ACRS-3145

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CERTIFIED BY:
Graham B. Wallis - 3/9/99

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Date Issued: 3/1/99

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
THERMAL HYDRAULIC PHENOMENA SUBCOMMITTEE MEETING MINUTES
WESTINGHOUSE BE LB LOCA METHODOLOGY FOR UPI PLANTS
FEBRUARY 23, 1999
ROCKVILLE, MARYLAND

INTRODUCTION:

The ACRS Subcommittee on Thermal Hydraulic Phenomena held a meeting on February 23, 1999 with representatives of the Westinghouse Electric Company (Westinghouse), and the NRC Staff. The purpose of this meeting was for the Subcommittee to continue its review of the application of the Westinghouse best-estimate (BE) large-break (LB) LOCA methodology to nuclear power plants with upper plenum injection (UPI). The entire meeting was open to the public. Mr. P. Boehnert was the cognizant ACRS staff engineer and Designated Federal Official for this meeting. There were no written comments or requests for time to make oral statements received from members of the public. The meeting was convened by the Subcommittee Chairman at 8:30 am, February 23, 1999, and adjourned at 4:20 PM that day.

ATTENDEES

ACRS Members/ACRS Consultants:

G. Wallis, Chairman
T. Kress, Member
M. Fontana, Member
R. Seale, Member
V. Schrock, Consultant
N. Zuber, Consultant
P. Boehnert, DFO

Westinghouse:

M. Nissley
S. Dederer
K. Takeuchi
J. Hoss

NRC Staff:

F. Orr, NRR
D. Bessette, RES

There were approximately 10-12 other members of the public in attendance during this meeting. A listing of those attendees who registered is available in the ACRS office files. Public participation during this meeting was limited to the presentations by the above named industry representatives.

The presentation slides and handouts used during the meeting are attached to the Office Copy of these Minutes. The presentations to the Subcommittee are summarized below.

RS01

CHAIRMAN'S COMMENTS

G. Wallis, Subcommittee Chairman, convened the meeting. He indicated that since the last meeting by the Subcommittee on this subject (December 16, 1998 session), he had discussed with a representative of NRC's Office of Nuclear Regulatory Research (RES) the question of whether a sufficient experimental base exists for validation of the Westinghouse WCOBRA/TRAC application to UPI plants. Dr. Wallis said that Mr. D. Bessette (RES) will make the opening presentation to address this point.

TEST RESULTS FROM UPPER PLENUM EXPERIMENTS

Technical Presentation

Mr. Bessette (RES) discussed the results from UPI experiments. The experiments discussed included:

- Upper Plenum Test Facility (UPTF)
- Cylindrical Core Test Facility (CCTF)
- Slab Core Test Facility (SCTF)
- Dartmouth Air/Water Upper Plenum Experiment
- Semiscale Mod 1 (only integral UPI test available)
- FLECHT - SEASET (Full-Length Emergency Cooling Heat Transfer - Separate Effects and System Effects Test)

Observations noted by Mr. Bessette were:

- PCT and reflood rate are similar between cold leg injection and UPI experiments
- Information is lacking on details of UPI jet behavior, however this does not matter in terms of system response.
- Test data consistently shows channeling of flow from the UP through the core
- Important modeling phenomena include breakthrough (of water flow at the upper core tie plate), channel formation, entrainment, and deentrainment. Condensation is a second-order affect.

Regarding use of this data for code assessment, Mr. Bessette recommended use of: UPTF data for modeling of T/H phenomena behavior at the UP, hot leg, and steam generator inlet plenum, CCTF data for reflood heat transfer in the core, FLECHT-SEASET data for liquid evaporation entrained to the steam generator, and investigation of the Semiscale integral experiment.

Subcommittee Comments

1. In response to Dr. Zuber, Mr. Bessette noted that the ECCS accumulator injection dominates the reflood process, UPI is a secondary effect.

2. Dr. Zuber noted that his experience when employed at RES was that the details of the UPI process could not be adequately modeled. Mr. Bessette agreed and noted that the response of the reactor coolant system to ECCS refill/reflood overrides these details.

3. In response to Dr. Zuber, RES noted that the disparate experimental data can be reconciled based on analysis of the aspect ratio of the experimental rigs, i.e., the test data provides consistent results.

4. Dr. Kress indicated that the key parameter is how much UPI water is carried out the break, due to steam binding. Mr. Bessette noted that the test data indicate that while steam binding affects the reflood rate, PCT is not significantly affected. To this end, RES said that the Semiscale test is the only study of the effect of steam binding on reflood.

5. Dr. Seale noted that many problems seen with analyses stem from use of these codes by unqualified personnel. He said that a product is needed that will give one a template for code users, i.e., a code that will greatly mitigate or eliminate the "user effect".

6. Dr. Zuber opined that Westinghouse did not explicitly follow the CSAU methodology, as claimed.

EXTENSION OF BEST-ESTIMATE LOCA METHODOLOGY TO PWRs WITH UPI

Introductory Remarks

Mr. M. Nissley, Westinghouse, in introductory remarks said that for today's discussions, Westinghouse would focus on the specific concerns/ issues raised by the Subcommittee during the December 16, 1998 meeting.

Technical Presentations

Westinghouse provided presentations on the following topics:

Upper Plenum Pooling and Drain Distribution

- Predictions of UPTF and CCTF Data
- Sensitivity of Data Predictions to Injection Modeling
- Comparisons of PWR Predictions with MPR/Siemens Estimates
- Sensitivity of PWR Predictions to Injection Modeling

Assessment of Subcooled CCFL Predictions

- Comparisons with Data
- Assessment of PWR Predictions Using Correlations

Reflooding of the Hot Assembly in a UPI Plant

- Experimental Evidence
- Sensitivity of CCTF Predications to Modeling
- Details of Predicted PWR Flow Pattern
- Sensitivity of PWR Results to Modeling

With regard to the evaluation of the code's capability to model the phenomena of UP pooling and drain distribution, Westinghouse ran parametric studies using relevant data from UPTF and CCTF tests. The code was found to either match the test data or provide conservative results (under predictions) for most of the "Figures of merit" Westinghouse selected from these tests. Regarding the assessment of Subcooled CCFL (counter current flow limit) predictions, the code provided conservative predictions of GE and UPTF test data. Comparison of predicted UPI CCF conditions with the Bankoff Correlation confirms that the subcooled limit is not exceeded. The interfacial drag and condensation models were ranged, using the GE CCFL data, and application of these ranged models to UPTF data provided conservative results. Finally, Westinghouse showed results of calculations of the reflooding of the hot assembly for a UPI plant (using color-coded code calculations "snap shots"). It was concluded that (1) the high-power central assemblies are cooled by bottom-up reflood: (2) accumulator injection alone is sufficient to initiate reflood, and the uncertainties in accumulator initial conditions can contribute more to overall uncertainty than uncertainties associated with the UPI draining phenomenon, and (3) the frozen version of COBRA/TRAC provides conservative predictions of subcooled CCFL in a UPI plant.

Dr. Wallis had posed a set of questions, based on his perusal of Westinghouse material provided a background to this Subcommittee Meeting. A copy of the Westinghouse response is attached to these Minutes.

Subcommittee Comments

1. Dr. Wallis said that Westinghouse should have ranged the drag coefficient upwards to the point of holding all water in the upper plenum as a check on the fidelity of its model.

2. Dr. Wallis opined that Westinghouse should have ranged its models around the mean of the test data, since this is a best-estimate code.

3. Dr. Zuber asked why Westinghouse did not use relevant test data generated at INEEL (using Westinghouse prototypic tie plates) and Hanover (Germany). Westinghouse indicated that they were not aware of the existence of this data.

4. Dr. Zuber questioned the applicability of the Bankoff Correlation, given the small size of the test plate used (2.3 x 7.0 inches) and that Westinghouse did not range up Bankoff's test data.

5. In response to Dr. Zuber, Westinghouse said that NRC was not provided a copy of the UPI version of WCOBRA/TRAC to exercise in-house.

6. Dr. Wallis expressed concern with a lack of rigor in Westinghouse's model ranging studies.

NRR Presentation

Mr. F. Orr, NRR, discussed the status of NRR's review of the application of the Westinghouse BE LBLOCA methodology to UPI plants. The scope of review, findings, key technical issues, schedule for completion of review and conclusions were noted. NRR has found the Westinghouse application acceptable, pursuant to the requirements of 10 CFR 50.46, and plans to issue a Safety Evaluation Report to this effect in early- March 1999.

Subcommittee Comments/Concerns

1. In response to Mr. Schrock, Mr. Orr indicated that the split break is limiting for two-loop plants. This calculation was performed on a parametric basis.

2. In response to Dr. Zuber, NRR said that they based their review on the test data presented to them by Westinghouse; they were also not cognizant of the INEEL or Hanover test data.

3. Dr. Wallis asked how NRR decided that Westinghouse had adequately ranged its drag model. NRR indicated that adequate justification was provided in that the ranging was performed conservatively. Dr. Wallis noted that no basis exists to guide a decision on the adequacy of the ranging procedure.

4. Professor Schrock noted that the Westinghouse code calculation is showing evidence of hysteresis, which indicates a significant error in the coding.

5. In response to Subcommittee questions, Mr. Orr said that NRR believes that Westinghouse has met the intent of the governing regulations with the effort expended on this application.

SUBCOMMITTEE CAUCUS

Dr. Wallis noted that time has been allotted for discussion of this matter during the March ACRS Meeting. He asked Westinghouse to prepare an high-level presentation summarizing its work on this application. He also requested written reports from the ACRS Consultants within one week.

In order to help formulate a Subcommittee recommendation for ACRS action on this matter, Dr. Wallis requested input from the Subcommittee Members via an exchange of E-Mails.

BACKGROUND MATERIAL PROVIDED TO THE SUBCOMMITTEE PRIOR TO THIS MEETING

1. Memoranda, dated December 1, 1998, and February 17, 1999 from P. Boehnert ACRS to Thermal Hydraulic Phenomena Subcommittee including the following material:

   - Letter, dated August 6, 1998 from H. Stepp, Westinghouse, to U.S. NRC, transmitting "Comparison of Best-Estimate Methodologies for Westinghouse PWRs with Upper Plenum Injection and Cold Leg Injection"

   - Westinghouse Topical Report, "Application of Best Estimate Large Break LOCA Methodology to Westinghouse PWRs With Upper Plenum Injection", WCAP-14449-P, dated August 1995, including an Appendix of information provided to the NRC in response to Requests for Additional Information on WCAP-14449-P **(contains proprietary information)**

   - Letter to P. Boehnert, ACRS, from H. Stepp, Westinghouse, Subject: Information Regarding the December 16, 1998 Meeting with the ACRS Thermal-Hydraulic Phenomena Subcommittee, dated December 2, 1998

   - Excerpts from Westinghouse Topical Report, "Westinghouse Code Qualification Document for Best Estimate Loss of Coolant Accident Analysis", WCAP-12945-P-A, dated March 1998 **(contains proprietary information)**

- List of questions from G. Wallis for Westinghouse response at February 23, 1999 T/H Phenomena Subcommittee Meeting, submitted via E-Mail, dated February 16, 1999.

- NRR draft Safety Evaluation Related to Acceptability of Westinghouse Topical Report WCAP-14449 (P) "Application of Best-Estimate Large Break LOCA Methodology to Westinghouse PWRs with Upper Plenum Injection", **Draft**, Undated

- Draft Technical Evaluation Report, Application of Best-Estimate Large Break LOCA Methodology to Westinghouse PWRs with Upper Plenum Injection, WCAP-14449-P, INEEL/EXT-98-00802, undated

- U.S. Nuclear Regulatory Commission, Regulatory Guide 1.157, "Best-Estimate Calculations of Emergency Core Cooling System Performance", dated May 1989

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Response to Professor Wallis RAI

Kenji Takeuchi

Westinghouse Electric Co.
(412) 374-4263

Advisory Committee On Reactor Safeguards
Thermal-Hydraulic Phenomena Subcommittee Meeting
February 23, 1999

Professor Wallis RAI-1
What are the criteria for determining when to use the "stable" and "unstable film" equation? Is this the reason for the hysteresis sometimes shown in flooding curves?

Response:
Hystereses computed for analyses of GE CCFL tests are summarized at the end.

Stability of film flow is judged in the code by the critical void fraction (stable if $\alpha > \alpha_{crit}$):

1) The critical void fraction for the flow regime is lower bounded by 0.8;

$$\alpha_{crit} = max[0.8, \quad \alpha^*_{crit}] \qquad (1)$$

2) The critical void fraction for stable film flow is related to the film Weber number by

$$\alpha^*_{crit} = 1 - \alpha_e - 2.0/We_{film} \qquad (2)$$

where

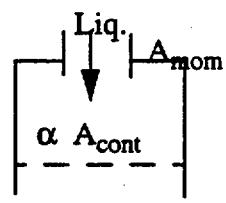
$$We_{film} = \rho_g D_h |U_{vl}|^2/\sigma \qquad (3)$$

3) It is assumed that liquid in excess of that required for a stable film is removed from the film and entered into drops (Lovell, 1977),

$$S_E = (\alpha^*_{crit} - \alpha)\rho_l |U_l| A_X \qquad (4)$$

4) 100% Break up of film into drops

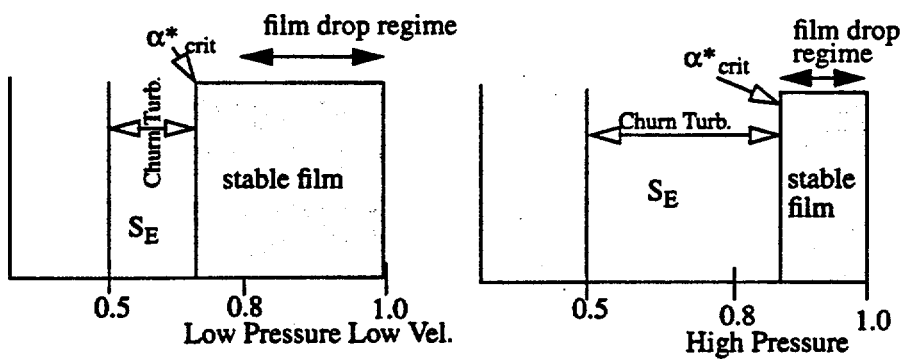
if $\alpha > 0.8$ and
if $0.95 * A_{cont} > A_{mom}$(donor)



Entrainment from Unstable Film

Entrainment due to items 1), 2), and 3) above is illuatrated.

These do not contribute to the hysteresis of CCFL.

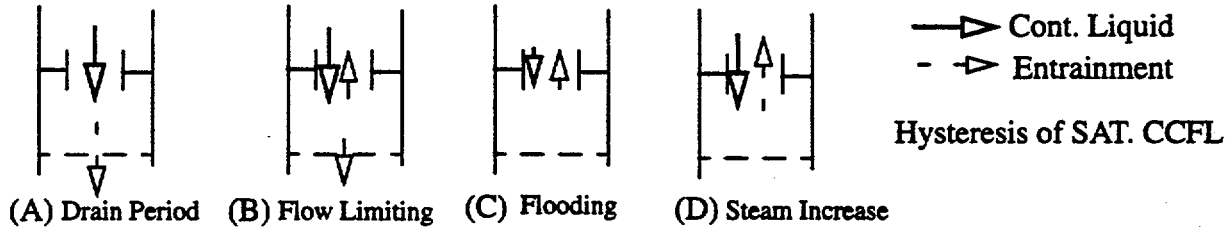


Hysteresis in SAT. CCFL in GECCFL

On the other hand, 4) is effective all the time for situation of liquid drain through the tie plate of GE CCFL tests, because $\alpha > 0.8$. When liquid film passes the tie plate, all the liquid is entrained. During *the drain period (A)*, all the entrained flow continues to drain downward. In *the Flow Limiting Period (B)*, the entrainment splits into down flow and upflow. In *the flooding period (C)*, any

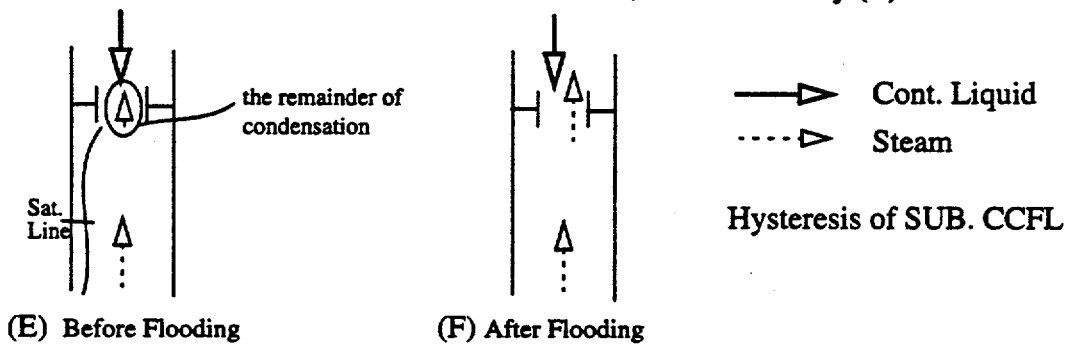
liquid passed the tie plate is turned around to the upflow. It becomes less with increasing steam injection rate. Once this situation is established, steam velocity in the tie plate is much faster than (A) or (B) for the same steam injection rate, because the effective steam flow area is reduced by the liquid flow.. Therefore, in order to reverse the state of (C) to (B) via. (D) in steam decreasing phase, steam injection rate must be reduced much more than (B) during the steam increasing phase. This created the hysteresis of the SAT. CCFL.

This was demonstrated by removing Condition 4).

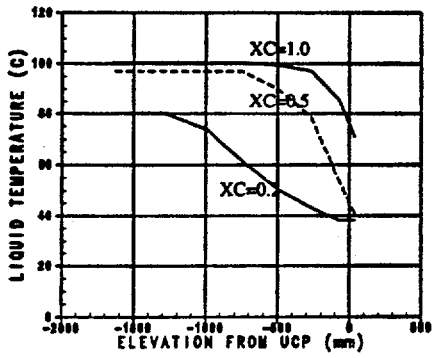


Hysteresis in SUB. CCFL

Hysteresis in subcooled CCFL, on the other hand, is caused by the mechanism of condensation reducing the amount of steam reaching the tie plate. *Before the flooding (E)*, subcooled liquid exists below the tie plate so that the steam flow rate at the plate is less than the injected flow rate. So, liquid continues passing through the tie plate and condensing steam below the plate. *After the flooding (F)*, however, there is no liquid below the tie plate. Thus, the steam injection rate has to be reduced to the level of the remainder of condensation, as illustrated by (E).



This is demonstrated by a sensitivity study which reduces the interfacial condensation above and below the GE CCFL tie plate using XC: More significant hysteresis occurs with XC=0.2 than XC=1.0 because more condensable exits below the plate with XC=0.2 (Figure below).



EL = 0 at the tie plate

Figure 5-1A Liquid Temperature vs. Elevation, Test 60

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Professor Wallis RAI-2

In discussing UPTF (and other) tests, make a distinction between downcomer annulus flooding (many data) and upper tie-plate flooding (few data). The latter is presumably of most relevant to UPI.

---------- *Response:* OK

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Professor Wallis RAI-3

Make clear in the figures and presentation which "points" are data and which are "computational experiment".

---------- *Response:* OK

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Professor Wallis RAI-4

It is puzzling how close the computational experiment comes to flooding correlations. Use of (15-1-34) will ensure j scaling but not predict a good straight line of slope minus one on a sqr(jg*) versus sqr(jf*) plot. How does Westinghouse make predictions come out so well?*

Response:

As relative velocity increased, Weber number increases and so α^*_{crit} increases. As a result, film is always entrained when flow limiting starts to take place. Therefore, WCOBRA/TRAC does not predict the flooding predicted by two fields of vapor and liquid film, alone.

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Professor Wallis RAI-5

The information about interfacial drag recipes on pp 15-1-22 and 15-1-23 is very incomplete.

(A) Does (15-1-34) switch suddenly to "unstable film" or is there a period of transition?

(B) Entrianment at a rate given by (15-1-35) appears independent of film thickness, which seems unphysical. There must be some corresponding deentrainment, otherwise the film will eventually dry out.

(C) When the film becomes "unstable" does its thickness suddenly switch to (15-1-36)? What happens to the momentum change of the entrained drops?

(D) Do the drops have a separate equation of motion? There is mention of a "three field model" in the NED paper. Does XYDRAG describe the vapor/drop interaction or the vapor/film interaction or both?

Response:

(A) Equation (15-1-34) applies to interfacial drag between stable film and vapor. As soon as the film is recognized to be unstable (the condition $\alpha < \alpha_{crit}$, Eq. (1)), the friction factor is switched to

$$f_{i,\,unstable} = max[5 \bullet Eq(15-1-34), f_{i,\,HH}] \qquad (5)$$

where $f_{i,HH}$ is the Henstock and Hanratty correlation (see Section 4-6-2 of CQD for 3/4 loop plant BE LOCA). Since $\alpha < \alpha_{crit}$, the flow regime is Churn-Turbulent regime.

(B) Equation (15-1-35) is a wrong reference. For the counter-current, the entrainment rate is determined by Eq. (4) in the above (or Eq. (4-128) of CQD).

(C) No, Eq. (15-1-36) is nothing but another expression of α^*_{crit} in Eq. (2), as shown below. The condition for instability, $\alpha < \alpha^*_{crit}$ in terms of vapor fraction, becomes

$$1 - \alpha_e - \alpha_l < 1 - \alpha_e - 2.0/We_{film} \qquad (6)$$

or

$$\alpha_l > \frac{2\sigma}{\rho_g D_h |U_{vl}|^2} \qquad (7)$$

Now that film thickness δ_l is related to liquid fraction by $\alpha_l = 4\delta_l/D_h$, the film instability condition becomes

$$\delta_l > \delta_{l,crit} \qquad (8)$$

where the right hand side of Eq. (7) becomes $\delta_{l,crit}$ which is Eq. (15-1-36) of CQD, in your reference.

(D) Yes, drops are governed by independent conservation equations of Mass and Momentum. But its Energy equation is in common with the continuous liquid phase. XYDRAG has been applied to both vapor/drop and vapor/film interactions.

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Professor Wallis RAI-6

(15-1-35) looks odd. The more viscous the film the harder it should be to entrain it. Is there no "critical" condition for initiating entrainment? What is the origin of this equation?

Response :

Equation (15-1-35) is a wrong reference. It is applied to co-current unstable film. It is due to Whalley et al. (1973) modified by Wurtz (1978) (see Eqs. (4-130) through (4-134) of CQD). The critical condition of film instability of the co-current film is the same as the counter-current entrainment, eq. (6), (7), or (8). This critical condit[illegible] does not depend on the liquid viscosity. Equation (15-1-35) is for co-current and not crucia[illegible] CFL.

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Professor Wallis RAI-7

Besides (surprisingly) providing a good correlation of flooding phenomena, is there other evidence that these recipes give good predictions?

Response:

During my prediction work with WCOBRA/TRAC, I always had the impression that the presence of the entrainment phase helped making good predictions. There is no other hidden recipes than those presented in publications and item 4) which becomes effective only for the tie plate CCFL.

Entrainment is also effective in prediction of HL Entrainment, Quench Front, and Heat Transfer at the Rod.

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Professor Wallis RAI-8

Is it Westinghouse's position that "ranging" only needs to be done to compute changes in PCT? Is PCT the only "indicator" of code validation? What about compensating errors in the crude models?

Response:
Yes, it is our position to range the uncertainty caused by code deficiency, because the compensation error was considered to be negligible in regard unique to UPI application of the code. The effect of the compensating error has been discussed to be not important in TER.

For the code validation, we have performed numerous analyses of SET (separate effect tests) and IET (integral effect tests) for BE LOCA of 3/4 loop plants, which are documented in CQD vols. 2 and 3. In summary,

(i) SETs for Blowdown Heat Transfer are ORNL high pressure film boiling tests, G-1 and G-2 Blowdown Experiments, and G-2 Refill Experiments.
(ii) SETs for Reflood Heat Transfer are FLECHT-SEASET Reflooding Tests, FLECHT Low Flooding Rate Tests, FLECHT Top-Skewed Power Tests, and FEBA Tests.
(iii) For Hydrodynamics, Marviken Break Flow Tests, CCFL in various geometries, Entrainment and Liquid Carryover, and Condensation were examined including scaling effects.
(iv) IETs are LOFT, CCTF, SCTF, and UPTF tests.

Among them, PCT related bias and uncertainties are used for evaluation of code bias and uncertainty.

The evaluation results of Marviken test analyses and downcomer condensation, for example, are used to define the ranges of uncertainties of respective phenomena. This type of analyses were also used to evaluate the compensating errors. The results were found to be no significant compensating error, except for Tmin and blowdown HTC, which were taken into account by ranging the error in the local hot spot evaluation.

For UPI specifics, on top of 3/4 loop validation, we analyzed GECCFL tests, as separate effect test (SET) and CCTF and UPTF tests as (IET). In these UPI specifics, we have looked into

HL Flow Rates,
Core Drain Rates,
Subcooling and Fluid Temperature Distributions,
UP Pooling and Level,
CCFL, and
Scaling,
in addition to PCT and Quenching,

for the code performance evaluation.

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Professor Wallis RAI-9
By how much does the interface friction factor have to be increased until CCFL causes significant increase in PCT? Was this parameter only ranged downwards? Why?

Response:
The ranging of XYDRAG was not determined by means of PCT. It was determined for the predicted CCFL curves to envelope the CCFL data. This purpose was achieved most effectively by ranging from XC=XYDRAG=1.0 to XC=XYDRAG=0.2, which was found empirically.

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Professor Wallis RAI-10

XCOND appears to have been ranged from 1 to 0.2. Why not upwards? Why not over a wider rage, since uncertainties in condensation coefficient can be orders of magnitude?

Response:

The range of XC is made downwards, because the nominal prediction of flooding takes place with much less steam upflow than GE CCFL data. Decrease of XC will help to improve the prediction.

In the 3/4 loop plants, condensation in downcomer and lower plenum was ranged from 1.05 to 0.4, consistent to the present range of XC, which is determined independently.

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Professor Wallis RAI-11

In the NED paper (1998) p139 it is claimed that interfacial drag and entrainment models "have been discussed earlier". I don't see this. A "three field model" is mentioned without saying how entrainment is computed, what is the drop size, how does XYDRAG relate to the forces on drops and liquid film?

Response:

The NED paper you have is about 'GE CCFL for subcooled CCFL' by Takeuchi, Nissley, and Young (Oct, 1998). The paper referenced is another NED paper on 'saturated CCFL on various geometries' by Takeuchi and Young (Nov. 1998) which came out a little later.

The three fields are independently governed by 8 3-D conservation equations. 3 mass conservation eqs. for each fields, 3 momentum conservation eqs. for each fields, and 2 energy equations for vapor and liquid (assuming same temperature for continuous and entrained liquid fields). These equations are numerically solved by semi-implicit donor cell method.

The entrainment is computed by Eqs. (1) - (4) as discussed in response to RAI-1. Drop size of the drops entrained from a film flow is determined by Tatterson's correlation,

$$r_{d,E} = 0.0056\left(\frac{g_c D_h \sigma}{\frac{f_s}{2}\rho_v |U_v|^2}\right)^{0.5} \qquad (8)$$

which is the average drop size of the Mugele-Evans log-normal distribution function. This size agrees well with Kataoka correlations (see RAI-77 to CQD for 3/4 loop plant BELOCA).

After finding the drop generation rate of Tatterson's drop size, de-emtrainment of the existing drop size in the cell, size increasing or decreasing rate at condensation or evaporation, drop size transport at the cell boundaries, the average drop size in a cell is computed by solving the TRANSPORT EQ. for Drop Interfacial Area;

$$\frac{dA_{i,drop}}{dt} + \nabla\bullet(A_{i,drop}\underline{U}_e) = (Ent/DeEnt) + S_\Gamma(PhaseChange) \qquad (9)$$

This equation is numerically solved by explicit method.

XYDRAG is the multiplication factor to be applied to the interfacial friction coefficients between vapor and continuous liquid and between vapor and drops, XKI and XKVE, respectively, for the axial momentum and, XKVL and XKVE, respectively, for transverse momentum equations (uisng the code notation). The obtained results are:

XDRAG * XKI and XDRAG * XKVE

for the axial momentum equations of relevant phases, and similarly

YDRAG * XKVL and YDRAG * XKVE

for the transverse momentum equations.

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Professor Wallis RAI-10

In the same paper it is hard to believe that reducing XYDRAG by a factor of 5 has so little effect on CCFL. Surely the basic balance is between gravity and drag, so that reducing drag by 5 should result in increasing steam flow by SQR(5) to obtain the same conditions?

Response:

In regard to Sqrt(5), turn around of liquid drain rate takes place for the SAT CCFL test 69, at

$u_{g0} = 0.45$ kg/sec for nominal XYDRAG, and at

$u_g = 0.6$ kg/sec for XYDRAG = 0.2

The difference is 30% and the results are qualitatively acceptable. But I cannot bring out a simple quantitative statement at this time.

Hystereses Computed in Analyses of GE CCFL

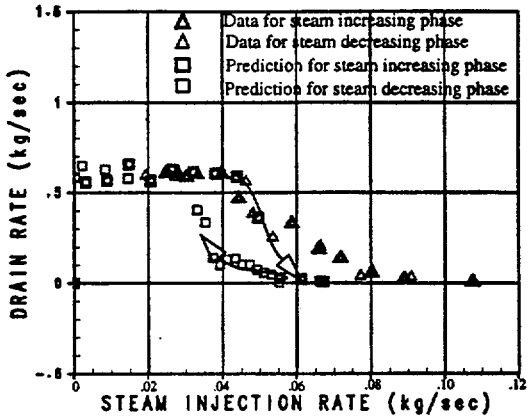

Figure 2-5 Liquid Drain Rate vs. Steam Injection Rate, for GECCFL Test 69

Hysteresis in Sat. GE CCFL

Hysteresis in Subcooled GE CCFL XC = XD = 1.0

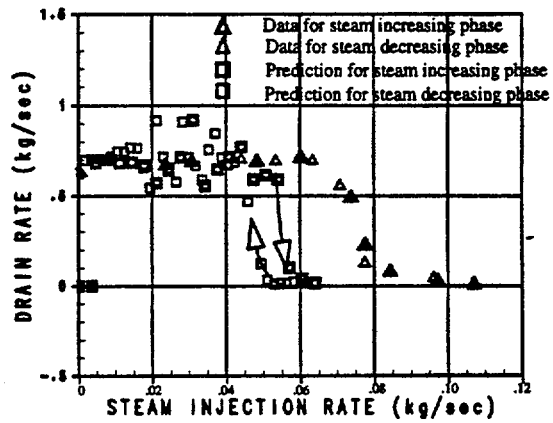

Figure 2-2 Liquid Drain Rate vs. Steam Injection Rate, for GECCFL Test 60

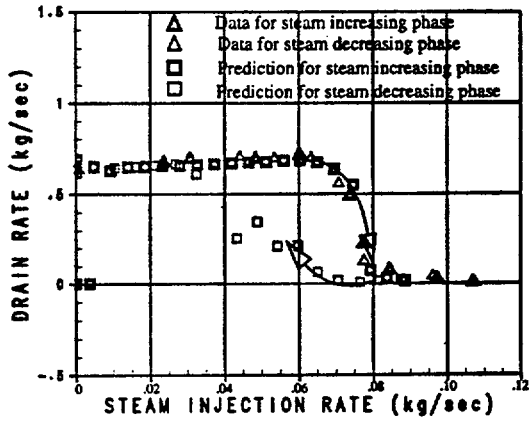

Figure 4-2 XCONDU = XYDRAG = 0.2 for Prediction of Liquid Drain Rate vs. Steam Injection Rate, for GECCFL Test 60

Hysteresis in Subcooled GE CCFL XC = XD = 0.2

Appendix ..... Physical Models and 3/4 Loop BELOCA RAI Responses

The physical models used to predict interfacial drag, condensation, entrainment/de-entrainment and drop size were not addressed at the meeting.

The physical models have not been changed from the previously approved code version, WCOBRA/TRAC MOD7A Rev. 1. The interfacial drag, entrainment/de-entrainment and drop size models of interest are summarized in Appendix A of Reference 1. The interfacial condensation models are summarized in Appendix B of Reference 2. Copies of those papers are enclosed.

A more detailed description of the physical models used in WCOBRA/TRAC MOD7A Rev. 1 may be found in Volume 1 of Reference 3. That reference includes a detailed description of the numerical implementation of each model, which was generated by Westinghouse based on a line-by-line review of the code (similar to the exercise currently being conducted for TRAC-M). The review of the physical models included the resolution of over 200 Requests for Additional Information (RAI). The accepted responses to those RAI are documented in Appendix C Part 1 of Reference 3. The RAI are cross-referenced within Volumes 1 through 5 of Reference 3 using superscripted numbers within brackets, where the superscripted numbers are cited in a "RAI Listing" at the end of each section. The topic of each RAI is also summarized at the beginning of Appendix C Part 1. For convenience, an index of the RAI associated with the physical models listed above is included in the attached Tables 1 to 4.

References

1) K. Takeuchi and M. Y. Young, "Assessment of Flooding in a Best Estimate Thermal Hydraulic Code (WCOBRA/TRAC)," Nuclear Engineering and Design, Vol. 186, pp 225-255, 1998.

2) K. Takeuchi et al., "Analyses of Subcooled CCFL Tests for Evaluation of WCOBRA/TRAC Applicability," Nuclear Engineering and Design, Vol. 185, pp. 127-140, 1998.

3) S. M. Bajorek et al., "Westinghouse Code Qualification Document for Best Estimate Loss of Coolant Accident Analysis," WCAP-12945-P-A (Proprietary), 1998.

TABLE 1. MODELS FOR INTERFACIAL AREA

Flow Regime	Reference 3 Section (page)	RAI (Topic)	Page in App C Part 1
Small Bubble	3-2-2 (3-4)	RAI1-22 (Bubble radius)	103
		RAI1-23 (Bubble number density)	110
		RAI1-24 (Minimum void fraction)	115
		RAI1-25 (Superheated liquid)	115
Large Bubble	3-2-3 (3-8)	RAI1-26 (Bubble radius)	115
		RAI1-27(Axial void gradients)	118
		RAI1-28 (Use of interfacial area)	120
		RAI1-1h (Typographical error)	6
Churn-Turbulent	3-2-4 (3-13)	RAI1-29 (Critical void fraction)	120
		RAI1-30 (Minimum droplet diameter)	121
		RAI1-31 (Film interfacial area)	125
Film/Drop	3-2-5 (3-15)	RAI1-77 (Droplet diameter)	276
		RAI1-31 (Film interfacial area)	125
Interfacial Area Transport	3-3-7 (3-24)	RAI1-35 (Transport equation)	127
		RAI1-1i (Velocity term)	7
		RAI1-34 (Phase change contribution)	127

TABLE 2. MODELS FOR INTERFACIAL DRAG

Flow Regime	Reference 3 Section (page)	RAI (Topic)	Page in App C Part 1
Small Bubble	4-4-1 (4-17)	RAI1-53 (Consistency with Ishii reference)	214
		RAI1-54 (Use of Ishii's drag coefficient)	215
		RAI1-55 (Details of Eq. 4-52 to 4-55)	218
		RAI1-56 (Drift velocity vs. terminal velocity)	220
		RAI1-57 (Drift velocity vs. terminal velocity)	220
		RAI1-58 (Weber number criterion)	221
		RAI1-59 (Taylor instability & bubble radius)	222
		RAI1-60 (Equation consistency)	223
		RAI1-61 (Void concentration parameter)	223
		RAI1-62 (Relative velocity ramp)	223
		RAI1-63a (Inverted pool criterion)	226
		RAI1-63b (Limits on bubble size)	226
		RAI1-64 (Drag coefficient selection)	227
		RAI1-65 (Effects of boiling)	229
		RAI1-66 (Relative velocity for horizontal flow)	232
Large Bubble	4-4-2 (4-26)	RAI1-67 (Drag at flow regime boundary)	232
Churn-Turbulent	4-4-3 (4-29)	RAI1-67 (Drag at flow regime boundary)	232
Film/Drop	4-4-4 (4-30) (vapor/film shear)	RAI1-68 (Use of Wallis model)	234
		RAI1-69 (Critical void fraction)	253
	4-4-7 (4-35) (vapor/drop shear)	RAI1-72 (Drop size)	266
		RAI1-73 (Drag coefficient w/ multiple drops)	266
Intercell Drag	4-5 (4-45)	RAI1-75 (Intercell drag coefficient)	273

TABLE 3. MODELS FOR ENTRAINMENT/DE-ENTRAINMENT

Process	Reference 3 Section (page)	RAI (Topic)	Page in App C Part 1
Entrainment	4-6-2 (4-48)	RAI1-81 (Droplet breakup)	283
		RAI1-76 (Liquid film thickness)	274
		RAI1-77 (Tatterson drop size model)	275
		RAI1-78 (Entrainment as a function of void fraction)	280
		RAI1-79 (Typographical error)	283
		RAI1-80 (Typographical error)	283
De-Entrainment	4-6-6 (4-78)	RAIF-3 (Comparison with Whalley data)	333*

* App C Part 4, last tab

TABLE 4. MODELS FOR INTERFACIAL CONDENSATION

Flow Regime	Reference 3 Section (page)	RAI (Topic)	Page in App C Part 1
Small Bubble	5-2-1 (5-2)	RAI1-111 (Interfacial HT coefficients, IHTC)	332
		RAI1-112 (Interfacial area limit)	403
		RAI1-113 (Subcooled liquid IHTC)	406
		RAI1-114 (Condensation vs. evaporation)	411
		RAI1-115 (Axial void gradients)	412
		RAI-116 (Limit on subcooled liquid IHTC)	415
Large Bubble	5-2-2 (5-6)	RAI1-117 (Use of Lee-Ryley correlation)	422
		RAI1-28 (Clarify use of Eq. 3-36)	120
		RAI1-118 (Use of small bubble IHTC)	426
Churn-Turbulent	5-2-3 (5-9)	RAI1-119 (Basis for Eq. 5-25)	426
		RAI1-120 (Use of Hughmark friction factors)	427
		RAI1-121 (Use of Colburn analogy)	429
		RAI1-122 (Thickness of liquid film)	440
		RAI1-111 (Liquid IHTC for drops)	332
		RAI1-123 (Conduction within drops)	440
		RAI1-124 (Superheated vs. subcooled drops)	448
Film/Drop	5-2-4 (5-14)	None	