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INTERNATIONAL TRAINING PROGRAM IN SUPPORT OF SAFETY ANALYSIS: 3D S.UN.COP - SCALING, UNCERTAINTY AND 3D THERMAL-HYDRAULICS/NEUTRON-KINETICS COUPLED CODES SEMINARS

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Abstract – *Thermal-hydraulic system computer codes are extensively used worldwide for analysis of nuclear facilities by utilities, regulatory bodies, nuclear power plant designers and vendors, nuclear fuel companies, research organizations, consulting companies, and technical support organizations. The computer code user represents a source of uncertainty that can influence the results of system code calculations. This influence is commonly known as the 'user effect' and stems from the limitations embedded in the codes as well as from the limited capability of the analysts to use the codes. Code user training and qualification is an effective means for reducing the variation of results caused by the application of the codes by different users. This paper describes a systematic approach to training code users who, upon completion of the training, should be able to perform calculations making the best possible use of the capabilities of best estimate codes. In other words, the program aims at contributing towards solving the problem of user effect. The 3D S.UN.COP (Scaling, Uncertainty and 3D COuPled code calculations) seminars have been organized as follow-up of the proposal to IAEA for the Permanent Training Course for System Code Users. Eleven seminars have been held at University of Pisa (two in 2004), at The Pennsylvania State University (2004), at the University of Zagreb (2005), at the School of Industrial Engineering of Barcelona (January-February 2006), in Buenos Aires, Argentina (October 2006), requested by Autoridad Regulatoria Nuclear (ARN), Nucleoelectrica Argentina S.A (NA-SA) and Comisión Nacional de Energía Atómica (CNEA), at the College Station, Texas A&M, (January-February 2007), in Hamilton and Niagara Falls, Ontario (October 2007) requested by Atomic Energy Canada Limited (AECL), Canadian Nuclear Society (CNS) and Canadian Nuclear Safety Commission (CNSC), in Petten, The Netherlands (October 2008) in cooperation with the Institute of Energy of the Joint Research Center of the European Commission (IE-JRC-EC), at the Royal Institute of Technology, Stockholm (October 2009) and in Petten, The Netherlands (October 2010) in cooperation with the Institute of Energy of the Joint Research Center of the European Commission (IE-JRC-EC). It was recognized that such courses represented both a source of continuing education for current code users and a mean for current code users to enter the formal training structure of a proposed 'permanent' stepwise approach to user training. The 3D S.UN.COP 2010 at IE-JRC was successfully held with the attendance of 23 participants coming from more than 10 countries and 20 different institutions (universities, vendors and national laboratories). More than 30 scientists (coming from more than 10 countries and 20 different institutions) were involved in the organization of the seminar, presenting theoretical aspects of the proposed methodologies and holding the training and the final examination. A certificate (LA Code User grade) was released to participants that successfully solved the assigned problems. The eleventh seminar has been held (March 2011) in Wilmington, North Carolina, involving more than 30 scientists between lecturers and code developers (http://www.nrgspg.ing.unipi.it/3dsuncop/).*

I. INTRODUCTION

The best estimate thermal-hydraulic codes used in the area of nuclear reactor safety have reached a marked level of sophistication. Their capabilities to predict accidents and transients at existing plants have substantially improved over the past years as a result of large research efforts and can be considered satisfactory for practical needs provided that they are used by competent analysts.

Some recognized inadequacies in code calculation results are due to the limitations embedded in the codes. These range from some model deficiencies to approximation in the numeric solution. The transformation of the actual reference system geometry into an approximate noding scheme constitutes an additional limitation. Nodalization imperfections, insufficient knowledge of initial and boundary conditions, and 'user effects' add to the limitations of the code prediction. User effects [2] lie at the origin of most of the inaccuracies for the following reasons:

- Fully detailed, comprehensive code user guidelines do not exist.
- The actual (three dimensional) plant is modeled with several one dimensional approximations.
- Engineering knowledge has to be applied in the preparation of the input deck in order to deal with some of the code limitations.
- Certain problems are inherent in the approaches used in the modeling process such as: use of local pressure drop coefficients, critical flowrate multipliers, application to transient conditions of models qualified for steady state, application of the fully developed flow concept for different nuclear reactor conditions, etc.
- The fact that an increasing number of users without adequate qualification have access to the system codes and nodalizations may produce diverging results and lead to the diffusion of erroneous evaluations.
- Experimental data, including the values of initial and boundary conditions that are used as a basis for comparisons are, in the large majority of cases, supplied without error bands.
- Clear criteria for the acceptability of the results have not been agreed upon among experts in the area.

A wide range of activities have recently been completed in the area of system thermal-hydraulics as a follow-up to considerable research efforts. Problems have been addressed, solutions to which have been at least partly agreed upon on international ground. These include: the need for best-estimate system codes [3] and [4], the general code qualification process [5] and [6], the proposal for nodalization qualification and attempts aiming at qualitative and quantitative accuracy evaluations [7]. Complex uncertainty methods have been proposed, following a pioneering study at USNRC [8]. This study attempted, among other things, to account for user effects on code results. An international study aiming at the comparison of assumptions and results of code uncertainty methodologies has been completed [9]. More recently, the IAEA developed a Safety Report on Accident Analysis of Nuclear Power Plants containing a set of practical suggestions based on best practice worldwide [10].

II. IAEA SAFETY REPORT ON ACCIDENT ANALYSIS

During the period 1997-1999, the IAEA developed a document consistent with its revised Nuclear Safety Standards Series [10] that provides guidance on accident analysis of nuclear power plants (NPPs). The report includes a number of practical suggestions on the manner in which to perform accident analysis of NPPs. These cover the selection of initiating events, acceptance criteria, computer codes, modeling assumptions, the preparation of input, qualification of users, presentation of results, and quality assurance (QA). The suggestions are both conceptual as well as formal and are based on present practice worldwide for performing accident analysis. The report covers all major steps in performing analyses and is intended primarily for code users.

Within the framework of the IAEA guidance the important role of the user effects on the analysis is addressed. The need for user qualification and training is clearly recognized. The systematic training of analysts is emphasized as being crucial for the quality of the analysis results. Three areas of training, in particular, are specified:

- practical training on the design and operation of the plant;
- software specific training; and
- application specific training.

Training on the phenomena and methodologies is typically provided at the university level, but cannot always be considered as sufficient. Furthermore, training on the specific application of system codes is not usually provided at this level. Practical training on the design and operation of the plant is, however, essential for the development of the plant models. Software specific training is important for the effective use of the individual code. Application specific training requires the involvement of a strong support group that shares its experience with the trainees and provides careful supervision and review.

Training at all three levels ending with examination is encouraged for a better effectiveness of the training. Such a procedure is considered as a step in the direction of establishing a standard approach that could be applicable on an international basis.

A significant number of the suggestions made by the IAEA relate to the preparation of input decks and to the collection of the relevant plant data as well as to the presentation and evaluation of the results and to QA. In addition, the report specifies a procedure for performing accident analysis that covers all important steps needed for this task.

III. CODE USERS

Best estimate codes are used by designer/vendors of NPPs, by utilities, licensing authorities, research organizations including universities, nuclear fuel companies, and by technical support organizations. The objectives of using the codes may be quite different, ranging from design or safety assessment to simply understanding the transient behavior of a simple system. In view of the current computing capabilities, a system code (e.g. RELAP, TRAC, CATHARE, or ATHLET) can be put into operation in a few days. In the same time span, results can be obtained for a complex system provided that there is a nodalization available. An unqualified input deck related to a complex system such as an NPP can be set up in time periods of a few weeks using the available code manuals. However, these periods can be shortened if the analyst is a 'qualified' code user. Qualified code user groups already exist; scientists who have been working with system codes for more than thirty years belong to such groups.

The most sensitive use of the code deals with situations in which the results obtained have an effect on the design or safety assessment of the NPP. In this context, the code validation process, nodalization qualification, qualitative or quantitative accuracy evaluation, and the use of the code by a qualified code user have been recognized as necessary steps to reduce the possibility of producing poor code predictions [11].

IV. PERMANENT USER TRAINING COURSE FOR SYSTEM CODE: THE PROPOSAL

As a follow-up to the Specialists Meeting held at the IAEA in September 1998, the Universities of Pisa and Zagreb and the Jožef Stefan Institute, Ljubljana, jointly presented a Proposal to IAEA for the Permanent Training Course for System Code Users [1]. It was recognized that such a course would represent both a source of continuing education for current code users and a means for current code users to enter the formal training structure of a proposed 'permanent' stepwise approach to user training.

Before finalizing the main outcomes in relation to the proposed user training, the following can be emphasized:

- the user gives a contribution to the overall uncertainty that unavoidably characterizes system code calculation results;
- in the majority of cases, it is impossible to distinguish among uncertainty sources like 'user effect', 'nodalization inadequacy', 'physical model deficiencies', 'uncertainty in boundary or initial conditions', 'computer/compiler effect';
- 'reducing the user effect' or 'finding the optimum nodalization' should not be regarded as a process that removes the need to assess the uncertainty;
- in general, it is misleading to prepare guidelines that focus codes predictions into a narrow part of the uncertainty.

As a follow up of the massive work conducted in different Organizations, the need was felt to fix criteria for training the code user. As a first step, the kind of code user and the level of responsibility of a calculation result should be discussed.

IV.A. Levels of User Qualification

Two main levels for code user qualification are distinguished in the following:

- Code user, level "A" (LA);
- Responsible of the calculation results, level "B" (LB).

A Senior grade level should be considered for the LB code user (LBS). Requisites are detailed hereafter for the LA grade only; these must be intended as a necessary step (in the future) to achieve the LB and the LBS grades. The main difference between LA and LB lies in the documented experience with the use of a system code; for the LB and the LBS grades, this can be fixed in 5 and 10 years, respectively, after achieving the LA grade. In such a context, any calculation having an impact in the sense previously defined must be approved by a LB (or LBS) code user and performed by a different LA or LB (or LBS) code user.

IV.B. Requisites for Code User Qualification

IV.B.1 LA code user grade

The identification of the requisites for a qualified code user derives from the areas and the steps concerned with a qualified system code calculation: a system code is one of the (four) codes previously defined and a qualified calculation in principle includes the uncertainty analysis. The starting condition for LA code user is a scientist with generic knowledge of nuclear power plants and reactor thermalhydraulics (e.g. in possession of the master degree in US, of the 'Laurea' in Italy, etc.).

Areas for code user qualification: The requisites for the LA grade code user are in the following areas:
A) Generic code development and assessment processes;
B) Specific code structure;
C) Code use -Fundamental Problems (FP);
D) Code use -Basic Experiments (BETF);
E) Code use -Separate Effect Test Facilities (SETF);
F) Code use -Integral Test Facilities (ITF);
G) Code use -Nuclear Power Plant transient Data
H) Uncertainty Methods including concepts like nodalization, accuracy quantification, user effects.

<u>Area A)</u>

Sub-area Al): Conservation (or balance) equations in thermalhydraulics including definitions like HEM/EVET, UVUT(UP), Drift Flux, lD, 3-D, 1-field, Multi-field, [4]. Conduction and radiation heat transfer. Neutron Transport Theory and Neutron Kinetics approximation. Constitutive (closure) equations including convection heat transfer. Special Components (e.g. pump, separator). Material properties. Simulation of nuclear plant and BoP related control systems. Numerical methods. General structure of a system code.

Sub-area A2): Developmental Assessment. Independent Assessment including SET Code Validation Matrix, [5], and Integral Test Code Validation Matrix, [6]. Examples of specific Code validation Matrices.

<u>Area B)</u>

Sub-area Bl): Structure of the system code selected by the LA code user: thermalhydraulics, neutronics, control system, special components, material properties, numerical solution.

Sub-area B2): Structure of the input deck; examples of user choices.

Area C)

Sub-area C1): Definition of Fundamental Problem (FP): simple problems for which analytical solution may be available or less. Examples of code results from applications to FP; different areas of the code must be concerned (e.g. neutronics, thermalhydraulics, and numerics).

Sub-area C2): The LA code user must deeply analyze[1] at least three specified FPs, searching for and characterizing the effects of nodalization details, time step selection and other code-specific features.

Area D)

Sub-area Dl): Definition of Basic test facilities and related experiments (BETF): researches aiming at the characterization of an individual phenomenon or of an individual quantity appearing in the code implemented equations, not necessarily connected with the NPP. Examples of code results from applications to BETF.

Sub-area D2): The LA code user must deeply analyze[1] at least two selected BETF, searching for and characterizing the effects of nodalization details, time step selection, error in boundary and initial conditions, and other code-specific features.

Area E)

Sub-area El): Definition of Separate Effect Test Facility (SETF): test facility where a component (or an ensemble of components) or a phenomenon (or an ensemble of phenomena) of the reference NPP is simulated. Details about scaling laws and design criteria. Examples of code results from applications to SETF.

Sub-area E2): The LA code user must deeply analyze[1] at least one specified SETF experiment, searching for and characterizing the effects of nodalization details, time step selection, errors in boundary and initial conditions and other code-specific features.

Area F)

Sub-area Fl): Definition of Integral Test Facility (ITF): test facility where the transient behavior of the entire NPP is addressed. Details about scaling laws and design criteria. Details about existing (or dismantled) ITF and related experimental programs. ISPs activity. Examples of code results from applications to ITF.

Sub-area F2): The LA code user must deeply analyze[1] at least two specified ITF experiments, searching for and characterizing the effects of nodalization details, time step selection, errors in boundary and initial conditions and other code-specific features.

Area G)

Sub-area Gl): Description of the concerned NPP and of the relevant (to the concerned NPPD and calculation) BoP and ECC systems. Examples of code results from applications to NPPD.

Sub-area G2): The LA code user must deeply analyze[1] at least two specified NPP transients, searching for and characterizing the effects of nodalization details, time step selection, errors in boundary and initial conditions and other code-specific features.

Area H)

Description of the available uncertainty methodologies. The LA code user must be aware of the state of the art in this field.

IV.B.2 LB code user grade

A qualified user at the LB grade must be in possession of the same expertise as the LA grade and:

I) he must have a documented experience in the use of system codes of at least 5 additional years;

J) he must know the fundamentals of Reactor Safety and Operation- and Design having generic expertise in the area of application of the concerned calculation;

K) he must be aware of the use and of the consequences of the calculation results; this may imply the knowledge of the licensing process.

IV.B.3 LBS code user grade

A qualified user at the LBS grade must be in possession of the same expertise as the LB grade and:

L) he must have an additional documented experience in the use of system codes of at least 5 additional years.

IV.C. Modalities for the achievements of the LA, LB and LBS Code User grades

LA grade: Two years training and "Home Work" with modalities defined in Table 1, are necessary to achieve the LA grade, following an examination.

LB grade: The steps and the time schedule needed to achieve the LB code user grade are summarized in Tab. 1. An examination is needed (5 years after the LA grade).

LBS grade: The steps and the time schedule needed to achieve the LBS code user grade are summarized in Tab. 1. The LBS code use grade can be obtained (5 years after achieving the LB grade) following the demonstration of performed activity in the 5 years period.

IV.D. Course Conduct

The training of the code user requires the conduct of lectures, practical on-site exercises, homework, and examination while, for the senior code user, only a review of documented experience and on-site examination is foreseen.

The code user training, including practical exercises, which represent an essential part of the course, lasts two years and covers the following areas:

A) Generic code development and assessment processes:

- general structure of a system code;
- conservation (or balance) equations in thermal-hydraulics;

[1] - to develop a nodalization starting from a supplied data base or problem specifications;
- to run a reference test case;
- to compare the results of the reference test case with data (experimental data, results of other codes, analytical solution), if available;
- to run sensitivity calculations;
- to produce a comprehensive calculation report (having an assigned format).

- conduction and radiation heat transfer;
- neutron transport theory and neutron kinetics approximation;
- constitutive (closure) equations including convection heat transfer;
- special components (e.g. pump, separator);
- material properties;
- constitutive (closure) equations including convection heat transfer;
- special components (e.g. pump, separator);
- material properties;
- simulation of NPP and balance of plant (BoP) related control systems;
- numerical methods;
- developmental assessment;
- independent assessment including the separate effect test code validation matrix [5], and integral test code validation matrix [6]; and
- examples of specific code validation matrices.

B) Specific code structure:
- structure of a system code selected by the code user: thermal-hydraulics, neutronics, control system, special components, material properties, and numerical solution; and
- structure of the input deck, examples of user options.

C) Fundamental problems or simple problems for which analytical solution may be available:
- definition of fundamental problems; and
- examples of code results from applications involving different areas of the code concerned (e.g. neutronics, thermal-hydraulics, numerics).

D) Basic test facilities and related experiments for the characterization of an individual phenomenon or of an individual quantity appearing in the code equations.

E) SETFs where a component (or an ensemble of components) or a phenomenon (or an ensemble of phenomena) of the reference NPP is simulated:
- details of scaling laws and design criteria; and
- examples of code results from applications.

F) ITFs where the transient behavior of the entire NPP is addressed:
- details of scaling laws and design criteria; and
- details of ITFs and related experimental programs;
- International Standard Problem activity; and
- an example of code results from applications to ITFs.

G) Applications to nuclear power plants:
- description of the NPP concerned and of the relevant BoP system and emergency core cooling system;
- an example of code results from applications to an NPP;
- practical exercises in the use of the code for NPP accident analysis highlighting the detection of errors in boundary and initial conditions and other code specific features;
- use of NPP simulators/analyzers.

H) Uncertainty methods including accuracy quantification:
- description of the available uncertainty methodologies; and
- state of the art and future prospects in this field.

In addition to the aforementioned areas, senior code user training also covers:

I) The use of accident analysis in reactor design and safety assessment.

J) Effects of analysis results on the licensing process.

IV.E. Training Exercises

Practical exercises foreseen during the training include development of the nodalization from the pre-prepared database with problem specifications. To this end, didactic material and presentations/lectures on the exercise will be provided with a detailed explanation of the objectives of the work that the trainee must perform. Extensive application of the code by the trainee at his own institution following detailed recommendations and under the supervision of the course lecturers is foreseen as ‘homework’. The use of the code at the course venue is foreseen for the following applications:

- fundamental problems including nodalization development;
- basic test facilities and related experiments including nodalization development;
- SETFs and related experiments including nodalization development;
- ITF experiments with nodalization modifications; and
- NPP transients including nodalization modifications.

For each of the above cases, the trainee will be required to:

1. develop (or modify) a nodalization starting from the database or problem specifications provided;
2. run the reference test case;
3. compare the results of the reference test case with data (experimental data, results of other codes, analytical solution);
4. run sensitivity calculations;
5. produce a comprehensive calculation report following a prescribed format whereby the report should include, for example:
   - the description of a particular facility;
   - the description of an experiment (including relevance to scaling and relevance to safety);
   - modalities for developing (or modifying) the nodalization;
   - the description and use of nodalization qualification criteria for steady state and transient calculations;
   - qualitative and quantitative accuracy evaluation;
   - use of thresholds for the acceptability of results for the reference case;
   - planning and analysis of the sensitivity runs; and
   - an overall evaluation of the activity (code capabilities, nodalization adequacy, scaling, impact of the results on the safety and the design of NPP, etc.).

TABLE 1

Subjects and time schedule necessary for the LA Code user grade

Code User Grade	WEEKS	LECTURES	SPECIF FOR HOME-WORK	HOME-WORK	ON-SITE TEST
LA	1-2	A1, A2^, B1, B2^, C1, D1			
	3		C2, D2		
	4-25			A, B, C2*, D2*	
	26				A1, B1, C, D, C2°, D2°
	27	A2, E1	E2		
	28-50			E2*	
	51				A2, E, E2°
	52	B2, F1	F2		
	53 -76			F2*	
	77				B2, F, F2°
	78	H, G1	G2*		
	79-102			G2*	
	103				G, H, G2*
LB (5 yrs after LA)	1				I*, J, K, K°
LBS (5 yrs after LB)	1				L*

^ Fundamental, * Report necessary, ° Solution of submitted problems and discussion

IV.F. Examination

On-site examination at different stages during the course is considered a condition for the successful completion of the code user training. The homework that the candidate must complete before attempting the on-site examination includes:

A) Studying the material/documents supplied by the course organizers.
B) Solving the problems assigned by the course organizers. This also involves the preparation of suitable reports that must be approved by the course organizers.

The on-site tests consist of four main steps that include the evaluation of the reports prepared by the candidate, answering questions on the reports and course subjects and demonstrating the capability to work with the selected code. Each step must be accomplished before proceeding to the subsequent one.The completion of all the steps of the examination requires that the candidate spend one full week at the course venue

V. 3D S.UN.COP SEMINARS: FOLLOW-UP OF THE PROPOSAL

V.A. Background Information about 3D SUNCOP Trainings

The 3D S.UN.COP (*Scaling, Uncertainty and 3D COuPled code calculations*) training aims to transfer competence, knowledge and experience from recognized international experts in the area of scaling, uncertainty and 3D coupled code calculations in nuclear reactor safety technology to analysts with a suitable background in nuclear technology.

The training is open to research organizations, companies, vendors, industry, academic institutions, regulatory authorities, national laboratories, etc. The seminar is in general subdivided into three parts and participants may choose to attend a one-, two- or three-week course. The first week is dedicated to the background information including the theoretical bases for the proposed methodologies; the second week is devoted to the practical application of the methodologies and to the hands-on training on numerical codes; the third week is dedicated to the user qualification problem through the hands-on training for advanced user and include a final exam. From the point of view of the conduct of the training, the weeks are characterized by lectures, code-expert teaching and by hands-on-application. More than thirty scientists (including the organizers and the external lecturers) are in general involved in the organization of the seminars, presenting theoretical aspects of the proposed methodologies and holding the training and the final examination. A certificate of qualified code user is released to participants that successfully solve the assigned problems during the exams.

The framework in which the 3D S.UN.COP seminars have been designed may be derived from Figure 1, where the roles of two main international institutions (OECD and IAEA) and of the US NRC (and the regulatory bodies of other countries) in order to address the problem of user effect are outlined together with the proposed programs and produced documents. Figure 2 depicts how the 3D S.UN.COP ensures the nuclear technology maintenance and advancements through the qualification of personnel in regulatory bodies, research activities and industries by mean of teaching of very well known scientists belonging to the same type of institutions.

At present, three institutions are planning and managing the 3D SUNCOP: 1- the Department of Mechanical, Nuclear and Production Engineering (DIMNP) of the University of Pisa, Italy (UNIPI, *the group was the pioneer in the organization of the initial 3D SUNCOP trainings*), 2-the group of Dynamic Analysis of Energy Systems of the Department of Physics and Nuclear Engineering, Technical University of Catalonia (UPC), at the premises of the School of Industrial Engineering of Barcelona, Spain (ETSEIB), and 3- the Department of Power Systems (ZVNE) of the Faculty of Electrical Engineering and Computing of Zagreb, Croatia (FER), University of Zagreb (UNIZG).

Eleven Training Courses have been organized up to now and were successfully held at:

- The University of Pisa (Pisa, Italy), 5 – 9 January 2004 (6 participants);
- The Pennsylvania State University (University Park, PA, USA), 24 – 28 May 2004 (15 participants);
- The University of Pisa (Pisa, Italy), 14 – 18 June 2004 (11 participants);
- The University of Zagreb (Zagreb, Croatia), 20 June – 8 July 2005 (19 participants);
- The Polytechnic University of Catalonia (Barcelona, Spain), 23 January – 10 February 2006 (33 participants);
- The Autoridad Regulatoria Nuclear (ARN), the Comisión Nacional de Energía Atómica (CNEA), the Nucleoelectrica Argentina S.A (NA-SA) and the Universidad Argentina De la Empresa (Buenos Aires, Argentina), 2 October – 14 October 2006 (37 participants);
- The Texas A&M University (College Station, Texas, USA), 22 January – 9 February 2007 (26 participants);
- The Hamilton & Niagara Falls, Ontario, Canada (2007), 8 October – 26 October (33 participants);
- The IE-FRC Petten & Alkmaar, (Amsterdam, Netherlands) 13 October – 31 October 2008 (35 participants);
- The Royals Institute of Technology (Stockholm, Sweden) 12 October – 30 October 2009 (38 participants)
- The IE-JRC Petten (Netherlands) 18 October – 5 November 2010 (23 participants)

V.B. Objectives and Features of the 3D S.UN.COP Seminar Trainings

The main objective of the seminar activity was the training in safety analysis of analysts with a suitable background in nuclear technology. The training was devoted to the promotion and use of international guidance and to homogenize the approach to the use of computer codes for accident analysis. Between the main objectives are:

- To transfer knowledge and expertise in Uncertainty Methodologies, Thermal-Hydraulics System Code and 3D Coupled Code Applications;
- To diffuse the use of international guidance;
- To homogenize the approach in the use of computer codes (like RELAP, TRACE, CATHARE, ATHLET, CATHENA, PARC, RELAP/SCDAP, MELCOR, IMPACT) for accident analysis;
- To disseminate the use of standard procedures for qualifying thermal-hydraulic system code calculation (e.g. through the application of the UMAE <Uncertainty Methodology based on Accuracy Extrapolation> [12]);
- To promote Best Estimate Plus Uncertainty (BEPU) methodologies in thermal-hydraulic accident analysis through the presentation of the current industrial applications and the description of the theoretical aspects of the deterministic and statistical uncertainty methods as well as the method based upon the propagation of output errors (called CIAU <Code with the capability of Internal Assessment of Uncertainty> [13, 14]);
- To spread available-robust approaches based on BEPU methodology in Licensing Process;
- To address and reduce User Effects;
- To realize a meeting point for exchanges of ideas among the worlds of Academy, Research Laboratories, Industry, Regulatory Authorities and International Institutions.

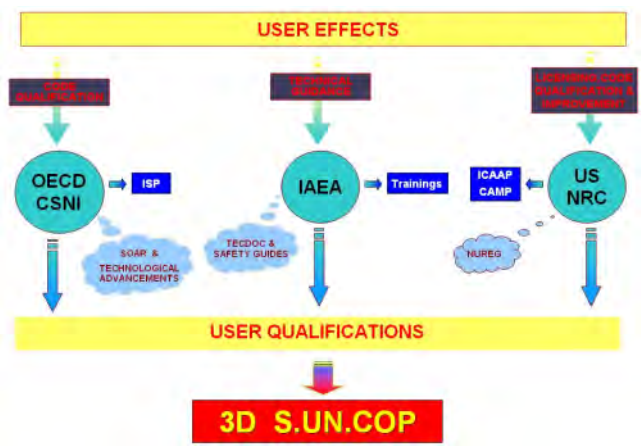

Fig. 1. 3D S.UN.COP Framework to address the user effect problem.

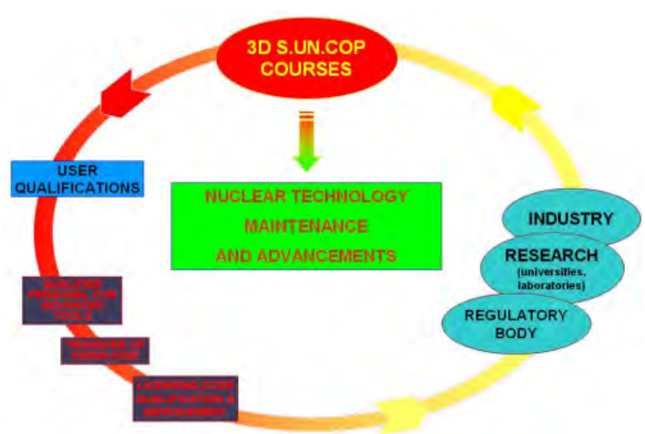

Fig. 2. 3D S.UN.COP Loop of benefits.

Other two fundamental goals to achieve are:

- *To ensure of a suitable Quality Assurance (QA) for the training*. Higher Education in Europe is nowadays involved in a process of change as focus has to be set on the student's workload and on his significant learning. This is a wide subject with many implications that are leading to important changes. Different initiatives have been already carried out in many European universities looking for this new approach in teaching organization and in the methodology used. Some essential aspects to be taken into account are the definition of the learning objectives and results, the planning of activities necessary to reach these objectives, the use of active learning methodologies (cooperative learning, problem-based learning) and the use of continuous learning measurement. To fulfil this main goal, some other objectives have been established:
  - To ensure the teaching quality at the following levels
  - To ensure an adequate learning measurement
  - To establish a procedure for admission of participants
  - To ensure adequacy of teachers
  - To consider the tools for preserving the knowledge
  - To follow the international developments
- *The connection with EC objectives and framework.* To connect the 3D SUNCOP training with EC objectives and framework. This includes:
  - Experience and dissemination from past and present EC projects which have links with the 3D SUNCOP training subjects (CRISSUE-S, VALCO, CERTA…)
  - Consideration of key results of EC Framework Programs.
  - Consideration of transfer of knowledge inside EC TACIS and Phare projects.
  - Consideration of any individual EC program that may have any connection with the 3D SUNCOP subjects.
  - Consideration of ENEN network initiatives.
  - Consideration of (new) relevant political areas for the EC.
  - To establish a permanent contact with EC offices (Bruxelles, JRC, etc...)

The following main features of the seminar-course may be identified and outlined:

- *The idea of practical use of the code*: a course without practical code application has (much) lower validity.
- *The idea to mix different codes*: the use of different code is worthwhile also to establish a common basis for code assessment and for the acceptability of code results.
- *The need of exam*: exams were in the past courses (very) well accepted by code users. The exam gave them the possibility to show their expertise and to demonstrate the effort done during the course.
- *The practical use of procedures for nodalisation qualification* that can be directly applied in the participants institutions.
- *The practical use of procedures for accuracy quantification* that are demonstrated at the qualitative and the quantitative level.
- *The "joining" between BE codes and uncertainty evaluation* that shows the full application of uncertainty methodologies and the worth of these within a licensing process.
- The establishment, promotion and use of international guidance through *large participation of very well known international experts*

V.C. 3D S.UN.COP Training Structure

The seminar is subdivided into three main parts, each of one with a program to be developed in one week. The changes between lectures, computer work and model discussion showed up useful to maintain a steady high level of participant's attendance. The duration of the individual sessions varied substantially according to the complexity of the subjects and the training needs of the participants:

- The first week (titled "Fundamental Theoretical Aspects") is fully dedicated to lectures describing the concepts of the proposed methodologies. The following 8 technical sessions (with more than 30 lectures) are presented covering the main topics hereafter listed:
  - *Session I: system codes: evaluation, application, modelling & scaling*
    - models and capabilities of system code models
    - development process of generic codes and developmental assessment
    - scaling of thermal-hydraulic phenomena
    - separate and integral test facility matrices
  - *Session II : International Standard Problems*
    - lesson learnd from OECD/CSNI ISP
    - Characterization and Results from some ISP
  - *Session III: best estimate in system code applications and uncertainty evaluation*
    - IAEA safety standards
    - origins of uncertainty
    - approaches to calculate uncertainty
    - user effect
    - evaluation of safety margins using BEPU methodologies
    - international programs on uncertainty (UMS [11] and BEMUSE [12])
  - *Session IV: qualification procedures*
    - qualifying, validating and documenting input deck
    - the feature of UMAE methodology
    - .- description and use of nodalization qualification criteria for steady state and transient calculation
    - use of thresholds for the acceptability of results for the reference case;
    - qualitative accuracy evaluation
    - quantitative accuracy evaluation by Fast Fourier Transform Based Method (FFTBM)
  - *Session V: methods for sensitivity and uncertainty analysis*

- GRS statistical uncertainty methodology
- CIAU Method for Uncertainty Evaluation
- ASAP and GASAP procedures for Sensitivity Analysis
- Comparison of Uncertainty Methods with CSAU Methodology

o *Session VI: relevant topics in best estimate licensing approach*
- best estimate approach and rules in licensing

o *Session VII: 3D Neutron-Kinetics/Thermal-Hydraulic Coupling*
- Cross section generation: models and applications
- coupling 3D neutron-kinetics/thermal-hydraulic codes (3D NK-TH)
- uncertainties in basic cross-section
- CIAU extension to 3D NK-TH

• The second week (titled "Industrial Application, Coupling Methodologies and Hands-on Training") is devoted to lectures on the practical aspects of the proposed methodologies and to the hands-on training on numerical codes like ATHLET, CATHARE, CATHENA, RELAP5 USNRC, RELAP5-3D ©, TRACE, PARCS, RELAP/SCDAP and IMPACT. The following 4 technical sessions are presented covering the main topics hereafter listed:

o *Session I: industrial application of the best estimate plus uncertainty methodology: general Aspects and Procedures*
- Historical Evolution of LOCA Regulatory Requirements
- CSAU and EMDAP (RG 1.157 and RG 1.203) methodologies with particular emphasis to the PIRT process
- Computer Code, Evaluation Model Assessment of Biases and Uncertainties
- Industry Best Practices in Evaluation Model Development and Assessment

o *Session II: industrial application of the best estimate plus uncertainty methodology: Vendors' Application and Sample Results*
- Westinghouse realistic large break LOCA methodology
- AREVA realistic accident analysis methodology
- GE Technology for Establishing and Confirming Uncertainties
- BEAU for CANDU reactors
- UMAE/CIAU application to Angra-2 DEGB licensing calculation

o *Session III: Interactions of Thermal-Hydraulics with Fuel behaviour, Structural Mechanics and Computational Fluid Dynamics*
- Modelling Fuel Behaviour and its Interaction with Thermal-hydraulics
- Safety Limits, with Particular Reference to High Burn-Up
- Mox Fuel and related Safety Issues
- Pressurised Thermal Shock
- Role of CFD Codes and Bases for their Use in Nuclear Reactor Technology

Each of the *parallel hands-on trainings on numerical codes* consists of about 20 hours and covers the following main topics:
- Structure of specific codes
- Numerical methods
- Description of input decks
- Description of fundamental analytical problems
- Analysis and code hands-on training on fundamental problems (e.g. for RELAP5 fundamental proposed problems deal with boiling channel, blow-down of a pressurized vessel, pressurizer behaviour)
- Example of code results from applications to ITFs (LOFT, LOBI, BETHSY)

• The third week (titled "Code Hands-on Training for Transient Analysis in ITF") is designed for advanced-users addressing the user effect problem. The participants are divided in group of three and each group receive the training from one teacher. The applications of the proposed methodologies (UMAE, CIAU etc.) are illustrated through the BETHSY ISP 27 (SBLOCA) and LOFT L2-5 (LBLOCA) tests. Applications and exercises using several tools (RELAP5, WinGraf, FFTBM, UBEP, CIAU, etc…) are considered. The following main topics are covered:
- Modalities for developing (or modifying) the nodalization
- Plant accident and transient analyses
- Examples of code results from application to a NPP (PWR-Type and VVER-Type)
- Code hands-on training through the application of system codes to ITFs (LOFT and BETHSY)

A final examination on the lessons learned during the seminar is designed and consists of three parts:

I) Written Part: Questions about the topics discussed during the seminar are proposed and 20 questions are assigned both to each participant and to each group. At least 14 questions must be correctly answered by the group and 14 by each participant.

II) Application Part: Two types of problems are proposed to the single participant and to the group:
- *Detection of Simple Input Error:*
  Each participant receives the experimental data of the selected transient, the correct RELAP5 nodalization input deck and the restart file of the wrong input deck containing one simple input error. Each participant shall identify the error
- *Detection of Complex Input Error:*
  Each group receives the experimental data of the selected transient, the correct RELAP5 nodalization input deck and the restart file of the wrong input deck containing one complex input error. Each group shall identify the error

Evaluation reports are submitted in a written form containing short notes about the reasons for the differences between results of the reference calculation and results from the 'modified' nodalization. At least one problem over two shall be correctly solved to obtain the certificate

III) Final Discussion: Each participant takes an oral examination of about 15-20 minutes, discussing own results (or results obtained by own group) with the examiners. General questions related to lectures presented during the three-weeks seminar are asked to the participants.

A certificate of type "LA Code User Grade" (see Table 1) like the one depicted in Figure 3 is released to participants that successfully solved the assigned problems.

V.D. 3D S.UN.COP 2010 in IE-JRC-EC Petten (Netherlands)

The 3D S.UN.COP 2010 was successfully held in Petten (Netherlands) from October 18th to November 5th with the attendance of 23 participants coming from 8 countries and 16 different institutions (universities, vendors and national laboratories). 32 scientists (13 countries and 23 different institutions) were involved in the organization of the seminar, presenting theoretical aspects of the proposed methodologies and holding the training and the final examination.

All the participants achieved a basic capability to set up, run and evaluate the results of a thermal-hydraulic system code (e.g. RELAP5) through the application of the proposed qualitative and quantitative accuracy evaluation procedures.

At the end of the seminar a questionnaire for the evaluation of the course was distributed to the participants. All of them very positively evaluated the conduct of the training as can be derived from the charts in Figure 4.

VI. CONCLUSIONS

An effort is being made to develop a proposal for a systematic approach to user training. The estimated duration of training at the course venue, including a set of training seminars, workshops, and practical exercises, is approximately two years. In addition, the specification and assignment of tasks to be performed by the participants at their home institutions, with continuous supervision from the training center, has been foreseen.

The 3D S.UN.COP seminars constitute the follow-up of the presented proposal. The responses of the participants during the training demonstrated an increase in the capabilities to develop and/or modify the nodalizations and to perform a qualitative and quantitative accuracy evaluation. It is expected that the participants will be able to set up more accurate, reliable and efficient simulation models, applying the procedures for qualifying the thermal-hydraulic system code calculations, and for the evaluation of the uncertainty. The twelfth seminar will be held in March 2011 in Wilmington, North Carolina (USA), in cooperation with GEH, AREVA NP, Westinghouse and INL and will involve more than 30 scientists between lecturers and code developers (www.nrgspg.ing.unipi.it/3dsuncop/).

Fig. 3. 3D S.UN.COP "LA Code User Grade" Certificate.

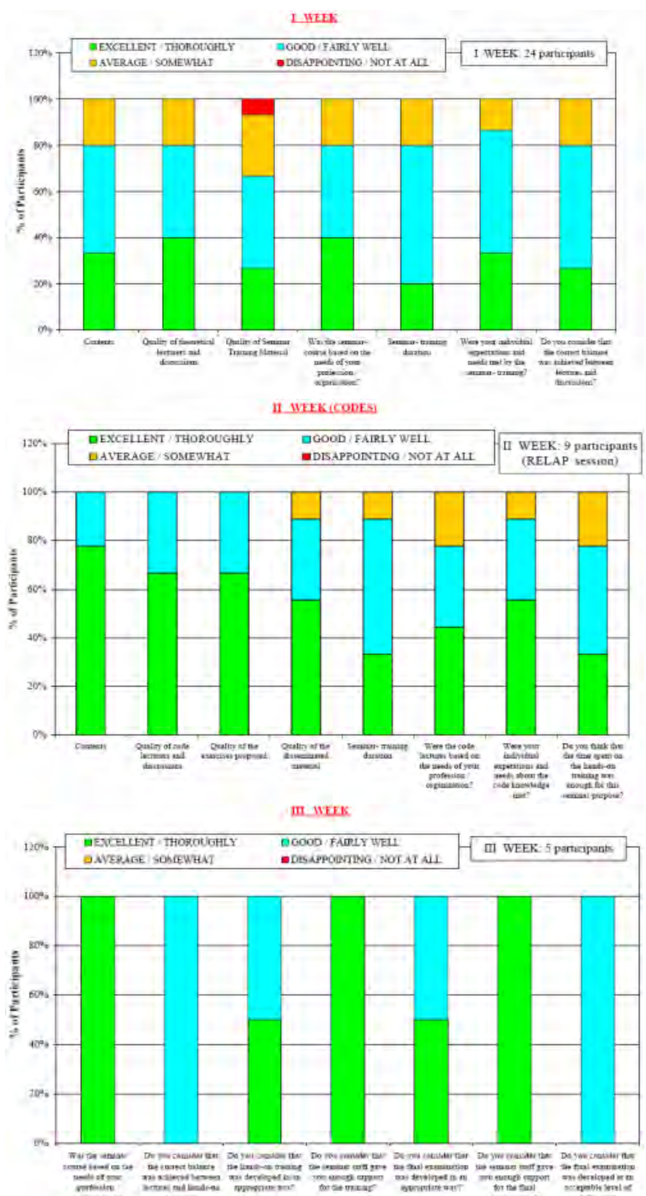

Fig. 4. Design & conduct of the seminar-training.

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