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November 14, 1996

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Washington, DC 20555

SUBJECT: JFM-148-96: Forwarding of Session Summaries For CSNI Workshop On T/H And Neutronic Codes: Contract No. NRC-03-95-026, FIN No. W6618, B&R No. 66015115005, APPN No. 31X0200.660

Dear Dr. Ebert:

I have enclosed working-draft versions of the session summaries which were developed during the meeting last week. I have also included a disk file in WordPerfect 5.1 for your use. Copies of these session summaries have been E-Mailed to the respective session co-chairs. We have asked them to make final revisions to the drafts and E-mail them back to SCIENTECH by November 22, 1996. We will then do the final technical editing and forward them to you for CSNI review, comment and approval. Please note that the enclosed are *working draft* documents that have not had the benefit of session co-chair final review and SCIENTECH technical editing.

I thought that the meeting went very well and appreciate your contribution as well as the contribution of other NRC staff. Please call me, Marlin Strand, or Tracey Canty if you have any questions.

Sincerely yours,

Jim Meyer

James F. Meyer, Manager
Risk Analysis and Thermal-Hydraulics

Enclosures: Working-Draft Session Summaries -- Hard Copies
Working-Draft Session Summaries -- Disk files in WordPerfect 5.1

cc: F. Eltawila (NRC) with Enclosures
R. Webber (NRC) w/o enc.
S. Afable (SCIENTECH) w/o enc.
J. Kelly (NRC) w/o enc.
L. Ruth (NRC) w/o enc.
M. Strand (SCIENTECH) w/o enc.

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CF: PDR per D. Ebert

TOPRP

Working Draft

11/8/96
SCIRV

OECD/CSNI Workshop

On Transient Therml-Hydraulic and Neutronic Codes Requirements

Session Summaries

Working Draft

Opening Plenary Session
Current and Prospective Plans of Thermal Hydraulic Codes Development

Co-Chair: G. Yadigaroglu and L. Ybarrondo

Dr. Farouk Eltawila addressed the attendees at the Worrkshop on Thermal-Hydraulics (Principal Working Group 2). This meeting was called to discuss current and future uses of thermal hydraulic and neutronic codes, additional experimental needs, numerical methods, programming language, and code architectures and user interfaces for a future generation of safety analysis codes. The proceedings of this meeting will be published in a report. The excellent attendance, approximately 140 participants from 21 countries, shows the international community realizes the importance of discussing and reaching consensus on these issues.

Dr. David Morrison, Director of the NRC Office of Nuclear Regulatory Research, also welcomed the attendees, and introduced Dr. Jackson.

Dr. Shirley Jackson, Chairman, USNRC, also welcomed the participants and discussed the purpose of the meeting, which is to reach conclusion concerning the capabilities needed in Thermal-Hydraulic codes to accurately model reactor systems. She noted that this is not a new need, it goes back to 60s and early 70s. The old codes developed during that era were very conservative. Testing in 70s, 80s allow us to model phenomena more realistically and remove these conservatisms. However, new demands have been placed on the Best Estimate codes -- advanced reactors, severe accidents, beyond design basis analysis. The NRC needs to develop a new set of coupled thermal hydraulic - neutronic codes to take us into 21st century. This meeting will help determine how to best do this, taking advantage of two-phase models and new computer capabilities, and make them more user-friendly. She noted that NRC has preliminary answers, but wants the views of the CSNI member countries. NRC is now working with severe budget constraints. Help is needed to focus and prioritize. NRC needs to proceed in a framework of international cooperation. Dr. Jackson closed by stating that she will be pursuing this initiative through the next year.

Mr. Gianni M. Frescura, Head of Nuclear Safety Division, OECD/NEA, added his welcome. He thanked the NRC for arranging this meeting, which has attracted the best qualified experts to discuss these issues. Safety Analysis has many roles, including design, audit, and event analysis. CSNI has played a leading role in developing and validating safety analysis models. CSNI reviews, on a periodic basis, the bases and capabilities of the Thermal-Hydraulic models. System computer codes have attained a high degree of maturity. However, these codes were developed some years ago, and need to be more reliable and more accurate. The objective of this workshop is to identify a set of requirements and attributes for new codes, and issues to be addressed by research. An international approach is desirable -- Possible

efforts include:

1) Cooperation on Code Development and Assessment
2) Development and enforcement of International QA program
3) Development/comparison of Specific Models with Specific codes

Co-Chairmen Prof. Yadigaroglu (Switzerland) and Dr. Ybarrondo (USA) summarized the capabilities of current generation of thermal hydraulic codes and future plans using the material form the following papers:

- Methodology, status and plans for development and assessment of RELAP 5 code (G. Johnsen, et al., INEL, USA)

- Methodology, status and plans for development and assessment of TRAC code (B. Boyack, et al., LANL, USA)

- Methodology, status and plans for development and assessment of CATHARE code (D. Bestion, et al., CEA Grenoble, France)

- Methodology, status and plans for development and assessment of TUF and CATHENA codes (J. Luxat, et al., Ontario Hydro, AECL, Canada)

- Methodology, status and plans for development and assessment of ATHLET code (V. Teschendorff, et al., GRS, Germany)

- Methodology, status and plans for development and assessment of Finnish reactor dynamics codes and APROS code (T. Vanttola, et al., VTT, Finland)

Dr. Yadigaroglu's summary was presented in view graph form.

Dr. Kelly, NRC, USA, reviewed RELAP5 code modifications and work-arounds which were adopted as a results of work performed by the NRC/RES and the INEL. This work was performed to demonstrate the applicability of the RELAP5 code to passive designs, such as the AP600 for NRR. As the LB LOCA performance of the AP600 is generally similar to standard reactors, it was decided to focus the assessment studies on SB LOCA & Transients. Passive, natural circulation systems have relatively small driving pressures. In addition, the success of the transient mitigation depends on properly triggering ADS. Therefore, after review of the PIRT, it was decided to look at phenomena from

- SPES
- OSU

- ROSA/AP600

Events were judged on 4 level criteria -- RELAP5 response was not judged to be insufficient to any event. Most events were judged to be adequate or better.

Initially RELAP5 was unable to perform the analysis due to code problems. These problems were fixed, and some improvements and work-arounds were found to improving predicted accuracy:

- Henry-Fauske Critical Flow
- Eliminate non-physical two-phase recirculating flows
  (Use 1-D for temporary fix and turn off momentum flux terms in downcomer)
- More physical interfacial heat transfer
- Core level improvements needed in future.

The end result is that Version 3.3 is judged to be applicable to AP600. This version to be released will contain all of these improvements.

Dr. Barre's presentation on The Role of Uncertainty in Code Development attempted....[**see his section 8 - Conclusions, p. 13**].

Dr. Wilson discussed The Role of PIRT in Code Development or Identifying Improvements . [**Put summary of his paper here - shorter! see his page 10, section 4.**]

A discussion plenary session followed the presentation of the above papers.

TECHNICAL SESSION 1:
CURRENT AND ANTICIPATED USES OF THERMAL-HYDRAULIC CODES

Co-Chair: D. Grand and R. Caruso

Ralph Caruso (USNRC) presented a paper outlining the basis of the thermal-hydraulic codes developed to date by the USNRC and the intended direction within the USNRC on future uses. The codes were originally developed for technical experts to provide information on the performance of nuclear power plants to regulators for making licensing decisions. Thermal-hydraulic codes have been used to cross-check vendor codes and calculations, to perform sensitivity calculations, for event analysis, and for plant simulations. A recent role has been to use thermal-hydraulic codes in the support of PRA analysis for risk-informed decisions. All of these uses of thermal-hydraulic codes has created three distinct user communities. The first group (Category 1 users) is composed of highly technical and specialized codes users who are scientists and engineers with strong backgrounds in fluid flow, heat transfer, nuclear engineering, and computer science. They have detailed knowledge on code input, correlations, solution techniques, and output. The "Category 2" users are engineers who build simple models and have an overall knowledge of the code. However, they typically do not have the time to learn the intricacies of running a thermal-hydraulic code. The third category are system analysts who have a basic knowledge of reactor fluid dynamics and system behavior but run the codes to simulate the plant performance. Category 3 users are primarily associated with PRA and operator training. The future thermal-hydraulic codes must be able to support all three user groups based on similar needs. These needs include robustness, defensible, linkable to other codes, fast running, consistent, ease-of-use (GUIs), and have proper documentation. Progress has been made with growing cooperation between code developers and users while applying lesson learned from current generation NPP analysis.

Gandrille (FRAMATOME) described the current and anticipated uses of the CATHARE code used by EDF and FRAMATOME. The CATHARE code is used in safety studies and as a simulator. For safety studies, a realistic deterministic methodology (also called Best-Estimate) is applied for licensing calculations, realistic plant response analysis, and evaluating advanced NPP designs. A version of the CATHARE code (CATHARE-SIMU) forms the driver for a NPP simulator (SIPA). Current plans call for an upgrade of the simulator to use CATHARE 2 for improved system performance. Important requirements have been identified, such as the range of validity (over all plant operation modes), determination of code uncertainty, multidimensional capability, fast run times, good code documentation and user guidelines, and visualization tools. Vacher (EDF) continued with the uses of CATHARE but concentrating on its use for simulators. The SIPA and SIPACT

simulator versions were presented. A demonstration of SIPACT was available during the meeting. The simulators are used for training of safety organization engineers, plant operators, and for studies of Emergency Operating Procedures. Future work will convert all simulators to CATHARE 2 so there will be only a single code available for safety, engineering, and training. This will require development of the capacity to analyze conditions at low pressure in real time, the automatic generation of CATHARE modules and extending the simulation domain to all transients for all plant initial states.

Teschendorff (GRS) presented a paper on the uses of thermal-hydraulic codes in Germany. The thermal-hydraulic codes (ATHLET) are used by licensing organizations and utilities. S-RELAP5 is used by SIEMENS. Applications of the codes are for operating plant performance, licensing calculations, evaluation of PTS, assessing Accident Management plans, evaluating plant upgrades, and verifying ECCS performance for advanced designs. There was emphasis on correctly modeling the secondary side in including control systems and the validation of the results. Future requirements include low pressure models (including an interfacial area concentration model), boron mixing, multi-dimensional, coupling to other codes, quality assurance, machine independence, and reduced user influence.

Caruso (NRC) presented a summary of papers from member countries on current and anticipated uses of thermal-hydraulic codes. The papers were from France, Germany, Italy, Korea, Japan, Spain, Switzerland, and the United States. Information for each paper was extracted and placed into a common table format for current applications and future needs. For current applications, the table includes the codes used, the problem application, and the application type (Licensing, Best-Estimate, and Research). Under future needs, the application area and specific needs were listed for each country. There were common recommendations throughout all the papers. These include improved user interface, coupling to other codes, improved numerical methods (especially for low pressure transients), assessment of uncertainties internal to the codes, minimization of the user effect, multiple fluids, modular code structure and building on previous work.

Grand (CEA) presented a summary of papers form USA, France, Germany, United Kingdom, Japan, and Canada) on interface requirements to couple thermal-hydraulic codes. The need for coupling comes from the need to solve complex problems in a multi-discipline manner. Previous methods involved external iterations between codes or the creation of an integrated code. Either method was labor intensive for transferring the information between codes or for maintaining and improving the integrated code. New methodologies involve the merging of separate processes or for static linking. The coupling schemes for the core physics to the

thermal-hydraulic can be made at the core boundaries, or by overlapping in the core. An important consideration when coupling the codes is time synchronization. This occurs because the two codes most likely will not have the same time steps. Therefore, schemes must be developed so that one code does not overly slow down the complete calculation by the use of fully explicit, iterative, or simplified methods. Coupling with severe accidents was also covered and the problems arising form tightly coupled phenomena (cladoxidation) were identified. Coupling with containment codes was the third domain. Certain general requirements are also driving this topic. These requirement include optimization (minimize computer overhead, development and maintenance costs), physical relevance of coupling (conservation of mass, energy, and momentum), and the impact of new software technologies (parallelism, standards).

The final session agenda item was an open forum on the future development of thermal-hydraulic codes. A majority of the discussion centered on how the user requirements are developed and implemented. Some of the issues that were raised included: 1) what can be considered good enough, 2) how one defines the success criteria, the relationship to improvement in the physics models, 3) the level of uncertainty needed in each code, 4) the level of detail that adequately models the problem. It was understood that the rate of improvements in computer hardware makes the goal of reasonable run time a constantly changing requirement (a "running" target). Others emphasized the need to "get the physics right" as the first and foremost important requirement. However, others expressed the view that improvement in physics can proceed as a parallel process to shorter run times.

TECHNICAL SESSION 2
ADVANCES IN MODELING OF THERMAL-HYDRAULIC PHENOMENA, ADDITIONAL EXPERIMENTAL NEEDS

Co-Chair; **Dr. Reocreux** (France), **Dr. Lillington** (U.K.)

Dr. Reocreux opened the session by providing a brief description of the papers to be presented in the session and their relationship to the first day's proceedings.

Status of Thermal-Hydraulic Modelling and Assessment: Open Issues (D. Bestion, F. Barre, CEA, Grenoble, France)

Dr. Bestion presented this paper which focuses on open issues regarding the ability of the T&H system codes to predict the progression of nuclear power plant transients. It was noted that 10 to 20% of IETs are predicted very well, while 50 to 75% are predicted adequately. The remaining cases are not predicted well. The focus was on identifying the causes of mispredictions which can generally be categorized as:

1. nodalization or schematization problems (user effect).
2. models used outside the range of validity
3. physical process not modeled
4. highly sensitive transients, e.g. loop seal clearing

It was also noted that averaging restricts the predictions to large scale phenomena. Another limitations related to the system of equations is an incorrect number of fields for some more complex phenomena. Use of steady-state relationships for unsteady flow is yet another limitation. Examples were given to illustrate these and additional code limitations. Oscillatory reflood for a LBLOCA was used as an example to illustrate how spacer grids create local perturbations in a complex geometry, a situation which is difficult for the codes to predict. Improved numerical schemes were shown to improve the accuracy of the predictions. The main code limitations were summarized and recommendations given for future development, including:

1. multi-fluid models for some flow patterns,
2. additional transport equations, e.g. interfacial area concentration,
3. improved 3-D modeling,
4. new experimental programs to provide data to qualify closure relations

Questions and Comments from the Audience

1. Dr. Ishii (Purdue U., USA) When additional fields are introduced, problems can arise. It may be easier to use a formulation similar to drift -flux rather than introduce additional fields.
2. Instances where solutions did not satisfy the second principle of thermodynamics were noted for code calculations performed by the questioner (entropy decrease predicted for a LBLOCA?). Dr. Ishii stated that if flow friction acts to retard flow and heat transfer is from hot regions to cold regions, the second principle will be satisfied for code calculations.
3. Dr. Langenbuch was asked what was done to decrease predicted oscillations during reflooding. He stated that changes were made in the calculation to improve the modeling when the quench front moved from one node to another.

Dividing Phases in 2-f Flow and Modelling of Interfacial Drag (M. Rajamaki, T. Narumo, VTT, Finland)

Dr. Narumo described four models for one-dimensional two-phase flow:

1.six equation model
2.six equation model with virtual mass term
3.six equation model accounting for nonuniform transverse velocity distribution
4.Separation of two-phase Flow According to Velocity (SFAV)

Conservation equations for the six equation and the SFAV methods were presented. Dr. Narumo noted that without the virtual mass terms, the governing equations for the six equation model can be elliptic. Results of simulations of steady-state and sinusoidally varying inlet flux to a channel obtained using the SFAV method were compared to results of a drift-flux model. The channel represented a section of a BWR bundle between spacer grids with no heating. The results agreed well at steady-state, but differences began to be seen at frequencies of 5 Hz.

This work showed the possibilities of SFAV modeling, including:

1. equations are well posed; derivation is based on physical reasoning
2. one dynamic model covers the whole void fraction range and agrees with experimental data
3. progress has been made in modeling cocurrent vertical flow
4. horizontal stratified flow can be modeled
5. countercurrent flow limitation can be included in the model

6. high velocity flows, critical flow, approach to critical flow may be modeled

Questions and Comments from the Audience

1. Why do you put so much emphasis on obtaining hyperbolic equations? This is likely a small effect. In response, Dr. Narumo noted that the solution technique used requires that the equations be hyperbolic.
2. What is the physical interpretation of the eigenvalues and eigenvectors obtained using SFAV? Dr. Narumo noted that the characteristic values are the two phase velocities, pressure wave propagation speed and void propagation speed.
3. How is wall friction divided between the two phases? What is the physical basis for partitioning? In response Dr. Narumo stated that the partitioning is done according to phase velocity with different values of friction assigned to the slower and faster moving phases.

Advances in Modelling of Condensation Phenomena (W.S. Liu, et al., Ontario Hydro, AECL, Canada)

Dr B. Hanna presented the paper which describes both analytical and experimental work related to the prediction of condensation induced water hammer. The CATHENA and TUF codes were used to predict condensation events in the Cold Water Injection Test (CWIT) facility and Ontario Hydro Technologies (OHT) water hammer facility. These are both separate effects facilities. The CWIT facility is intended to provide data relevant to injection of cold water into a CANDU feeder channel. OHT provides data to determine the threshold between the water hammer and no water hammer regimes. The CATHENA and TUF codes use different approaches to modeling condensation water hammer. TUF tracks the motion of the injection front, while CATHENA identifies the location of the injection front from calculated liquid fraction gradients.

An overview was presented of the CATHENA condensation model. The primary variable of interest is the interphase area. CATHENA results were compared with the CWIT data. Overall trends were predicted and differences explained. The code tends to overpredict the pressure rise. TUF results were compared to the OHT data.

Future work will include evaluation of a transient flow regime evolution map.

Questions and Comments from the Audience

1. How is the increase in interfacial surface area due to increased entrainment predicted? Dr. Hanna responded that a correlation is used to predict interfacial area.
   1. Do you allow multiple fronts? Dr. Hanna responded that only a single front is simulated.
   2. How are the effects of dissolved noncondensible gases treated? Dr. Hanna responded that they have found no evidence that dissolved gases have an effect in CANDU plants. However, they are looking at this area in conjuction with shutdown conditions.
   3. A question was addressed to the RELAP code developers as to whether RELAP could predict condensation water hammer. Mr. Johnsen (INEL, USA) responded that INEL has not attempted to model this phenomenon.

At this point, Dr. Lillington summarized the papers to be presented in the remaining portion of the session and summarized the areas where multi-dimensional neutronics modeling is needed.

Multi-Dimensional Reactor Kinetics Modeling (D. Diamond, BNL, USA)

This paper addressed three areas: recommendations for the type of multidimensional reactor kinetics model which should be included in a coupled neutronics/thermal-hydraulics code for the beginning of the next millennium, other important physical models needed for reactor dynamic capability and specific events for which coupled modeling is needed. The focus was on LWRs.

Recommendations are as follows:

1. only 3-D capability should be considered (plus point kinetics and no kinetics)
2. assume isotropic flux, i.e. diffusion theory
3. two energy groups
4. the solution space should be the fuel region or the entire reactor with reflector region
5. six delayed neutron groups
6. nodal methods or course mesh diffusion
7. time dependence by the direct method
8. modern matrix solution algorithms to minimize computation time

Other important physical models include:

1. cross section generator - data required for each mesh box includes exposure and spectral index (void and control rod history)
2. reactivity feedback - control rods, boron
3. decay heat
4. initialization procedure - start from any operating state
5. ability to handle fixed source
6. equilibrium and transient samarium and xenon
7. flux reconstruction for CHF, PCT and pellet enthalpy
8. coupling to T&H subchannel analysis
9. in-core and ex-core instrumentation
10. calculation of temperature and boron concentration across core inlet
11. fuel pellet temperature distribution

Applications are listed separately for PWR/VVERs and BWRs and include: return to power following steam line break, rod ejection boron dilution and ATWS for PWR/VVERs and stability analysis, rod drop, ATWS and overpressurization events for BWRs.

Questions and Comments from the Audience

1. In the UK, most of the features discussed have already been implemented. Flux reconstruction pin by pin for PCI assessment, CFD to determine core inlet conditions, etc. In response to queries regarding qualification of the UK methodology, it was stated that excellent results were obtained for the rod ejection benchmark.
2. It was stated that extension of any 3-D steady-state neutronics method to transients is relatively straightforward.
3. Six delayed neutron groups may not be sufficient for long term events.

3D Neutronic Codes Coupled with Thermal-Hydraulic System Codes for PWR, BWR and VVER Reactors (S. Langenbuch, GRS; M. Rohde, FZR, Germany and M. Lizorkin, Kurchatov I., Russia)

Dr. Langenbuch noted that T&H codes and neutronics codes have been separately developed. The need now is to couple the codes. Iterative schemes can be used but result in uncertainty related to feedback effects. Safety problems requiring coupled codes include boron dilution, cooldown with strongly negative MTC (recriticality), ATWS, BWR instability and new reactor concepts based on natural circulation.

Results of studies performed by coupling the BIPR-8 and DYN3D codes for VVERs and

the QUABOX/CUBBOX code for LWRs with ATHLET were described. Two different approaches to coupling were used: internal coupling where the neutronics model is brought into the system code, and external coupling, where the core region is modeled with the neutronics code, including the thermal-hydraulics. Both approaches were implemented using ATHLET and DYN3D. Internal coupling was implemented using BIFR-8 and QUABOX/CUBBOX with ATHLET. The author indicated a preference for internal coupling. In this case the thermal-hydraulics is fully consistent.

Events analyzed with the coupled codes were:

1. single pump coastdown in a VVER-1000 using ATHLET/BIRP-8
2. hypothetical control rod group ejection in a VVER-440 using ATHLET/DYN3D
3. ATWS total loss of heat sink in a PWR using ATHLET/QUABOX/CUBBOX

Results were very promising for these first applications of the coupled codes.

Areas for further investigation were identified, including:

1. possibility of solving for hundreds of T&H channels.
2. manner of grouping T&H channels
3. effect of using various fluid dynamic models
4. identification of accidents which require multi-dimensional core or downcomer
5. required accuracy for modeling cross flows between bundles

Questions and Comments from the Audience

1. Dr. Turinsky (NCSU, USA) stated that the situation for BWRs is much different than that for PWRs and VVERS in terms of the accuracy of results. In a recent benchmark the results obtained using different codes were widely divergent. The basic problem is the inability to accurately predict void distribution.
2. The question of whether GRS is planning to introduce features such as flux reconstruction and bypass flow modeling was raised. In response, it was stated that bypass flow is now included as a separate channel.
3. Dr. U. Rohatgi (BNL, USA) noted that the RAMONA-4B code is available with coupled neutronics/thermal-hydraulics capability. The author was aware of RAMONA-4B, but believes that the coupled models presented are more detailed.

The Need for Multi-Field Capabilities (S. Banerjee, UCSB, USA)

Dr. Banerjee noted that a transition in our ability to model two-phase flows has been brought about by increased computational capability, including parallelization. He presented a tutorial on the multi-field approach (interpenetrating continua) noting its strengths and weaknesses. Also discussed was structure resolving/subgrid modeling and particle methods. The need for a three field formulation to eliminate distribution effects was explained.

Multifield formulations were shown to be acceptable for separated and dispersed flows (particularly when closure relations are less important), but to do poorly for oscillating or intermittent flows. The method has a real weakness when there is a nonlinearity in a constitutive relation. Reflux boiling in a PWR was used as an example to illustrate the point. In this case, using a flooding correlation is a preferred approach. Components were identified where multi-field models are needed to analyze reactor performance during normal operation. Examples were presented on flow in steam separators and flow between the core exit and the separator standpipes. The need for multi-field modeling in advanced passive PWRs was identified for the highest ranked (in the PIRT) phenomena for the SBLOCA and LBLOCA. Eight of the twelve phenomena for the LBLOCA were identified as requiring multi-field models. Interfacial area tracking and developing flows were identified as areas requiring additional development work.

Questions and Comments from the Audience

1. It was noted that Dr. Banerjee did not address the question of what is an acceptable error, which is directly related to whether more advanced formulations are required. It was pointed out that in the case of reflux boiling, there may be other reasons for inaccuracies other than those given in the paper. It was also noted that use of the PIRT to identify areas requiring multi-field modeling may be misleading. Dr. Banerjee stated that, indeed, there are other reasons for inaccuracies, such as lack of capability at low pressure in the present codes.
2. A representative of Siemens noted that the industry has been quite active in the area of multi-field modeling. They have demonstrated capability to model 3-D flows in variable geometry. Dr. Banerjee noted that large utilities have also been quite active in this area due to the need to support plant operations. The licensing arena, using codes such as RELAP5, has not seen this same level of activity.

DISCUSSION TECHNICAL SESSION 2

- Mr. G. Johnsen (INEL, USA) noted that RELAP5 has added a phase separation model at TEE components and has successfully predicted reflux condensation in Semiscale and BETHSY experiments. The ensuing discussion revealed that the models used in RELAP5 are empirical correlations, not multi-field models. The potential shortcomings of using empirical models include potential scale effects. Mr. Johnsen noted that the RELAP5 TEE model was validated against data at two different scales and no scale effect was evident.

- In regards to the presentation by Dr. Diamond, it was noted that neutronics modeling requirements for Canadian plants are very similar to those given by Dr. Diamond. A history based method is necessary to include effects such as on-line refueling.

- The need for the neutronics and thermal-hydraulics code developers to work together was noted by Dr. A. Barratta (PSU, USA).

- The vision should be to have a single code so that maintenance costs are reduced and a single analyst can perform the entire calculation. The practicality of a single worldwide code was questioned and it was noted that the comment applied only to the three NRC T&H codes.

- Adding transient capability to neutronics codes was again stated to be straightforward. However, it was noted that a two energy group formulation may be poor in some circumstances and result in spectral effects.

- It was noted that the approach recommended by Dr. Diamond does not utilize the latest techniques, such as unstructured grids, transport theory, angular discretizations as a function of energy groups, etc. Dr. Diamond recognized the need for continued research and development of neutronics methods.

- The interface between the T&H and neutronics methods presents several problems including: how to match the modules, e.g. initial steady-state conditions, and how to match the level of detail - typically neutronics models have orders of magnitude more detail than T&H models.

- The need to identify which safety issues require coupled neutronics/thermal-hydraulics analysis for resolution was noted by Dr. F. Eltawila (USNRC, USA).

TECHNICAL SESSION 3
Numerical Methods in Multi-Phase Flows

Co-Chair: V. Teschendorff and J. Luxat

The papers presented during Technical Session 3 held on November 6, 1996 discusses approaches to improvements in numerical methods based on experience with versions of RELAP5, TRAC, and the CATHARE computer codes. A summary of the papers presented during this session is provided followed by a synopsis of the general discussion after the papers were presented.

Paper Summaries:

Problems with Numerical Techniques: Application to Mid-Loop Operation Transients: Dr. J. N. Lillington presented a paper coauthored with Dr. W. M. Bryce (AEA, United Kingdom) discussing problems with numerical techniques found from applying RELAP5 and SCDAP/RELAP5 to mid-loop operation transients. The focus of the paper was on generic lessons learned as opposed to proposing fixes to these computer programs. Calculations were performed for the BETHSY 6.9 series of shutdown transients under experimental conditions at low temperature and pressure both with and without the presence of non-condensables using versions of RELAP5/MOD3. Calculations were also performed using both SCDAP/RELAP5 and RELAP5 for the Sizewell B loss of RHR studies. The types of problems encountered during these analyses were subdivided into six groups which are: weaknesses in modeling non-condensables at low pressure, poor time step control, problems with water packing, non-stratified flow in sloping pipes, numerical heat transfer instability and mass error. The problems were frequently found to be interdependent. In each case, alterations were made to RELAP5 or SCDAP codes to correct the problem. Generally, single code modifications were used which fixed problems with the existing models. Lessons learned include: 1) the need for careful initialization of properties before each property calculation iteration and consideration of side effects of altering any property such as non-condensable quality in the area of non-condensable modeling, 2) better detection of time step calculations that cause first order property extrapolations to break down, and 3) careful checking of system mass and energy totals.

Several questions were posed to Dr. Lillington including the effect of nodalization on code behavior. It was suggested that some of the problems could be circumvented through judicious selection of node characteristics as opposed to making code modifications. Volume differences were cited as being important. It was also noted

that an important lesson learned is that the codes are being applied outside of their range of intended application, requiring development of new models or extending the capabilities of existing models. Dr. Lillington believes that a combination of new models and model extensions is needed. He had no recommendation on how to handle steam and non-condensable flow without assuming that the two components are well mixed. In a response to a question on mass error reduction, Dr. Lillington stated that convergence criteria were tightened in addition to other fixes.

Elimination of Numerical Diffusion in 1-Phase and 2-Phase Flows: Dr. M. Rajamaki (VTT Energy, Finland) presented a paper discussing the development of a new solution method called PLIM, Piecewise Linear Interpolation Method. This method was developed to avoid errors due to numerical diffusion and dispersion. The PLIM method is a shape-preserving characteristics method which is integrated into the hydraulics solver CFDPLIM. The CFDPLIM routines solves the system of N flow equations in an arbitrary hydraulic network consisting of nodes and one dimensional flow paths. CFDPLIM has been incorporated into a three dimensional reactor dynamics code, HEXTRAN, resulting in a code called HEXTRAN-PLIM. Boron dilution accidents under conditions close to natural circulation were analyzed using both HEXTRAN and HEXTRAN-PLIM to show the effects of numerical diffusion. Results presented based on HEXTRAN analysis show clear indications of numerical diffusion while the solutions from HEXTRAN-PLIM show little effect from numerical diffusion. The effect of numerical diffusion impacts predictions of the effect of boron dilution since the reactivity worth of the boron slug , which is "smoothed" as a result of numerical diffusion, is decreased relative to the HEXTRAN-PLIM predictions,. This decrease in predicted reactivity worth results in an underprediction of the fission rate and energy release to the vessel as a result of the event. Hence, numerical diffusion can mask erroneous results and can have a significant impact on predicted behavior of plant behavior during a boron dilution event. The CFDPLIM package has also been applied to the SFAV two fluid problem.

Advanced Numerical Methods for Three Dimensional Two-Phase Flow Calculations: Dr. I. Toume (CEA, France) presented a paper co-authored with Dr. D. Caruge on new, fully implicit finite volume methods that have been developed to analyze both one and three dimensional two phase flow problems. The one dimensional solutions scheme makes use of the Riemann solver approach to define backwards and forward differencing to approximate spatial derivatives. The Rieman solver approach has been validated against various test problems including the water faucet problem and the Edward's pipe problem This method has been extended to a three dimensional

unstructured meshing with improvements performed to obtain a fully implicit solution method. This method has been implemented in the FLICA-4 computer program which is used to perform steady state and transient calculations of rod bundles, and PWR reactor cores and assemblies. The FLICA-4 program has been used to analyze the effect of rod bow on hot channel coolant flow and PWR upper plenum flow calculations. The FLICA-4 program is planned to be incorporated coupled to the CATHARE code.

Recent Advances in Two Phase Flow Numerics: In a paper co-authored with Mr. Rafael Macian, Dr. John Mahaffy (Pennsylvania State University, USA) presented a review of two-phase flow numerics. Topics covered included automatic differentiation, iterative solutions of sparse linear systems, interface tracking, higher order numerical methods and quantification of numerical diffusion. Automatic differentiation is seen as a tool useful to the code developer for developing analytic derivatives which are part of a new model or correlation for prototyping implicit numerical methods. Programs such as ADIFOR can be applied to generate the FORTRAN codes for the derivatives. However, it was noted that use of ADIFOR and similar codes requires improvement in producing efficient code and in documentation. Iterative solutions of sparse linear systems has undergone a great deal of development in the past 20 years to the point where there are many methods to choose from for a particular problem. Current methods used include conjugate gradient methods and the Krylov subspace methods. The key to success with such methods is preconditioning of the matrix system for rapid convergence. A variety of iterative solution packages are available so that testing of a variety of options for a particular class of problems is not difficult. Interphase tracking is of most use in following liquid levels in vertically stratified regions and plugs of liquid moving through pipes. Lagrangian methods have been used to track interfaces. The computer code OLGA, a major oil and gas pipeline analysis code, uses Lagrangian methods for tracking liquid slugs. In the area of higher order numerical methods, a wide range of methods have been refined for shock wave problems. Research using methods developed by Leonard and Smolarkiewicz has yielded promising results. Use of a well posed equation set is a good idea with these methods. Quantification of numerical diffusion is important, however, an important first step is to quantify the degree of physical diffusion so that the relative importance of numerical diffusion may be ascertained.

Questions raised after Dr. Mahaffy's presentation included the use of the method of characteristics on multi- processor parallel machines for the solution of hyperbolic systems. Dr. Mahaffy believes that finite element and finite volume methods are a better choice for solving these systems. Dr. Mahaffy also noted that most recent

advances in two phase flow numerics are adaptations of methods developed for single phase flow. He notes that these adaptations frequently require far more effort than the original development for single phase flow.

Current and Planned Numerical Development for Improving Computing Performance for Long Duration and/or Low Pressure Transients: In his paper, Dr. B. Faydide presented the current and planned development in the area of improved computing performance for long duration or low pressure transients. The CATHARE program, particularly in the area of simulator applications. The CATHARE code employs a fully implicit six equation, two fluid model . A complete set of models for two phase flow patterns, cocurrent and countercurrent flow, and heat transfer with wall structures and fuel rods is included. The CATHARE code has been benchmarked against experimental data. The CATHARE program has been simplified to allow real time operation in plant simulators. This modified version, initially developed in 1986 and referred to as CATHARE-SIMU, utilized a 2 fluid, 6 equation model on the primary side and a 3 equation model on the secondary side. Improvements in computational speed was achieved by optimizing the data management strategy in CATHARE-SIMU. CATHARE-SIMU is being improved by adding a drift flux model to the 3 equation secondary side model and in developing a multi-processor version with a 100 millisecond CPU execution time per time step. A further stage of CATHARE development and application to simulators is the Simulator CATHARE Release (SCAR) project. The purpose of this project is to utilize standard Cathare models without any simplifications in engineering and training simulators. Effort is being focused in improving the calculation efficiency and in improving code reliability and avoiding convergence failures. The version of CATHARE developed from the SCAR project will be benchmarked against a large variety of transient tests, including loss of RHR during mid-loop operation.

Questions on the availability of neutronic models in CATHARE were posed to Dr. Faydide who stated that these are external modules that are provided by the user.

General Discussion:

The desirability of using three dimensional neutronics models in CATHARE given that 1-D models are currently being used. Also, the impact of control system calculations on computation time in CATHARE was noted. In a simpler CATHARE model, control system calculation time is significant.

Answering questions regarding refinement of two phase flow computational methods, Dr. John Mahaffy stated that higher order methods should be evaluated. He suggested a two year program to evaluate and benchmark various approaches prior to selection of a method for installation in a computer code. Regarding a question on the connection between nodalization and numerics, Dr. Mahaffy noted that the simple answer is that a fine mesh leads to a converged solution and if this is not so, then there is a problem with the approach.

The possibility of using unstructured mesh was discussed. Dr. Mahaffy noted that unstructured mesh has been used in single phase analysis. For two phase analysis, use of unstructured mesh is complex and would require a significant development effort which would likely be more that what people are willing to pay for. Actual engineering systems complicates the application of unstructured mesh. The subject of adaptive methods was raised and Dr. Mahaffy noted that these methods have been applied to gas dynamics and that robust numerics are needed to extend these to two phase flow problems.

Numeric diffusion was discussed. Dr. Mahaffy reiterated that the magnitude of physical diffusion needs to be estimated in any evaluation of numerical diffusion. It is acceptable if physical diffusion dominates and it is not necessary to totally eliminate numerical diffusion.

Further method development was discussed by Dr. Mahaffy who stated the best approach to improving numerical techniques is to identify and solve specific problems. He noted that benchmarks suggested by Ransom and others could be used to focus the problem. Dr. Mahaffy also noted that in the area of single phase turbulent modeling, analysts are just coming to the point where they believe that these models produce good results.

It was suggested that development of numerical methods is not independent of computer capability. With the move towards parallel computing architectures, model developers need to rethink the approach to numerical algorithms and how they can be developed to best take advantage of these platforms.

TECHNICAL SESSION 4
Programming Language and Code Architecture and User Interfaces

Co-Chair: T. Vanttola and M. Naitoh

Development of computer hardware and software during the last 10 years has been very rapid, which has considerably extended the possibilities to perform detailed safety analysis calculations. Up until now, the increased calculation power in nuclear safety applications is mainly due to speed of serial architecture hardware and increased memory capacity. It is not, however, clear that such an increase of serial computing power would continue very long, and the future increases in speed mainly comes through the development of parallel hardware architecture (or through inherent fine grain parallelism in single processor architecture).

Early attempts have been made to vectorize or parallelize some of the existing safety analysis codes, or codes under development (CATHARE, APROS, IMPACT) with fairly encouraging results. Parallel processing hardware and software have been available already for some time, but the required new way of thinking "parallel" and certain problems associated with architecture dependencies, difficulty of correctness verification and lack of reliable software tools have made the approach too difficult to apply. At present, however, more standard procedures begin to be available such as languages supporting parallelization (F90, HPF,etc.) and message passing protocols (MPI, PVM) which support generation of portable codes.

Some choices have to be made when starting a modern code development project. Basically three types of parallel hardware architecture are available: shared memory machines, distributed memory machines, and distributed networks - out of which the distributed memory machines seem to be more favorable for portability and for extensions of the number of processors (Liebrock).

In the programming style loop based parallelism, functional parallelism, data parallelism, or a combination of these may be chosen. Data parallelism might be most attractive (Liebrock) (also applied in CATHARE and IMPACT) if such new tools as object oriented programming are used to increase quality, maintenance, extendibility, and reusability of the code, but such an approach necessarily requires a high degree of rigor.

The data base system is obviously the core of all functionality in a new safety related software because, in addition of storing data optimally, it should take care of interconnections of models and also connections to graphical user interface (GUI).

In the conduction of a large software project, it is of paramount importance that well structured procedures are obeyed, starting from definition of requirements up to final release to the users and where feedback from various user groups is guaranteed.

Development of a well functioning graphical user interface is a necessity for a modern safety analysis code, where model development and display, routine control and display, and post processor output (including playback) are supported. All should be connected directly to the data base of the code. Backfits on existing old code structures may eventually run into difficulties because of the continuous changes made to the underlying code.

In the development, GUI feedback from the end users is of particular importance. Modularity and separation of the solution algorithms from the models is important to guarantee easy exchanges of models and possibilities for extensions.

It appears that the extensions of FORTRAN (F90, HPF) seem to be most efficient in purely calculational tasks. They are also compatible to the existing F77 coding. The extensions of FORTRAN, however, need a lot of training and learning of new thinking. On the other hand, C and C++ are much more suitable for such tasks as data base treatment or generation of GUI.

Portability is a very important code feature, and it should be kept in mind in all phases of code development.

Drs. Vanttola and Naitoh: The following information (about 7 pages) is the minutes from the technical papers presented in session 4. It has been attached for you reference. I do not know if you would like to include this in your section summary. If it is useful, please edit and integrate this information with the above summary.

TECHNICAL SESSION 4: SUMMARY OF PAPERS
PROGRAMMING LANGUAGE AND
CODE ARCHITECTURES AND USER INTERFACES
Co-Chair: ***Dr. Vanttola*** (Finland), ***Dr. Naitoh*** (Japan)
5 papers, 3 of which describe code development projects from various countries, 1 on GUI

Current Implementation and Future Plans on New Code Architecture, Programming Language and User Interfaces (**Dr. B. Brun**, CEA Grenoble, France)

Over the past few years, computers have improved and evolved at a fast pace. Computer power doubles every 18 months. However, codes last longer, more complex. Methods obsolete every 3 years, languages every 10 years, but codes 20 years. Need to update codes every five years. This is what we do in France with CATHARE.

Development Environment, Quality and Metrics, Team Location must be stable for long term, Code documentation and help system, Assessment Database.

Language Choices:

- Fortran90
  - new structured language, has polymorphism
  - well adapted to parallel computation
  - no inheritance, not really OOP
- C++ Object Oriented
- Java Multi-platform portability **[Developed by SVN, interactive, portable]**

Parallel Processing

- New Languages (CRAFT, HPF) are inherently inefficient
- Automatic Tools (Preprocessors, Compilers) are very Efficient for fine tuning
- Message Passing (PVM/MPI is more efficient and more portable

Speed ups of a factor of 3 (on 5 processors) are possible with new generation of **shared memory** computers. Factor of 4 may be possible.

Parallelization and Automatic Data Distribution for Nuclear Reactor Simulations (**Dr. L. Liebrock**, L-H Research, USA)

3 Types of Parallelization

Shared Memory

Uniform memory model - but heavy cost for sharing. Use at most 5-10 processors.

Not scalable, or portable.

Distributed Memory

Separate computers - each handling separate mesh nodes

Scalable . Portable. Message passing is a detailed bookkeeping process. Requires careful management of message passing.

Distributed Networks

Network is the bottleneck. OK if portions of models are loosely coupled.

Can use existing computers. Communication and support is complicated and expensive. Load balancing is difficult.

Parallelism Options

Loop Based

Parallelize Individual Loop Nests

Advantages:

Fast & Inexpensive to Use

Extensive Compiler Support

Disadvantage

Targets Shared Memory Machines

Not Efficient Use of all processors

Functional Parallelism

Parallel Execution of Subroutines

Advantages :

Able to do complex tasks in parallel.

Disadvantages

Requires separation of the subroutines

Complicated control

Difficult to express loop parallelism

Data Parallel Programming Languages

Compiler language takes care of communications, slower but allows tool support

Combined Functional and Data Parallelism

Data Parallelism over a Physical Model, develop algorithms independently

Functional Parallelism (PVM) to link codes

Advantage - Flexibility Disadvantage - Complexity

Code Architecture

Use modern constructs for data structure design, these support better compiler optimization.

Recommendations for further investigation

Implicit Two-Phase Flow - explore decoupling options

Parallelism Options

Data Parallelism

Explicit Message Passing

Difficulty

Requires rewriting of solution techniques

QA for Compilers is an issue in general, not only for parallelization. This is a real problem. Data parallel approach must be checked by checking compilers as part of QA process. This is one reason parallelization should be done by the compiler not in the code. Data parallel gives the advantage that communication does not effect the answers. For explicit communication, may have to run full test suite for all configurations.

Data parallelization can be portable over the whole range of machine architechtures we are looking at.

Most users do not have access to real parallel machines. They only have access to heterogeneous networks. Not all languages support run time topology mapping. This is a hard problem. But using **such** languages is the best approach because it is the most uniform way of getting support for various machine architectures.

The data should be organized by component because this is the way that the scientist thinks about the physical problem. Container arrays such as in RELAP may give better load balancing distribution information but some optimization can be brought over. Pointers break optimization for parallelization. HPF and F90 have modules which will allow you to reformulate the component based arrays. We need to let the compilers do more of the work now instead of manually setting the pointers. This is a task which the optimizer does much better.

Parallelization takes a major rethinking of data structures and algorithms. To avoid problems associated with the stability of computing environment, standard languages, tools, libraries and implementations, which are generally supported around the world, should be used.

TOOKUIL: A Case Study in User Interface Development for Safety Code Apllication
(D. Gary, *et. al.*, KAPL Inc., USA) Presented By: **J. G. Hoole, KAPL**

TOOKUIL is a Cradle to grave GUI -- for Trac-P 5.4.15
Started late 1991, Development effort 12-13 staff years.

The presentation followed the text of the paper, covering the following topics:

Icon Based Model Generation
Runtime Control
Online Help
Output Processing

Functions not yet implemented:
3D Vessel, Control Variables, Links to Database

Lessons Learned
Output processing is the biggest payback, cheapest to do.
Runtime control is good for production shops
Model generation is the most difficult
Access to manual through code is important
Completeness of GUI functional requirements are important.

Team is important
definitely need computer science and database people, but don't cut them loose -- let engineers be involved.

Recommendations to finish TOOKUIL.
Add database
Automate sensitivity studies.
Improve restart capability.
Add XTV.
Improve physical appearance/descriptiveness of iconic display.

TOOKUIL is still of a fairly early stage about input processisng. so it does not untangle, e.g. the nodalization diagram when it reads in an existing deck. The learning curve for TOOKUIL itself is only an hour or two. But it does not really help with the learning curve for TRAC, which is much longer.

It was suggested that 1) handling existing decks is very important, 2) it is also important to model the complete systems, not just thermodynamics, including controllers and balance of plant systems, 3) linking GUIs to expert systems will save a lot of time and be really valuable, also need to link to libraries of reference documents.

Requirements for A Multi-Functional Code Architecture (O. Tiihonen, K. Juslin, VTT, Finland) **O. Tiihonen**, Presentor

The APROS simulation system is under development with more than 50 different components. Can be used to build training simulators for all types of plants. Tracking simulators and predictive simulators(for accident management) need much greater speed (~100 times faster). Work in progress (parallelization). Code which has been vectorized performs well in parallelization compilers. For maximum performance, reprogramming may be necessary.

General Requirements for Modern Safety Analysis Codes
Wide range of capability
Reactor modeling including thermodynamics, auxiliary systems, automation and electrical
Extensive validation

Database should contain
all calculational level parameters
component definitions
process level parameters
symbol definitions
picture definitions
output definitions
documentation
Component definition language
parameterizable components
subprocesses
data dependent parameter lists
data conversions
Strict rules for access rights

Currently using X/Motif, next yearsÕ version will be in MS windows.

Development of the Simulation System *"IMPACT"* for Analysis of Nuclear Power Plant Severe Accidents (M. Naitoh, et al., NUPEC, Japan)

- 10 year project 1993 to 2002.
- Supported by MITI at NUPEC
- Promote understanding of severe accident LWR phenomena
- Minimize empiricisms/Maximize use of mechanistic models
- Use parallel computer technology
- User assistance for input generation/output visualization
- Modular, fast running
- Number of engineers involved involved for software development: currently 8 inside NUPEC and about 20 as NUPEC contracters
- Use F90 for analysis modules and C++ for control modules
- Use MPI as message passing library.
- Phase 1 (1994 - 1997) concentrates on finishing fast running analysis and simulation. Interface in phase 1 period will be based on commercial interface product. Will build our own GUI within 1998-2000.
- Parallelization method and results for single-phase flow analysis will be published in a journal in 6 months or so.

BREAK-OUT SESSION 1

Advances and Needs on Thermal-Hydraulic Modelling

Co-Chair: J. Lillington, M. Reocreux and G. Yadigaroglu

The discussion in this session was based on the characteristics of the existing codes that were summarized in the Opening Plenary Session and the application needs that were identified in Session 1 and listed in Table 1.

The Top Level Code Design Objectives that were identified during this meeting are listed below and can be used to guide future developments.

INCLUDE YADI SLIDE Code Design Objectives

It was agreed that the time horizon for the developments discussed here is the next 5 to 10 years.

A list of nine Proposals for Code/ Model Improvements was established as follows and was the basis of the discussion that followed:

1. Multi-field models
2. Transport of interfacial area/dynamic flow regime definition
3. 2D or 3D hydrodynamics and their closure laws
    - 3a. system wide global two-phase transports
    - 3b. single phase detailed CFD capability
    - 3c. two-phase detailed CFD capability
4. Turbulent diffusion models
5. Operation at low pressure/ low flow
6. Operation in the presence of noncondensibles
7. Neutronics
8. Phenomena in Eastern reactors
9. Containment phenomena and situations beyond DBA in the primary system

For each code/ model improvement the following factors were considered:

Why is the model or improvement needed? There should be identified uses of the code that make such improvements necessary.

How should the proposed improvements be implemented and feasibility of implementation; more specifically:
- how mature are the approaches or the models?
- how much further research is needed before implementation?
- do present code structures and numerical methods allow implementation?

In addition the extent of any experimental support needed before implementation should be considered. Finally, the various code and model improvements should be prioritized.

Initially the discussion centered around the need for a new code or code improvements and whether simply accepting the errors in present code predictions is a viable alternative. The consensus of the majority of participants was that improvements to the existing capability are absolutely essential. In particular, this capability is essential for the regulatory agencies that need to understand well all situations taking place in operating reactors. Proper code uncertainty evaluation requires the elimination of certain code biases that can only be made possible with the addition of the appropriate physical models. For example, it is not possible to estimate the uncertainty due to the neglect of three-dimensional effects when one-dimensional codes are used. It was also pointed out that understanding the basic physics was the best way towards progress. It was also felt that maintaining expertise and know-how in safety analysis was linked to the a minimum level of related research and development.

Each of the nine proposed areas for code/model improvement was then discussed in detail within the pre-established framework.

MULTI-FIELD MODELS

Needs: Multifield models are essential for prediction of certain phenomena, such as BWR normal operation and transients, containment analysis, transition from inverse annular to dispersed flow during LBLOCA reflooding, entrainment and de-entrainment in the upper plenum, description of phenomena in the PWR downcomer, etc.

The obvious need that was clearly identified was for codes with two fields for the liquid phase, namely film and droplets. Such multifield descriptions already exist in industry codes. Adding this type of model is possible within the present code structure and numerics. Multi-field models are more physically based so that closure relations are straightforward; however, a larger number is required. For example, it will be easier to treat drag on drops and films separately rather than develop a model for the average of the combined liquid fields. Some additional experimental data are neeeded to validate the models.

2. TRANSPORT OF INTERFACIAL AREA/DYNAMIC FLOW REGIME DEFINITION

Needs: All interfacial transfers are directly dependent upon the interfacial area. In the present generation of codes the latter is determined using flow regime maps based on steady-state flow observations. In fact, it is necessary to describe the dynamic evolution of the interfacial area that governs flow regimes instead of using such steady-state flow regime maps to avoid unphysical flow descriptions. For example, the evolution from bubbly to stratified flow after a bend cannot be properly described using a steady-state flow regime map. Description of the developments of the flow at the entrance of reactor pipes also requires a dynamic flow regime treatment.

It was agreed that in terms of present code weaknesses this item was potentially having the greatest effect. Implementation of interfacial area transport equations will eliminate the use of flow regime maps based on steady-state and fully developed flows. Ishii's paper on the subject outlines the manner in which an interfacial area transport equation can be implemented. For multi-scale phenomena (e.g., a spectrum of droplets), more than one transport equations may be needed. Describing interfacial area source terms is an area that will require analytical and experimental work.

Success will depend on getting properly scaled experimental data that we now don't have. Some data are available, particularly from the chemical industry. The need for testing in geometries representative of small pipes, large pipes, bundles, annuli, and directional changes was identified.

3. 2-D OR 3-D HYDRODYNAMICS AND THEIR CLOSURE LAWS

Three different aspects of this general problem were identified:

a. system wide global 2-phase transports
b. single phase detailed CFD capability
c. two-phase detailed CFD capability

Regarding the first item, the need is to describe global mass movements, such as these happening during vessel injection, multi-dimensional downcomer behavior, multidimensional core behavior driven by unsymmetric loop operation (which is often encountered in power plant operation), etc.

Such capability has already been built into certain system codes but these describe such situations with coarse meshing.
The scale for such a multi-dimensional treatments is yet to be established, but it was agreed that it would be somewhere between the present coarse meshing (e.g.,TRAC) and that used in CFD codes. The need to define flow regimes under 3-D conditions was identified. Validation of these models against experimental data is required.

The second item is related to the need to treat in detail certain single-phase multi-dimensional phenomena such as thermal-mixing (related to pressurized thermal shock, PTS), boron dilution, mixing in containment volumes, etc.

The need may be met by coupling system codes to existing CFD codes.

The third item is the modeling of two-phase flows with methods similar to the ones used today for single-phase flows, including phase turbulence. This is a fundamental research area for the support of all multi-dimensional two-phase flow developments. It is exploratory research that will hopefully result in multi-phase flow models addressing the phenomena at a much more detailed and physical level. It will, in the long-term, also result in a more physical modeling of the phenomena identified under the first item here. Some research efforts are already underway in this area.
Alternative approaches such as Large Eddy Simulation (LES) should also be studied, starting now.

4. TURBULENT DIFFUSION MODELS

Turbulence diffusion models are needed for the second and third cases described in Section 3, above. Thus, additional separate discussion of this item was not necessary. It was, however, noted that inclusion of such models in two-phase flow codes requires implementation of low-diffusion, higher-order numerical techniques.

5. OPERATION AT LOW PRESSURE/LOW FLOW

This region of operation is characterized by rapid changes in flow regime and unstable flows due to the large density ratio.

Needs: Such conditions appear at mid loop operation, in passive ALWRs, in the containment and during severe accidents.

Existing correlations need to be validated for these conditions and properly implemented.

6. NON CONDENSIBLES

The needs are similar to the ones identified for low-pressure / low flow operation: mid loop operation, passive ALWRs, containment, and severe accidents. In addition, non-condensibles are present during accumulator injection.

One of the major problems with some existing codes is that the noncondensible models were added later and are not an integral part of the model and of the solution scheme. Thus, "clean-up" of present coding is needed. For a new code, noncondensibles should be included in the basic approach. Mass transfer models will also need to be implemented.

Data on heat and mass transfer in the presence of noncondensibles exist for condensation in tubes and on walls, although some gaps may be present. There is little data on condensation of bubbles with non condensibles.
Interfacial heat transfer models should be able to properly describe heat transfer in the limiting case when the gaseous phase is constituted of noncondensible gas only; e.g., this case appears during cold nitrogen injection from accumulators.

For severe-accident and containment applications, *several* noncondensible gas fields may be needed.

7. NEUTRONICS

Needs: Multi-dimensional neutronics are needed to treat situations such as Reactivity Induced Accidents (RIA), Anticipated Transients Without Scram (ATWS), BWR stability, etc.

Three-dimensional neutronics models are available and should be used whenever necessary (rather than more limited one or two-dimensional models). Consistency in the spatial detail with the corresponding thermal-hydraulic models should be verified. The uncertainties of the neutronics need also to be quantified.

Remaining issues are homogenization and flux reconstruction.
These need to be considered, in particular for the case of transients.
Three-dimensional neutronics is thus mostly a matter of implementation of available techniques.

8. EASTERN EUROPEAN REACTORS

Differences of these reactor designs that must be modeled include horizontal stem generators and hexagonal fuel. There are ad hoc groups addressing these areas and plant data exists. The fourth of a series of meetings on horizontal steam generator analysis will be held in Finland. Validation of models for eastern designed reactors is now underway (OECD Report). GIVE REFERENCE

9. PHENOMENA IN CONTAINMENT AND BEYOND DBA SITUATIONS IN THE PRIMARY SYSTEM

Needs: Phenomena taking place in the containment include heat and mass transfer in the presence of noncondensibles described above, as well as certain phenomena taking place in pressure-suppression containments.

Description of certain phenomena, such as hot/cold steam counter-current flow in the hot leg, quenching of overheated cores, core flow blockages, radiation heat transfer,

etc. is required for beyond DBA events. Water properties under extreme conditions need to be implemented.

Containment models are available and need to be implemented or coupled via special modules. This could be done in a modular fashion.

Coupled code capability for severe accidents already exists examples are RELAP/SCDAP and CATHARE/ICARE; implementation is possible.

PRIORITIES AND RESEARCH NEEDS/IMPLEMENTATION

Priorities were established for each of the nine code/model improvement areas identified above. The need for any additional experimental (E) and/or theoretical (T) research was also identified. The areas where simple implementation will suffice are indicated (IMPL). The following table summarizes the results. Priorities were characterized as Very-High (VH), High (H), Medium-High (MH) and Medium (M). ELT indicates Exploratory Long-Term research needs:

Code/ Model Improvement	Priority	Further Research
1. Multi-field models	MH	E
2. Transport of Interfacial area	MH	E,T
3. 2D or 3D hydrodynamics and their closure laws		
a. system wide global 2-phase transports	MH	E,T*
b. single phase detailed CFD capability	M	Comp.Sci**
c. two-phase detailed CFD capability	ELT	E,T
4. Inclusion of turbulent diffusion models	same as 3b,c	
5. Operation at low pressure/ low flow	HH	IMPL
6. operation in the presence of noncondensibles	HH	(E),IMPL
7. 3D neutronics	H	T
8. Phenomena in Eastern reactors	underway by ad hoc groups	
9. Modeling of contaiament and beyond DBA	H	IMPL

* need to consider numerical diffusion - higher order schemes

** Computer Science effort needed

BREAK OUT SESSION 2
NUMERICAL TECHNIQUES AND COUPLING INTERFACE REQUIREMENTS

Moderators: J. Luxat, J. Mahaffy,V. Teschendorff

The objective of this session was to establish the desirable characteristics of numerical techniques and coupling interfaces for system thermal hydraulic and neutronics codes. During this process we considered the general topics of numerical robustness, accuracy, models for coupling separate solution packages, objective evaluation of numerical methods, and some related programming issues.

ROBUSTNESS

Our simple definition of Robustness is the ability of a code to run to problem completion without user intervention (time step adjustment) or code failure. This is a practical definition but there is a second part. The code must also give an accurate and repeatable solution. We require both robustness and accuracy within a defined range of validity. A wider range of robust behavior is acceptable only if the code inform the user that it is beyond its verified range of validity.

In general, the code must be able to handle any modeled fluid, from freezing to above the critical point (superheat). The pressure range has to be from partial pressures (near zero psi) to above maximum design system pressures for a PWR (3000 psi). This ability is also related to robustness but can also be considered as a "soft" limit (i.e. the code should have some ability to estimate an answer when going above or below the physical state limits). Some discretion can be given to the user on how the code will handle going outside its operating bounds. A more precise range must be specified by code users, and communicated to the developers.

The codes should be expected to handle the full range of problem time scales associated with physical processes. The current situation is phenomena with high propagation velocities (pressure waves) force small time steps to ensure accuracy. If these phenomena are always captured during a long term transient, then the complete calculation will take several days to weeks, even on the fastest workstations. It was suggested that an adaptive time step controller be implemented in the codes to give the user the small time steps only when absolutely required and to change the largest possible time step (for a given accuracy) at all other times. Users could request detailed tracking of sound waves by requesting a rigorous Courant limit within the robust time step controller.

When requesting the codes to resolve pressure waves and phenomena such as long term

cooling, using one set of governing equations, there is the potential for a loss in accuracy.

Running time is a major issue when considering numerical methods. In some ways, "reasonable and practical running times" is either in the eye of the beholder or a trick question. It clearly is a moving target since it is dependent on the latest in computer technology and architecture. The general approach is to make a balance between run time and accuracy. There are concerns regarding the most cost-effective use of the analyst's time. Real time might be acceptable for many applications but unattainable for other cases. It is a good target.

Real time is a target we can define today but there may be exceptions (cases with large number of nodes and local effects or information). This is secondary to robustness.

Discussion on the ability to accommodate situations involving "steep gradients in process variables and coupled feedback identified that this is of great importance in some key phenomena occurring in nuclear reactors. Therefore, the code must have the capability to track steep gradients, two-phase interfaces and other similar situations.

COUPLING OF MODELS

A major issue imposing constraints to providing flexible and extendible coupling between different discipline models is the degree of modularity in a code. It was considered desirable to maintain a high level of modularity within a code and, to the extent practical, maintain separation between disciplines as a separation of programs.

The question of whether explicit or implicit coupling of modules was preferable was considered. There is no single solution since this is truly process dependent. There is a risk of discontinuity between how you couple the code and sections of the plant (example: linking core T-H and loop T-H). Thus, there are two levels of modularity: Internal (core and loop T-H coupling) and external with the linking of modules developed by different disciplines (RCS and containment coupling). One must ensure that the interface is tightly controlled and that the physical condition of the fluid does not change when switching from one module to another. The general conclusion was that the interface should permit, but not require, implicit coupling.

We should establish unified interface protocols that allow modular coupling with clearly defined structures to control interactions and data transfer between coupled modules. Other disciplines have set standards for data transfer (example: Reactor Physics and their transport codes). This is important not just for data transfer but also for coordinating events between modules. The transfer must occur through one point to avoid the corruption of data from

multiple transfer points within a module. However, careful thought should be given on how this would affect parallelization of the code. The QA and maintenance of the code would be simplified by having only one through-data transfer point. This transfer point must never involve intervention of one program into another's database.

OBJECTIVE EVALUATION OF NUMERICAL METHODS

We need to establish a set of numerical benchmark problems that provide an objective measure of numerical method abilities. There can be no good measure of how effective the numerics from one code to another are unless there is some commonalty in the testing. The problem is selecting the numerical benchmark and its boundary conditions in such a way as to separate out effects due to the physics versus those due to the numerics. Specific models must be provided for source terms such as phase change to test the response of methods to typical nonlinear terms. Solution of linearized equations should be tested both in the context of flow problems and with specific matrix solution benchmarks.

One wants to benchmark to problems with known analytical solutions. In this case, you must be able to separate the physical and the mathematical solutions. Based on mesh or spatial convergence and time step convergence, one could produce a reference solution. Important to track the mass and energy error in an easily accessible form.

Test problems should cover:
- Robustness
- Accuracy
- Run time (count of floating point operations)

Within the context of :
- Basic two-phase flow solutions;
- Solutions with specified source terms (mass & momentum sources, etc.)
- Basic matrix solutions

Measures of a methods quality would includes:
- Ability to obtain solution convergence as mesh length or time step are decreased
- percent error in mass and energy
- L^2 norm of fall results
- Variance of results when executed on a range of compilers and optimizations, run time at a specified accuracy

OTHER FACTORS

The discussion on which programming language to use was surprising civil. There are several issues related to this that are not controllable by the code developer. The programming language should have a standard definition (i.e. FORTRAN90) and should be portable to other machines. However, as seen in the compilers currently available, there is no true standardization of language compilers. This can have an effect on what ever benchmark you may be comparing to the code results.

Parallel processing was also considered. It was agreed that there should be an allowance for parallelization of a code at the time of design. The important result is the final answer should not change whether in parallelization or not.

RECOMMENDATIONS

The most important recommendation is early establishment of the benchmarks. Second is establishment of protocols for a coupling interface. Finally, we recommend research into more accurate difference methods. These are important to the short term for following phenomena with sharp spatial gradients, and in the long term to permit implementation of turbulence models. Early development would include interface tracking techniques and research into promising higher order methods. All such methods must be tested early against typical two-phase benchmarks. The most promising high-order methods are those of Leonard, and the generic group of high order Riomann solvers. We also note that new methods will require reconsideration of the details of iterative linear systems solvers, particularly the choice of matrix preconditioning. It is recommended that code be structured to facilitate the testing of "computational engines" developed from the above research.

Breakout Session 3
User Needs and User Interfaces

Moderators: R. Caruso, D. Grand, T. Vantolla, and M. Naitoh

Breakout Session 3 addressed user needs and user interfaces to thermal hydraulic programs. The meeting was attended by about 25-30 people from the regulators, national laboratories, domestic utilities, vendors, and overseas institutes. The meeting was chaired by Mr. Ralph Caruso of the NRC, Dr. Dominique Grand of CEA-Grenoble (France), Dr. Timo Vantolla of VTT-Energy (Finland), and Dr. Masanori Naitoh of the Nuclear Power Engineering Corp (Japan). The focus of the meeting was to obtain a consensus on the code capabilities desired by users, codes features needed to assist users, characteristics of the user interface, and the mix of technical resources needed for code development. These points were previously posed as part of the call for papers prior to the CSNI meeting.

Discussion points for Breakout Session 3 are presented in Attachment 1 (the overhead slides used during the session). Modification were made to the discussion points based on discussion among meeting participants. The importance of code capabilities and features and the user interface characteristics was determined by ranking the attributes of each category by importance based on discussion among the meeting participants. This ranking may be used by code developers throughout the OECD to guide their code development activities.

A summary of the discussion for each main discussion point from Attachment 1 is presented below.

What Capabilities Do All Users Want For The Next 10 Years?

Code capabilities required for the next 10 years were reviewed. The time window of 10 years was selected since that is judged to be the maximum length of time that reasonable forecasting can be done, given the changes in computer technology. Much of the early discussion focused on defining just who is the user. Generally, meeting participants felt that codes are developed to provide decision makers with information. These decision makers can be regulators, utility engineers, reactor vendors, and fuel engineers among others. The needs of the users tend to vary and may be competing as well as diverse, complicating the code development process. As an example, the utility engineer who is interested in operating plant support may have different needs compared to and engineer working on the design of an advanced reactor. However, it

was noted that six years of code development work for advanced reactors has proven valuable for current reactors for analyses involving midloop operation and PRA. In particular, the improvements made in handling non-condensable mixtures at low pressure for advanced reactors has been important for midloop operation analysis.

The level of code capability and features is directly linked to the needs of the users. The types of codes that were discussed included both thermal-hydraulic and neutronic codes. Mechanical engineering simulation capabilities (e.g. pipe stresses) were also mentioned. The question of whether a code that "does everything" is needed was raised. Generally, it was agreed that another hierarchy is needed to establish desired user capabilities based on how the codes will be used in lieu of those listed in Discussion Point 1A. Although there may be a difference in perspective between the utility engineer and the regulator, the code capabilities needed are generally the same.

Code users among the meeting participants were asked to identify their code uses. The uses mentioned include:

- PIUS reactor analyses including SBLOCA, LBLOCA, spectrum of other design basis and beyond design basis events to evaluate PIUS reactor performance.
- Heat sink strategy studies
- Licensing safety evaluations
- Appendix K break spectrum evaluations
- Time and frequency domain stability evaluations

Utility needs cited were analyses used to support power uprate and midloop operation, generally for a specific plant. In contrast, regulators must be able to analyze a spectrum of reactors and review models, including input provided by licensees. It was noted that a GUI would be invaluable in supporting input model evaluation. It was also noted that regulator approved codes (and code models) through the review of topical reports and audits the capabilities of codes.

As a result of this discussion, analysis types were requested and then ranked in importance as presented in Table 1.

Table 1 - Types of Analysis Typically Performed with Importance Ranking

Ranking	Analysis Types
1	Design Basis Accidents
2	Operational Analysis - load runback and emergency operating procedure analysis cited. Plant transients would also be included.
3	Simulator/Plant Analyzers
4	Accident Management
5	Midloop Analysis
6	PRA Support Including Success Criteria and Event Timing
7	Component and System Design Analysis
8	Emergency Protection Analytical Support
9	Assessment of Other Codes (Cross Code Comparisons/Assessments)
10	Fire Protection Support

What Code Features Should Be Provided To Assist Users?

Desired code features were identified by meeting participants and are listed in Table 2 along with importance ranking.

Table 2 - Desired Code Features With Importance Ranking

Ranking	Code Feature
1	Robustness (i.e. no code aborts due to properties errors or other problems)
2	Documentation (User and Developers (Programmers) Manual)
3	Graphical User Interface
4	Internal Assessment of Uncertainty (automatically performed by the code)
5	Conserve Investment - by maximizing the use of previous model development efforts and user experience
6	Identification of the Range of Validity of Code Models and Correlations - warnings would be generated if validity range is exceeded

7	Structure the Code/Input Requirements to Miminize the User Effect - examples are time step control and automatic nodalization)
8	Near Real Time Code Performance
9	Training Guidelines - also user guidelines based on previous experience
10	Portability - Easy installation across a variety of computer platforms/compilers
11	Modularity - allow substitution of different models for 3-D thermal hydraulics, turbulence, etc.
12	Coupling Capability To Other Models - possible models to be coupled include kinetics, containment and those used for severe accident analysis

Several desired user interface features were identified by meeting participants. Strong concerns were expressed about losing the investment in knowledge and experience in previous model development. This investment must be preserved and it was proposed that knowledge base development based on expert system techniques. The user interface features are listed in Table 2 along with the importance ranking.

Table 3 - User Interface Requirements With Importance Ranking

Ranking	User Interface Requirement
1	Post Processing Plot Generation/Replay
2	Fluid System and Control System Logic Diagram Generation
3	On-line Component Library - allow user to select previously developed models for components such as steam generators
4	Expert System Assistance (Input and Runtime) - utilize animated graphics to show changes in important physical phenomena
5	Error Resolution Assistance (Input and Runtime)- clear diagnosis of problems when they occur
6	User Generated Input Documentation - allows notes and comments to be incorporated into the model for future reference and traceability.

7 Configuration Control of Input - previously developed models would be stored and users could access and modify these models to suit their needs. Changes could be highlighted using colors.
8 Interactive Runtime Changes - changes in problem specifications during execution
9 Runtime Display of User Selected Results
10 Input Translation Between Codes - e.g. TRAC, RELAP5, CATHARE, ATHLET
11 Hardware Based Input - example is to pick a Schedule 40 pipe of a given diameter and length and have the pipe automatically nodalized.
12 Common GUI for Multiple Codes
13 Assistance in Coupling Codes
14 Report Generation - input summary in tabular format

One item that was noted that nodalization for various components should be based on test data where applicable. However, this may not be practical in all cases since nodalizations developed for topical report submittals by licensees for specific applications are not changed. It was also noted that on-line diagnostics during run time could be done by utilizing color changes to highlight changes in a particular parameter (ex. temperature limits, rate of temperature increase).

The role of the user in the code development process was extensively discussed. Generally, the code development process requires developing requirements which are translated to software specifications. Software design specification (preliminary and final) are then developed and then the code development process proceeds. An example of a requirement is midloop operation capability. Code developers would develop model specifications to meet the requirement. Users would then review the specifications. It will be necessary to iterate (negotiate) between the users and developers until agreement is reached. Then, the software design and development process proceeds. It is noted that knowledgeable users are needed to successfully implement this process. It was emphasized that feedback from the users is important and that user experience is an important component of this process. It is also noted that the role of experienced, knowledgeable users is generally not defined in the current software design approach. Conversely, developers should be involved in applications of their software periodically and probably visit some of the sites where application work is done to gain perspective on the use of the software.

The steps for integrating the user in the software development process were outlined by the meeting participants as follows:

- Use all available technical user (and software developer) resources in the international community
- Involve the user in the code design and implementation process in the following ways:
  1. Users will specify design requirements and success criteria
  2. Users will review code development design specifications
  3. Code developers design and develop the code
  4. When the developer believes the code meets the success criteria, it is then delivered to the user for acceptance testing.
  5. Developers are available for user support, including training and continuing information exchange.
- Utilize useful information on software development (tools and techniques) from other engineering disciplines and from computer programming sources. Note that some of these were identified by Dr. John Mahaffy in his review of two phase flow advances during Session 3.

Resources need to be considered in the software development process and that user requirements may have to be negotiated based on available resources. Software specifications should include manpower requirements.

It was emphasized that the user is the reason that the code is developed and that the user should have the "last word."

Additional Recommendations

The meeting participants reiterated that it is necessary to have access to data used for code validation and archival experimental data used in the code validation process. It is recognized that companies may designate some of the data as proprietary which would limit access to certain data. However, the larger risk is that experimental data from unique tests such as LOFT may be lost. Also information on how the data was measured (instrumentation details) and processed is needed and must be included. The need to have the data stored with a stable organization in a retrievable manner was strongly emphasized.

Finally, it was noted that the results of all computer analyses should be carefully scrutinized by a human analyst who understands the phenomena of interest, and who

can identify anomalies in the results.

CLOSING PLENARY SESSION

Code Capabilities and Desired Attributes

(Minutes from Closing Plenary Session on November 8, 1996)

Dr. Eltawila made the opening remarks. He also moderated the discussion.

•Dr. Eltawila (USNRC) asked if different numerical schemes could be used for different areas in the same problem based on their effectiveness. He said that the La Salle transient calculation would benefit from such a scheme. Dr. Mahaffy (PSU) replied to him with a humor, asking "How much would NRC pay for it?" He added that getting a higher order method in one region and first-order methods in other regions to talk to each other was very difficult. He also pointed out that in a transient such as La Salle, driving forces and damping forces compete, eventually dictate the outcome, and such a scheme would be sometimes very dangerous.

•Dr. Reocreux (France) said that we ought to improve the multi-dimensional capability in codes. He also asked from the group that the exploratory numerical work should be carried out parallel to the ongoing physics research. He added that as a group, they ought to be consistent in recommending both numerical methods and the physics.

•According to Dr. Teschendorff (Germany), the numerical methods are also a major cause of code deficiency besides the physics. To improve the methods, low diffusive methods must be developed. Referring to Dr. Ishii's presentation, he emphasized the importance of including the interfacial area transport in two-phase flow models. On the other hand, the numerical community was not ready to accomplish it today. In his view, this was a mistake. He said that we should not repeat the same mistake and therefore direct today's research by considering our needs at least 10 years from today.

- Mr. Kelly (USNRC) stated that implementing new methods to the codes in order to test them was too expensive. He thinks that small pilot/test codes must be written to test a new method, e.g. low diffusive schemes.

- Dr. Lillington (UK) reminded the group that there were already advanced two-phase methods in CFD codes and they were successfully applied in several areas although interfacial transport had little or no significant importance in these applications. He said that these methods could not be carefully tested with interfacial mass, energy and momentum transport if it was desired to implement them in our codes.

- A question from the audience about establishing common criteria for time step selection noting that the time step size was usually adjusted by ad hoc methods but not criteria from the first principals. It was also asked if we were ever going to have a single code to accomplish everything. Dr. Eltawila answered, "A single interface can be designed to call different modules from a library and the user would not have any feeling that different codes are used in the background." Dr. Eltawila's answer opened up a discussion on the modularity of codes. On this matter, Dr. Grand (France) added that a level of modularity had been already achieved in CATHARE with conventional programming techniques and it could be further facilitated by the object oriented technologies. Dr. Teschendorff said that he thought the subject of modularity should not be regarded as an easy way out from the problems and a highly modular code would still have problems. In his view, a general code must have certain specifications for transients, time scales and flow regimes, etc... Dr. Reocreux reiterated that CFD codes and two-phase codes were fundamentally different. It is a fact that two-phase codes need careful assessment. In his view, breaking up the physics into individual modules must be carefully considered. When all models are brought together in a code, they usually compensate errors from each other. Therefore, the user would get radically different answers to a problem when he freely selects from a set of physical modules.

• Dr. Lillington repeated that the advanced numerical methods actually existed in today's CFD codes. Therefore, the research must concentrate on developing physical models. Dr. Reocreux reminded that everything developed for CFD codes must be tested with a comprehensive set of benchmark problems. As for getting hints from different fields, Dr. Grand added that the scientists in climate research had been developing new approaches to couple oceanic and atmospheric calculations with different time scales, and their methods could be a good example for coupling models with different time scales in nuclear safety.

• Dr. Eltawila returned to the subject of implementing the interfacial area transport equation. He asked Dr. Mahaffy how one could put together the physical models and numerical methods for area transport. Dr. Mahaffy replied that both research areas could be advanced in parallel. He indicated that the area transport methods were in fact not new unlike everybody thought and there were certain people with knowledge and experience with these methods. Adding to Dr. Mahaffy's reply, Dr. Luxat (Canada) said that the problem had to be defined clearly so that the research on the numerical methods could be carried out parallel to the work on the physical models. Another question on the subject came from Dr. Lillington, "Isn't it going to be straightforward implementing the method in one-dimensional flows?" Mr. Kelly answered him with an example from the industry: COBRA-TF has three fields and the interfacial area transport equation is already a part of the solution. This code employs a semi-implicit solver and the time step size is always limited by the Courant limit. Therefore, an extra equation for the interfacial area could be solved explicitly at the end of every time step (very simple). On the other hand, Mr. Kelly and Dr. Mahaffy agreed that it would be more difficult job to implement an extra equation for the area transport in an implicit solver.

• It was noted by an audience member that advances in numerical linear algebra could be very well used to improve the codes referred to in Dr. Mahaffy's presentation of the previous day, adding that the physics can be incorporated to the pre-conditioners in some of advanced linear solvers.

• Another audience member complained that a set of challenging test problems did not exist. If a suite of problems were provided, the code developers could compare their methods against each other. Dr. Yadigaroglu (Switzerland) replied that OECD had already published a book with such problems in the mid 80's. It was agreed that a journal could be published every 6 months with results from developers so that the problems would not be forgotten and remain effective. On the same topic, Dr. Luxat raised another concern. He said that the numerical benchmark problems should be carefully designed to test only the numerical method and should constitute very simple physics such as the oscillating U-tube manometer.

• Dr. Eltawila asked if there was any work to do in automatic input deck conversion from one code to another. This question brought conflicting answers from the audience. Some members positively agreed to have an automatic means of converting the input decks while others disagreed even to spend any resource to develop an automatic converter. Dr. Luxat commented that an input deck for one code could not be converted to another without human intervention and some work should be done manually. Prof. D'Auria (Italy) said he thought time and other resources should not be spent to develop an expert system for automatic input conversion when it was possible to use dedicated man power, e.g. graduate students. Dr. Teschendorff added to the discussion that an input deck for a power plant was more than thermal-hydraulics and neutronics, and no standard existed how to model a plant. Therefore, he thinks there are fundamental differences between the input decks for different codes. In his view, a standard for building plant models ought to be established before an automated input deck conversion between codes could be achieved. Mr. Kelly and Mr. Caruso agreed that eventually a mega-database should exist from which plant decks for different codes could be converted. On the other hand, Mr. Johnsen (INEL-USA) disagreed on the subject and he said the number of existing plant decks should be looked at before considering an automatic deck converter, which he thought, was finite. He also commented that deficiencies should not only be attributed to the models but also to the user. On the subject of automated deck conversion, it was concluded that an automatic converter could speed up the process and reduce errors although human intervention was still required.

On the discussion of building an expert system into codes and user errors, Dr. Mahaffy said that even experienced users will accept the results which could be regarded as nonsense based on his background in numerical methods. He said that an expert system would prove the user with expertise from experts in different fields. Mahaffy illicited positive audience response from the code users when he commented that all developers should be forced to use codes on real problems. He also admitted that he was not a good TRAC user eleven years ago, when he developed it but he was today.

An audience member said that USNRC was pursuing a graphical user interface which would incorporate an expert system.

- Dr. Eltawila asked if there was any common definition for the concept of modularity. Dr. Grand explained that component oriented technology, so-called objects, could be assembled together. It could be a particular physical model, numerical description of a plant, etc ... He continued that a module was an entity which had defined functions and attributes; it only knew the information that it needed know.

- An audience member asked if the group should recommend that the developers of new models consider parallelization. Dr. Mahaffy replied, "Yes, we did." Another audience member asked if time step control should be built into a code rather that having to "baby sit" the timestep. Dr. Mahaffy stated that the timestep control is an integral part of numerical method and it can induce stability problems unless carefully designed. Dr. Lillington commented that in general the timestep control fails to work in the current generation of safety codes. He gave an example: it is usually too late when a timestep controller discovers that the timestep size must be reduced and the code crashes. Dr. Teschendorff mentioned that many codes had different modules with different time scales. He continued, when a timestep controller for thermal-hydraulics sets a timestep size, other modules must "get along" with it. He thinks that a master step controller must be set up.

- An audience member asked for guidance from the group about the nodalization issues and added that it was currently a form of art. Mr. Wilson (INEL-USA) complained, explaining he was a potential user for the new code, that developers were not advising the users about the ongoing work and that they were simply told to "trust." He thinks that the developers must tell the users what their priorities are. Dr. Mahaffy that, in his view, first-order numerics works and we can live with it. However, he thinks that developers often repeat themselves on the need for higher spatial differencing schemes. At this point, he is not sure which way they will go. On the other hand, he and Mr. Kelly agreed that a new code will be fully implicit. Wall and interfacial shear, heat transfer and other closure relationships will be treated implicitly to enhance the stability.

Dr. Eltawila thanked the group and the audience, and made closing remarks.