UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

February 5, 2009

MEMORANDUM TO: ACRS MEMBERS

FROM: David Bessette
Advisory Committee on Reactor Safeguards/**RA/**

SUBJECT: CERTIFICATION OF THE MINUTES OF THE THERMAL HYDRAULIC SUBCOMMITTEE MEETING, TRACE PEER REVIEW, JULY 7, 2008

The minutes of the subject meeting have been certified as the official record of the proceedings for that meeting. A copy of the certified minutes is attached.

Attachment: As stated

cc via e-mail: ACRS Staff Engineers
S. Duraiswamy
J. Flack
V. Murphy

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MEMORANDUM TO: David Bessette, Senior Staff Engineer, ACRS

FROM: Sanjoy Banerjee, Chairman

SUBJECT: CERTIFICATION OF THE MINUTES OF THE THERMAL HYDRAULIC PHENOMENA SUBCOMMITTEE MEETING ON TRACE PEER REVIEW, HELD IN ROCKVILLE, MARYLAND, ON JULY 7, 2008

I hearby certify, to the best of my knowledge and belief, that the minutes of the subject meeting on July 7, 2008, are an accurate record of the proceedings for that meeting.

/RA/

Sanjoy Banerjee, Chairman
Thermal Hydraulic Phenomena

2/5/2009
Date

Certified by: Sanjoy Banerjee Issued: 2/5/2009
Certified: 2/5/2009

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
SUBCOMMITTEE ON THERMAL HYDRAULIC PHENOMENA
JULY 7, 2008
ROCKVILLE, MARYLAND

INTRODUCTION

The ACRS Thermal Hydraulic Phenomena Subcommittee met to consider the peer review conducted on the TRACE computer code. During the meeting, the Subcommittee heard presentations by and held discussions with staff from the Office of Nuclear Regulatory Research (RES), RES contractor, RES consultants who conducted the peer review, and Office of New Reactors Staff. David Bessette was the Designated Federal Official. The meeting was convened by the Chairman at 12:00 noon and adjourned at 8:00 pm.

ATTENDEES

ACRS
Sanjoy Banerjee, Chairman
Said Abdel-Khalik, Member
Michael Corradini, Member
William Shack, Member
Tom Kress, Consultant
Graham Wallis, Consultant
David Bessette, Designated Federal Official

Staff
Farouk Eltawila, RES
Mirela Gavrilas, RES
Chris Hoxie, RES
Andrew Ireland, RES
Joseph Kelly, RES
William Krotiuk, RES
Chris Murray, RES
Joseph Staudenmeier, RES
Kirk Tien, RES
Ralph Landry, NRO
Shanglai Lu, NRO
Weidong Wang, NRO

Public
N. Lee, AREVA
Cesare Frepoli, Westinghouse
Madeline Feltus, US Department of Energy
Spykos Traiford

AGENDA

1.	Introductory Remarks by the Chairman	Sanjoy Banerjee
2.	Staff Introduction	Chris Hoxie, RES
3.	Overview of the TRACE Peer Review	William Krotiuk, RES
4.	Conservation Equations and Numerical Methods	Marv Thurgood
5.	Models and Correlations and Assessment	Dominic Bestion
6.	Models and Correlations and Assessment	George Yadigaroglu
7.	System and Component Modeling and Assessment	Peter Griffith
8.	RES Prioritization of Peer Review Issues	Steve Bajorek, RES
9.	Staff User Experience with TRACE	Mirela Gavrilas, RES
10.	NRO User Experience with TRACE	Ralph Landry, NRO
11	Plans to Resolve Peer Review and Other Issues, Momentum Equation	Steve Bajorek, RES
12.	Subcommittee Discussion	

1. CHAIRMAN'S INTRODUCTORY REMARKS

The Chairman opened the meeting, stating that its purpose was to consider the peer review of the TRACE code. The plans of RES to respond to the peer review comments are to be discussed as well.

2. STAFF INTROCUCTION - Chris Hoxie, RES Staff

Mr. Hoxie, Branch Chief for code development, introduced the subject matter of the meeting. He stated that the current TRACE assessment exceeded any past NRC code assessment program. Four peers were selected to review the TRACE code and they will summarize their comments at today's meeting.

3. OVERVIEW OF THE TRACE PEER REVIEW - William Krotiuk, RES Staff

Mr. Krodiuk indicated that the objective of the peer review was to review the code documentation and to identify deficiencies. The peer reviewers had about six months of calendar time to perform their work. They were each allotted 200 hours for a total effort of 800 hours. The documentation made available to the reviewers included the theory manual, assessment reports, user guidance, and the code itself. The peers were asked to review conservation equations, numerical solution methods, models and correlations, assessment findings, and quality of documentation.

The Chairman asked about whether an extension to the theory manual that derived the conservation equations, as implemented in the code, had been prepared. This had been promised by Dr. Eltawila. The Chairman indicated that the theory manual as it stands does not appear to meet the stated objective. Dr. Bajorek responded that the current theory manual attempts to do this. In the future, however, the manual will be separated into two volumes, one of which is intended to meet the Chairman's objective, while the second is intended to contain historical development and other related or ancillary information.

Mr. Krodiuk summarized some of the findings from the peer review. One was that the documentation should include a validation matrix that relates basic and phenomenological assessment cases to individual physical phenomena. The new interface tracking model should

be described better. The user manual should be rewritten with respect to modeling guidelines for system components, features, and models.

The Chairman and Professor Wallis inquired whether TRACE is an improvement over TRAC or RELAP5. The staff made some attempts to respond, but a satisfactory answer was not available. The Chairman asked whether TRACE conserves mass and energy for each phase. The staff responded that an answer to this question was not documented.

Professor Wallis asked about numerical diffusion in applications where this is important, such as the chimney region of the ESBWR, particularly when using SETS numerical method. Professor Mahaffey responded that SETS was not intended for applications where waves or interfaces were important, but only for gradually evolving flows. For a density wave, semi-implicit numerics should be used. Professor Mahaffey added that the amount of numerical diffusion necessary to provide computational stability is less than what occurs in physical flowing systems. Dr. Staudenmeier added that the documentation of TRACE applicability to ESBWR does not include density waves. Also, while TRACE has been coupled to PARCS, NRO does not use TRACE for stability analyses.

Professor Abdel-Khalik asked whether the reviewers identified substantial deficiencies. It appears that none were identified.

4. CONSERVATION EQUATIONS AND NUMERICAL METHODS - Marv Thurgood

Dr. Thurgood discussed his review of the subject. A two-field code cannot adequately model dispersed flow regimes and the flow solutions are often oscillatory and unphysical. A droplet field should be added. Addition of a droplet field is in the TRACE development plan. A fourth field addressing bubbly flow bubbles would be better still.

Responding to Professor Wallis, while the additional fields would increase the run time per time step, fewer time steps are required because the code is more stable. Therefore, the actual run time might even decrease. There are experimental data on droplet deposition and film formation on bends and obstructions. The addition of a droplet field can help in the modeling two-dimensional flow situations. Responding to Professor Abdel-Khalik, Dr. Thurgood added that this does not mean the code is inadequate for its current applications because adjustments have been made to fit data.

Dr. Thurgood stated that RES should consider using the conservative form of the momentum equation rather that the nonconservative form. He added that TRACE code uncertainty evaluation has not been performed for current or advanced plants. Dr Thurgood indicated that the code documentation was generally well written. Some areas needed improvement such as momentum changes at turns or Ts.

Professor Wallis noted that the nomenclature did not include units, making it impossible in some cases to tell what was really meant. Also, the process of going from a stress tensor to loss coefficients is not described. A better description and justification is required for translating a three dimensional representation of flow, which CFD codes attempt to do, into a one-dimensional code. Dr. Thurgood indicated that TRACE uses losses at bends to offset the pressure rise produced by the code. Professor Wallis noted that problems of this nature previously led the ACRS to recommend rejection of RETRAN.

Dr. Thurgood indicated that the water packing model sometimes prevents pressure spikes and sometimes does not. However, the addition of the level tracking model resolves this difficulty. TRACE has been tested on cases including manometer oscillation and filling of a channel. More discussion should be added to the user manual on how and when to invoke the level tracking model.

Several problems with treatment of noncondensable gases were noted, such as constant specific heat, use of mole fractions rather than mass fractions, viscosity and conductivity of mixtures. Professor Abdel-Khalik inquired how this might affect treatment of a large gas bubble in an ESBWR. An answer was not immediately available.

The Chairman inquired about the merits of using hyperbolic forms of the equations to ensure numerical stability as node size is decreased. Dr. Bestion indicated that the nodalization would have to be very fine, much finer than ever used in practice, before this became a problem. In response to a question by Dr. Kress, Dr. Bestion noted that 200 hours was woefully inadequate to review the subject.

5. MODELS AND CORRELATIONS AND ASSESSMENT - Dominic Bestion

Dr. Bestion indicated that the focus of his review were the closure models. The review was with respect to LOCAs in present plants and did not include, for example, stability of new reactors.

Most of the models in the code seem adequate. Mechanistic models are used where possible. Empirical models are used where a better approach is not possible. The documentation of model selection was very good. Dr. Bestion stated that the assessment was generally adequate. In some cases, the documentation did not include sufficient analysis of assessment results, probably due to resource limitations. One important deficiency identified is that TRACE does not model turbulent direct contact condensation at the ECC injection location.

Dr. Bestion recommended separating the derivations of the balance equations for one-dimensional and three-dimensional flows. He recommended adding a dispersed droplet field. Dr. Bestion had many other comments with respect various aspects of TRACE models, assessment, and documentation. In response to a question from the Chairman, Dr. Bestion indicated that efforts towards parallelization are not worthwhile. If the code is numerically stable, run time is not an issue.

6. MODELS AND CORRELATIONS AND ASSESSMENT - George Yadigaroglu

Professor Yadigaroglu discussed his review of TRACE models. He began by indicating that to fully answer questions of code adequacy was far, far beyond the level of effort allotted to the task. The assessment manuals alone are huge. Just looking at one case can take a week and there are hundreds of cases. Also, the review process was not interactive. He formulated some 100 questions for RES response.

Professor Yadigaroglu indicated that, while the assessment matrix for released versions of TRACE was available, the developmental assessment cases are not generally known. The assessment report needs an initial chapter that provides rationale and a road map to what follows in a top down fashion. There is no place to find the logic of the code to see how flow

regimes are determined and, in turn, particular models are selected, and where to find the information within the bulk of the documentation. What is missing are tables that link individual phenomena to developmental assessment, which should normally be part of the theory manual.

Professor Yadigaroglu indicated that many models were developed for mixtures. Such models must be converted two the two-fluid situation. How this was done is often not described sufficiently.

Professor Wallis suggested that, given the enormity of the task, one approach would be to do selective spot checks. Professor Yadigaroglu replied that this was what he did. He described a number of areas of his review, including finding interfacial shear from void fraction data, interfacial heat transfer, critical heat flux, post-CHF heat transfer (wall-to-liquid directly to avoid instabilities). Professor Yadigaroglu noted that rewetting is based on T_{min} and does not take account of quench front propagation, which is the real controlling mechanism.

Professor Yadigaroglu concluded that the TRACE team has done much good work. The focus of his presentation had been on remaining questions he identified, subject to the very limited resources available.

7. SYSTEM AND COMPONENT MODELING AND ASSESSMENT - Peter Griffith

Professor Griffith indicated that his review focused on component models. The experience from the Code Scaling, Applicability, and Uncertainty Methodology Study is relevant. There, it was found that uncertainties in heat transfer modeling were unimportant compared to the fluid mechanics of the problem. The worst predictions were most often a result of user errors.

Professor Griffith indicated that TRACE does not model surface effects associated with rewetting of oxidized Zirconium, and that this is very important deficiency. Mr. Kelly agreed that the rewetting modeling in TRACE is based on Inconel rods. This is a built-in conservatism that should be looked at in the future. It was not done for the current version due to resource constraints.

Professor Griffith indicated that the manual should clarify how users should model radiation heat transfer. The documentation includes descriptions of models that are no longer used but which are included for historical purposes. These should be moved to an appendix. The discussion of component models and modeling guidelines should be consolidated. The discussion of separator modeling should be rewritten. Professor Griffith endorsed the use of established, frozen nodalization schemes.

Discussion of code performance should not be based strictly on time, which is not necessarily the important independent variable when what is really important is inventory. Modeling break flow for a given area or break geometry is not important since a spectrum of break sizes must be considered. Experiments should be run with a break orifice that can be readily predicted such as a converging-diverging nozzle with an L/D of ~20.

8. RES PRIORITIZATION OF PEER REVIEW ISSUES - Steve Bajorek, RES

Dr. Bajorek indicated that RES staff had found the peer review to be very valuable and that a standing peer review panel would be helpful. Professor Wallis recalled that the only reason RES

staff was able to conduct the peer review was that the ACRS recommended that it be done. The Chairman noted the absence of RES management in the room.

Since the last meeting with the Subcommittee in February 2007, other TRACE-related activities have progressed, for example, input deck development. Much of this work is associated with converting RELAP5 and TRAC-B decks to TRACE decks. Concerning new reactors, calculations are being performed for ESBWR and AP1000. An EPR deck has been created and an APWR is planned.

Responding to the Chairman's question with respect to reflux condensation, Dr. Bajorek indicated that assessment has included ROSA, APEX, FLECHT-SEASET, and BETHSY. This includes secondary side cooldowns, along the lines of EPR. RES is also participating in the OECD ROSA program, which is looking at vessel head breaks, among other things.

TRACE applications often encounter problems with instabilities that cause the calculations to fail. The time step may become minuscule and the numerics cause unphysical results. When these problems occur, they are being fixed. This work is very important to NRR and NRO users, as well as others applying the code. Another priority is to update the documentation and assessment at the same time changes are incorporated into the code, rather than years later.

Another objective stated by Dr. Bajorek was to improve the user guidance. The user effect generally dominates over physical modeling in determining analytical results. User guidance on nodalization will be specific to PWRs and BWRs. Nodalization of components will refer back to the relevant assessment cases. In keeping with recommendations by the peers, discussion of history will be moved from the text of the manuals to appendices.

Dr. Bajorek discussed the modeling of ESBWR. The focus of the TRACE analyses of ESBWR has been in-vessel inventory. TRACE has been assessed against PANDA and extensive work has been done on modeling condensation in the PCCS. MELCOR is being used by NRO for containment. The focus of the containment analyses in pressure. For long term cooling the vessel and containment are coupled. Mr. Krodiuk indicated he has performed coupled TRACE-CONTAIN analyses and found numerical problems.

Dr. Bajorek indicated that high priority will be given to the momentum equation. If it cannot be "fixed" then simplifications will be justified. He agreed with the recommendation by Dr. Bestion that direct contact condensation at the ECC injection location is a high priority model to be added to TRACE.

Dr. Bajorek noted that the only nuclear rod data are from NRU and LOFT. NRU ran experiments focused specifically on fuel cladding burst, so those data are important for inclusion in the assessment matrix. Where peak cladding temperatures exceed ~800C, the cladding of those rods are expected to burst.

Professor Wallis noted that what was needed was a specific plan for addressing all the peer review comments. Committee members inquired whether the peer review report will include the RES response to each comment. The final peer review report will do so.

9. STAFF USER EXPERIENCE WITH TRACE - Mirela Gavrilas, RES

Dr. Gavrilas indicated that, in support of the NRO ESBWR review, RES has performed TRACE analyses and prepared a code applicability report. The analyses have been used to help NRO prepare requests for additional information. TRACE has also been applied in support of Browns Ferry extended power uprate and for GSI-191.

With respect to Browns Ferry, Dr. Ward indicated he performed small break LOCA analyses to investigate why one of the industry analyses had peak clad temperatures that were seemingly low, some 400F below the staff's RELAP5 and TRACE results. These staff calculations agreed with analyses submitted by GE using TRAC-G. Dr. Ward found that the low temperature in this particular vendor submittal was due to greater downflow of liquid from above the core. Dr. Ward's found that TRACE ran well for a spectrum of Browns Ferry small breaks.

Dr. Gavrilas noted that work is underway on input decks for BWRs 3, 4, and 5, and Westinghouse 2, 3, and 4 loop plants. RES will support NRO for ESBWR, EPR, and APWR. A substantial effort is going into deck development to give NRR and NRO the tools necessary to run calculations for every class of plant in the country.

Dr. Kress asked about the ability to do best-estimate with uncertainty with TRACE. Such uncertainty analysis has not been done. While it remains an objective, it keeps getting deferred due to higher priority work. Dr. Kress indicated this should be included as a subject in a future Subcommittee meeting. Professor Wallis stated that until uncertainty analysis is done, the staff cannot confirm industry best-estimate licensing submittals.

10. NRO USER EXPERIENCE WITH TRACE - Ralph Landry, NRO

Dr. Landry began by discussing the momentum equation. Issues identified in working with TRACE were seen to be generic and applicable to the vendors. Based on these issues, RES formulated sample problems that were sent to the vendors. Dr. Bajorek added that the problems look at flow splits at Ts and at 1D-to-3D junctions.

Dr. Landry described calculations in support of GSI-191. One calculation had a uniform reduction in flow area at the core entrance of 95%. This was compared with 95% of the core entrance fully blocked. No significant difference was found in core response.

Professor Wallis indicated he was encouraged that the user offices were beginning to utilize TRACE and the cooperation appeared to be proceeding well.

11. PLANS TO RESOLVE PEER REVIEW AND OTHER ISSUES, MOMENTUM EQUATION - Steve Bajorek RES

Dr. Bajorek began with discussion of assessment results. Many of the separate effects reflood tests comparisons of TRACE with data were reasonable. For integral tests, temperature overprediction becomes worse proceeding up the bundle. TRACE overpredicts entrainment at the quench from, therefore, more water is transported to the upper plenum. Correspondingly, quench front propagation is slower in TRACE compared to the data. The behavior is the same both for gravity reflood and forced reflood tests.

These deficiencies point to the need to add a droplet field, as noted by the peer reviewers. Currently TRACE does not model breakup of droplets at spacer grids, and the droplets are not

desuperheating the steam as much because of reduced surface area. Subcommittee members noted that important issues exist with modeling droplet fragmentation, coalescence, and behavior at changes in flow direction. Mr. Kelly noted that the Penn State Rod Bundle Heat Transfer (RBHT) program was designed to provide improved data with which to assess the code in support of adding a droplet field. The addition of a droplet field is planned for TRACE version 6. The current priority, however, is to ensure that version 5 works well.

Professor Wallis inquired about how the interfacial area transport work at Purdue University will be utilized. Dr. Bajorek responded that it is in the long term plans and would most likely require the addition of a fourth field.

Dr. Bajorek indicated that studies thus far on the momentum equation identified problems with converging or diverging flows in Tees. TRACE predicted a pressure gain, as noted earlier in the meeting.

Another area of concern for momentum conservation was in the vessel where the flow turns and reverses direction in the lower plenum between the downcomer and the core entrance. TRACE was found to overpredict the pressure drop by an order of magnitude. Considerable discussion of this matter followed. Professor Mahaffey has worked on the problem and provided code updates that have now greatly improved the TRACE prediction. LOFT L2-5 was selected to evaluate the possible importance of the matter. A sensitivity study was done that had three cases: 1) the TRACE version that over-estimated the pressure drop by an order of magnitude; 2) the same TRACE version but with a multiplier on the lower plenum loss coefficient to make it even higher than the order of magnitude over-estimate; and 3) the new TRACE version of TRACE with the improved pressure drop prediction. The difference in peak cladding temperature between the three cases was very small. Professor Wallis indicated that, while that may be true for this particular test case, it is not clear how a passive system might be affected. However, if it were important for current plants, it should have been noticed by now.

Dr. Bajorek stated that the test cases formulated for the momentum equation will be added to the TRACE assessment matrix and the results will be documented. If at some time it is determined to be a problem, the option exists to convert to the conservative form of the momentum equation or to use the mechanical energy form.

12. SUBCOMMITTEE DISCUSSION

The subcommittee discussed the letter to be prepared at the September full Committee on the TRACE peer review.

Professor Abdel-Khalik inquired again about what progress had been made towards answering the high level questions originally posed to the peer reviewers. Professor Corradini indicated that the peer reviewers were unable to make those kinds of determinations based on the material and time constrains presented. The Subcommittee concluded that while the peer review was a very valuable exercise, it is by no means the final word.

The meeting adjourned at 8:00 p.m.