evaluation is to provide assurance that the licensing limits will not be exceeded with a probability of 95% or more.

BDBA analysis should not be conservative when the analysis is needed for risk reduction.

The existing uncertainty methods are useful. Guidelines on the choice of methods has been given in the frame of the Uncertainty Methods Study (UMS). There is no completely general theory available. The differences in the results of various uncertainty methods are due to differences in application, mainly due to the more or less conservative specification of ranges or distributions for the uncertain input parameters. In the Uncertainty Methods Study the uncertainties were specified to the conservative side by most participants. The situation would be similar for conservative bounding analyses using best estimate codes when for some dominant parameters conservative values have to be specified.

Further remarks and conclusions are included in the summaries of the specific sessions in next following pages.

3. Session specific summaries and conclusions

SESSION 1:
Keynote presentations **Chairmen: Reocreux / Kadiroglu**

Session 1 was devoted to four keynote presentations. The objectives of these presentations were to provide insights on practices in some selected countries which will give a representative description about the status in OECD countries of the use of Best Estimate thermal hydraulic codes in safety analyses and in the subsequent licensing process.

The first paper which was presented by USNRC (A. Thadani), gave a broad and historical overview of the evolution of regulatory requirements for the US commercial nuclear power plants.

As starting point of this overview, the safety studies initiated by USNRC (AEC before 1974) were first reviewed. The long story of these studies started in 1950 with the WASH-3 report which analyzed blast damages resulting from run away reactions as potential accidents in the existing reactors. It continued with the WASH-740 in 1957 where hazards from three scenarios of fission product releases were evaluated. These studies were followed by the development of siting criteria with the 10 CFR part 100 and by the development of the Environmental Impact Statement in continuation of the National Environmental Policy Act in 1969. The well known report WASH 1400 issued in the mid 70s was the first attempt of a Probabilistic Risk Assessment (PRA) approach which will be later extensively used. It was followed by the issue in 1991 of the as well known NUREG 1150 which evaluated severe accidents risks in five US nuclear plants.

At the same time, some events in the "nuclear life" occurred which influenced significantly the safety approach. Among these events the following were recalled:

- EBR 1 incident in 1955, SL1 accident in 1961, Browns Ferry and Salem events in the 80s which led progressively to the definition of a policy for reactivity accident.
- SEMISCALE test on ECCS in 1971 which prompted the conservative approach of 10 CFR 50 and Appendix K.
- The fire which occurred in Browns Ferry in 1975 and which initiated the discussion on fire safety requirements.
- TMI2 accident which caused a redistribution in safety analysis between large break LOCA design accidents which were before too much emphasized and beyond design basis events which were neglected.

In this historical context, USNRC defined and used some principles and methods for the evaluation of plant design. A review of them has been provided which included for example conservative deterministic engineering, defense in depth, analysis of the effectiveness of maintenance (introduced in 1991). From this review it came out that there was a need for regulators to accurately predict the expected plant behavior and that this requires consequently a good understanding of the physical phenomena and processes.

The second item developed in the paper was the development of the Commission's Safety Goals and the Severe Accident Policy Statement. The first issue of these two Policy Statements was done in 1983. It was followed by a second issue, in 1985, for the Severe Accident Policy and in

1986, for the Safety Goal. The role of Probabilistic Risk Assessment (PRA) in these statements has been discussed in detail and was shown as increasing with time.

As a logical result, on the basis of all the data and knowledge gained on risk, USNRC developed a risk information decision methodology. The different steps for introducing these risk informed processes have been discussed and some examples of applications have been detailed, such as the review of the next generation nuclear power plants, Advanced Boiling Water Reactor (ABWR) from GE, 80+ from ABB, AP 600 from Westinghouse.

These regulatory activities were supported by extensive research programs. The current related activities have been discussed. The main directions of research which have been reviewed covered the CAMP effort on thermalhydraulic codes, research on aging (vessel integrity, non destructive examination,...), steam generator integrity, containment structures testing, severe accident research, advanced thermalhydraulic codes development, high burnup fuel related research, digital instrumentation and control in plants, human performance.

In conclusion, this paper provided a broad and detailed view of the evolution which occurred in the regulatory practices in US. These practices which have been more or less followed by several countries can be considered as representative of the international environment where the subject of this seminar i.e. the use of Best Estimate methods in Thermalhydraulics Safety Analysis has been developed. The three following papers of session 1 gave indeed three examples in three countries (Canada, France and Germany) on how these developments have been and are being performed.

In Canada, the situation exhibits a developing role of best estimate (realistic) calculations, complemented with uncertainty evaluations. It has been explained that this role has raised from two main reasons. First, there are some unresolved safety issues with highly conservative methods for low frequency events where BE methods can be an alternative. Second, in some cases, it has been experienced that key phenomena, plant uncertainties and modeling uncertainties had proved to be far more important than originally estimated in the analyses, even though these analyses appeared to be very conservative. This is clearly not satisfying. Two trial applications of BE calculations have been presented, one on large LOCA on Bruce B reactors, the second on loss of flow events on Darlington reactors. The problems and lessons learnt from these trials have been discussed. They highlighted some key issues: a) potential complexity of the methodology, b) adequacy of the analytical techniques and code validation, c) combination of uncertainties, d) need for stronger tie between plant operation and analysis, e) degree of statistical rigor required, f) need for good quality documentation. In conclusion, realistic calculations are considered in Canada as useful potential alternatives or additions to old conservative methods, but more work appears required both on the regulator side for developing standards and on the research side for the development of realistic analysis method.

The next presentation showed that there was also in France a clear and increasing tendency in the licensing process, to use Best Estimate codes in the analysis of safety cases. In the overall safety evaluation which includes in France the analysis of the specific assumptions, the use of the code itself and the comparison with the safety criteria, some specific cases have been analyzed using the French Best Estimate code CATHARE. These cases have been described. They cover mainly some small and intermediate break studies and analyses of emergency procedures. The best estimate approach will certainly be generalized for the future reactor EPR. A more systematic approach for licensing will have then to be defined. In support to these trends in the safety analysis area, several research programs have been started in France. Presentation of these programs was given especially on the general studies of uncertainties evaluation methods (IPSN approach), the development of statistical tools, the evaluation of the uncertainties of elementary individual physical models. It came out that there was still a need in getting results from the research programs in order to perform complete practical application, even if several limited attempts in real cases have been performed. Consequently, it has been recognized that the use of Best Estimate methods in licensing in France was in an intermediate state and that this situation will certainly evolve greatly in the next years.

The last paper described the situation in Germany. Here, the practice in licensing is based on deterministic thermal hydraulic analyses which have to follow rules released by the federal ministry in charge of the safety of nuclear installations. In these rules, the guidelines concerning the assumptions for the calculations are providing some latitude, and especially it is accepted that alternative assumptions, models and correlations can be used if one can prove that safety is assured at least in an equivalent way. Therefore, from the beginning, German licensing practice contained simultaneously conservative and best estimate features. Due to the increasing availability of experimental data and due to the progress in modeling, more and more realistic calculations have been replacing the conservative approaches. These calculations should be supported mainly by an improved comprehensive validation of the codes. In parallel, methods for the quantification of uncertainties of calculated results were developed but are not yet introduced in the regulatory process. For the future reactors (EPR) recommendations have been stated, for the safety demonstration, in direction of the use of realistic assumptions and models. For Germany the prerequisite for such use will be a high standard of code validation, qualified users and a reliable quantification of uncertainties. It was explained that such quantification were under development both by the designer who is developing a method similar to CSAU, and by GRS which is completing a statistical method.

In conclusion of session 1, it was clear that the papers presented were certainly not covering the complete problem but that they represented a good introduction for the presentations which had to be given next during the several sessions of the seminar. In particular the historical view of regulatory practices which was presented allowed to get a perspective of future regulations and of the role of Best Estimate approaches. The three examples of attempts in using "Best Estimate methods" in licensing which were presented raised a number of questions which were all further discussed in more detail during the seminar. The general discussion after the session reflected well this introductory character. All the items discussed, as it has been confirmed later during the seminar, converged on the fact that progress was being made but that further work was still needed to finalize the practical application of "Best Estimate Methods" in licensing.

SESSION 2:
Overview of past and current CSNI TH activities Chairmen: Eltawila / Yesin

The first paper in this session was given by Mr. Réocreux and described the “Activities of Principal Working Group 2 on Coolant System Behaviour”. First, the mandate of PWG2 was described and put into context with the mission of the other working groups (Nos. 1,3,4 and 5). PWG2 focuses on in-vessel thermal-hydraulics during transients and accidents, core physics, fuel behaviour and core degradation during severe accidents. The main activities of PWG2 fall into four categories: 1) Providing a forum for technical exchange; 2) Review and synthesis of ongoing research (e.g. state-of-the-art reports); 3) Technical analysis (e.g. international standard problems and benchmarks); 4) Investigation of new areas. It was stressed that perhaps the most significant contributions have been in the ISPs and the development of the validation matrices. In particular, the ISPs provide a well documented (and archived) test that is invaluable for code development and assessment and lead to the identification of the importance of the user effects.

The second paper was given by Mr. N. Aksan and discussed “Best Estimate Codes and Use of ISPs in OECD Countries”. To date, there have been 41 ISPs and two more are being prepared (Boron dilution at the University of Maryland and Passive Cooling in the PANDA facility at PSI, Switzerland). The general objectives of the ISPs are to aid in the development of codes, documenting and archiving experiments of general interest, and improve code assessment. The use of BE codes is motivated by the needs to address scaling issues (requires real description of behaviour), to quantify conservatism, and determine real plant response for EOPs. The various types of ISPs were reviewed and their benefits to the host countries, the participants and to research managers described.

The third paper was presented by both Mr. N. Aksan and Mr. H. Glaeser and gave an “Overview of CSNI, SET and ITF Validation Matrices”. Originally, PWG2 focused on the development of the integral test facility matrix assuming that separate effects assessment would be adequately covered by the code development teams. When it became clear that this was not the case, PWG2 undertook the development of a SET verification matrix to: 1) Enable continuous comparison with SET data for developmental assessment; 2) Aid in uncertainty quantification; and 3) Address scaling issues. A description of the SET and ITF matrices was then given, showing the phenomena-facility cross-reference tables and examples of the facility information available in the CSNI reports.

The last paper in the session was given by Mr. J. Misak and discussed “Thermal-Hydraulic Activities in the IAEA”. The main emphasis was on the IAEA’s efforts to provide licensing guidelines for VVERs, RBMKs and to countries in the process of developing their licensing methodologies. The most discussion resulted from the proposal to use best-estimate codes for conservative calculations. In effect, abandoning the use of evaluation models and using BE codes with “conservative” input (e.g. initial conditions, availability or capability of safety systems, etc.).

This proposal evoked much commentary and the session naturally evolved into the discussion period. On the subject of using BE codes for conservative calculations, the opinions of the attendees were divided. Some strong objections were raised that this violated the philosophy of BE codes and that it would be difficult to decide how and to what extent one should maintain conservatism. Also, the question was raised concerning combinations of conservatism in a non-linear system. On the other hand, as was later evidenced in several presentations, both vendors, utilities and research institutes are pursuing conservative BE approaches. This group maintained that the use of realistic physical models was better than the Evaluation Model (EM) approach and provided an intelligent way to investigate conservatisms without the burden of performing a full CSAU-type uncertainty study.

As the discussion progressed, Mr. F. Eltawila redirected by posing the questions: ‘what are the T/H issues we face today? and what should be the CSNI PWG2 role in the future?”

It was generally agreed that phenomena identification was essentially done but that assessment was incomplete, that is, no code can adequately model all expected phenomena. For a list of code requirements it was suggested to refer to the summary of the Annapolis Meeting (1996).

SESSION 3

Part 1: BE methodologies and associated uncertainties Chairmen: Aksan / Glaeser

UK (Nuclear Electric, AEAT, NNC)

Status:
A licensing case was performed for the Sizewell Safety Case during the 80ies. Considered were bounding limiting design basis faults (less than 100 cases). Westinghouse conservative codes (e.g. LOFT-5 code) were used and some own developments were applied. DNB failures in frequent faults were investigated, statistical 95%/95% statements derived, and additional margins applied.

Future:
A need for „better estimate" thermal hydraulic codes was stated.

Germany, Siemens KWU

Status:
An application of a best estimate analysis plus uncertainty evaluation according to the Code Scaling Applicability, and Uncertainty Evaluation Methodology (CSAU) was presented. The bounding scenario (large break in the cold leg between pump and reactor vessel) was determined deterministically by sensitivity calculations. A statistical treatment was performed to evaluate the uncertainties of code, plant parameters and fuel. This is the first uncertainty evaluation in a licensing case for a reactor under construction.

Hungary, KFKI

Status:
In the frame of the AGNES project different initiating events are considered: DBA, PTS, ATWS. Pessimistic assumptions are applied to bound uncertainties from code model imperfections. Pessimistic moderator density reactivity coefficients were assumed. In addition, a loss of AC power at the occurrence of high cladding temperature was considered. After a review of these conservatism, the reactivity feedback was replaced by 3D reactor physics, the cladding gap conductance, and the engineering factor for the hot assembly was revised.

Future:
The USNRC and IAEA Guidelines for best estimate calculations plus uncertainty evaluation will be applied. However, no test data are available for large breaks in VVER reactors. An uncertainty analysis will be performed using the ATHLET code and the GRS uncertainty method for a pressuriser surge line break on the PMK test facility.

Canada, AECL

The CANDU reactor analysis was performed by conservative bounding in the past, and will move to best estimate analysis in the future. The best estimate codes and modules for such an analysis were presented. The treatment of uncertainties was topic of a later presentation in this Seminar (CSAU demonstration for the blowdown phase of a large LOCA on a CANDU reactor).

Spain, IBERDROLA

The utility perspective was presented.

Status:
Best estimate codes have been used since 1986. An intermediate approach between conservative Appendix K rules and uncertainty evaluation was discussed and applied for BWR transients. Best estimate codes are used, and 2σ values for some dominant variables and/ or additive terms are applied. Additional conservatism is introduced to cover variables not considered. For LOCA analyses in BWRs a relaxed Appendix K approach was applied.

Future:
For BWR LOCA analyses a CSAU based method will be applied, for transients a statistical method will be used.
PWR LOCA analyses will be performed using the intermediate approach, for transients the TRACTEBEL method (a bounding method) will be used, based on the intermediate approach.

Japan, TOSHIBA
Several performed BWR analyses were presented:
Stability
Abnormal transient
Reactivity initiated transient.

Status:
Best estimate codes are used to support the licensing analyses.

Future:
Aiming to use best estimate codes to upgrade the licensing analyses in the near future.

SESSION 3 - Part 2:
BE Methodologies and Associated Uncertainties **Chairmen:** **Krishnan / Toth**

Papers presented in this part of the session covered topics ranging from a description and comparison of uncertainty assessment (UA) methodologies to the application of BE methods to APWR, EPR, and containment analysis. The main points that emerged in the presentations can be summarized as follows:

- Some countries are doing BE analysis on a voluntary basis.
- BE methods have been applied in EPR's ECC system design optimization.
- BE methods have been applied to containment safety analysis.
- UA is a complex task. However, it is needed because approximations are made at every step of a BE analysis. It is therefore important to quantify the error or uncertainty in code calculation results.
- UA is necessary if useful conclusions are to be obtained from BE calculations.
- A structured approach is important in the integration of UA in code, representation and plant.

The following summarizes the highlights of the discussions and recommendations for the future:

Much progress has been made in BE analysis over the last 10 years, but it is not time yet to fully apply UA methodologies in the BE framework. Recent applications tend to quantify the uncertainties related to the most important parameters, while maintain a bounding approach for those having less influence on key parameters.

A number of rigorous UA methods are available. The challenge is to come up with a simplified method that can be used with confidence.

BE/UA should be restricted to design-basis accidents for now, until beyond-design-basis accident phenomena are well understood and codes can model them properly.

A full BE analysis may be considered in the future, but UA propagation between the various disciplines such as neutronics, thermalhydraulics, and containment must be accounted for properly.

SESSION 3:
BE Methodologies and Associated Uncertainties **Conclusions**

A move towards best estimate analysis in licensing is taking place. A best estimate code should predict the mean of the data (if available), rather than providing a bound to the data. The uncertainty of the calculation result in the specific application should be quantified. During this Seminar several best estimate code applications were presented but only a few uncertainty evaluations:

- 1 application of a statistical uncertainty analysis in a PWR licensing case (the first one) by a vendor (Siemens KWU, Germany);
- 1 demonstration application of the CSAU method to CANDU large break LOCA blowdown (AECL, Canada);
- 5 investigations performed in the OECD/CSNI Uncertainty Methods Study:
  - 1 extrapolation of accuracy (University of Pisa, Italy),
  - 1 bounding parameter uncertainties (AEA Technology, UK),
  - 3 statistical methods (GRS, Germany; IPSN, France; ENUSA, Spain);
- 1 investigation is under way for a PMK-2 experiment using the ATHLET computer code and the GRS Method (KFKI/ GRS, Hungary/ Germany).

Some participants prefer a bounding approach by using best estimate codes with conservative parameter values to evaluate the margin to licensing limits without a detailed uncertainty analysis. This consideration is based on their perception of cost-effectiveness. A statistical uncertainty evaluation is considered as time consuming, and a requirement to perform a statistical evaluation of uncertainties may discourage people to use best estimate codes [Y. Kukita, Japan]. However, if a licensing case is performed according to USNRC rules either a conservative analysis applying Appendix K rules has to be undertaken, or a 95% (or more) probability statement has to be provided that the licensing limits are not exceeded.

A disadvantage of applying Appendix K regulation is that the high level of code validation can not be utilised. The conservative approach is often not reflecting the physical behaviour. Also, conservative assumptions may not always lead to conservative results (for small and intermediate breaks). For example, the conservative increase of reactor power may lead to an overprediction of the swell level in the core. The resulting overprediction of cooling would be opposite to the intended conservative result.

Bounding by conservative values on a few dominant input parameters needs a demonstration of an overall conservatism on the target calculational result (maximum cladding temperature, for example). It has also to be checked that the dominant input parameters cover the contribution of other neglected input parameters. This needs to compare the results with an appropriate experimental basis and to perform sensitivity calculations.

An advantage of statistical methods is to evaluate the effect of variations of relevant parameter values and their combinations over the whole transient of an accident scenario.

The common difficulty for a bounding analysis (using best estimate codes) as well as for an uncertainty analysis is the specification of values for uncertain input parameters. This may be the bounding value, the uncertainty range or the probability distribution of an uncertain input parameter. Both, the Siemens-KWU and University of Pisa methods evaluate the code uncertainty by determining the accuracy of the calculation result compared with several similar experiments investigating the same accident scenario. Therefore, these methods need not to specify uncertain values for input parameters representing code models. Uncertainties due to scale effects are claimed to be included. The ranges or biases for uncertainties of plant conditions and fuel related parameters, however, have still to be specified (this has not yet been demonstrated for the University of Pisa Method). It was shown during the Seminar, that, in a large break scenario, the uncertainties of fuel parameters turned out to have the biggest influence.

In recent licensing cases the licensing authorities require that the uncertainty of calculation results is quantified instead of performing a conservative analysis according to Appendix K rules. It is up to the utility (or to the vendor because licensing analyses are very often contracted to the vendor) to provide an adequate evaluation of uncertainties. The first uncertainty analysis performed in the frame of a licensing case has been presented by Siemens-KWU during this Seminar.

A detailed uncertainty analysis, however, may not be necessary for results which are far from the safety limits. For these cases the distance of results from the safety limit should be clearly higher than usual uncertainty ranges, or higher than results of sensitivity calculations investigating important input parameters as well as initial and boundary conditions.

SESSION 4:
Selected Issues of TH Safety Analyses **Chairmen:** **D'Auria / Speis**

Seven papers are part of the Session dealing with different topics or problems to be solved in relation to the application of Best Estimate Codes in the Licensing Process.

The first two papers (authors A. Tanrikut and H.R. Choi, respectively) deal with typical examples of applications of system codes to the safety analysis of NPP or to the design of new reactors. Basically, the achievement of a suitable level of maturity of the adopted codes (or code versions) is recognized: the codes can be reliably used for the fixed purposes.

Two papers in the session (presented by G. Geffraye/J. Kelly and R. Kyrki-Rajamaki: actually, the first two authors of the same paper discussed the experience gained in France and USA, respectively) deal with the problem of coupling neutronic and thermalhydraulic codes; the importance of the coupling 3-D kinetics with 1-D or 3-D system thermalhydraulics codes was outlined as well as the difficulties currently being encountered.

One paper (presented by J. Kelly) deals with the problem of applicability of current codes to new generation reactors where driving forces and velocities may be very small; consequently, some physical model (or constitutive equations) can be inadequate. The author showed, as an example, substantial improvements in predicted break flow when changing the two phase critical flow model; the applicability, in the sense of produced accuracy, of the new approach to all situations of interest may still be under discussion.

A stimulating lecture was presented by T. Speis covering an historical overview of regulatory requirements based on operational experience and occurred events. In particular, the feedback of TMI and Chernobyl accidents upon the regulatory views and the licensing needs was discussed, together with the consideration of severe accident in the PSA (Probabilistic Safety Assessment) and in the licensing process itself.

A fundamental and provocative question was put by the author, dealing with the limits of a pure theoretical PSA approach: “Can the containment system be avoided if core damage frequency is calculated to be 10^{-7}?”. The answer is clearly NO.

The last paper (presented by R. Kirmse) dealt with the discussion of the current status of the French-German common approach in relation to licensing. The difficulties in homogenising the interpretation of safety requirements was outlined. However, the activity, still in progress, aims at a deep re-evaluation of the safety principles with the general objective of a reduction of the core melt frequency; among the specific objectives (just examples are reported here), there are the elimination from the current PSA sequences, of accident situations which could lead to large early releases of radioactive materials, and the need of emergency evacuation from the immediate vicinity of the plant when low pressure core melt situation should occur.

SESSION 5: Final discussion **Chairman: Reocreux / Aksan**

In this session, the discussions and reactions from the host country participants indicated that this Seminar was a very valuable and interesting meeting with a collection of papers reflecting the state of the art for the use of the best-estimate methods in thermal-hydraulics analysis and also neighboring subjects, e.g., neutronics, containment, PRA and severe accidents. They have now better appreciation of what needs to be done, if they go for nuclear power in the future. They also stressed the importance of having an access to various information and experimental data through participation in CSNI-PWG2 activities and hope to be more active in the future.

Discussions show that there is a very strong need to use better-estimate codes instead of conservative codes in licensing. Presently, some countries prefer bounding approach by using best-estimate codes with conservative parameter values, conservative boundary and initial condition assumptions to evaluate the margin to licensing limits. This is done without the use of a detailed uncertainty evaluation analysis, due to cost effectiveness considerations and time requirements for the necessary analysis. In this sense, existing uncertainty methods are found to be useful but there is a strong need to apply to different transient types. Since the uncertainty methods which have been developed are very rigorous, the challenge is to come up with simplified method which can be used with confidence in licensing process. A full best-estimate approach with uncertainty analysis may be considered in the future In addition, there is a transfer of uncertainties when computer codes are coupled from different disciplines, e.g., thermal-hydraulics, neutronics, and containment codes. These "transfer of uncertainties" are known,but the problem is not addressed in detail, presently.

OECD/CSNI SEMINAR ON
BEST ESTIMATE METHODS IN THERMAL HYDRAULIC ANALYSIS

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